The Biology and General Ecology of the Koaro (*Galaxias brevipinnis*) in some Tributary Streams of Lake Taupo.

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Frontispiece

Koaro (Galaxias brevipinnis) from the Waipehi stream.

Koaro habitat.

ABSTRACT

The ecology and general biology of *Galaxias brevipinnis* were studied in three tributary streams of Lake Taupo between May 1988 and April 1989. Adult koaro were found in relatively high densities in the Waipehi and Omori streams but in low densities in the larger Waiotaka stream. The results of population estimation studies suggest that the distribution and abundance of koaro is negatively correlated with that of trout. There was a general decline in the population density of stream-resident koaro in the winter months. Juvenile koaro were found to migrate into the tributaries from August to December, with migrations being at a peak in October and November.

Population length-frequency distributions and otoliths used to age koaro indicated that there were up to 5 age classes. Growth was allometric and was adequately described by the von Bertalanffy equation after the first year of life. Koaro were found to be in best condition in the Spring and lowest in Winter.

Spawning appeared to occur from December through to April. peaking in late Summer to early Autumn. The mean fecundity of koaro in the Waipehi Stream was approximately 5500. A sex-ratio of approximately 1:1 (males:females) were found in the koaro populations in the Omori and Waipehi streams, but during spawning there were always more ripe males than gravid females.

There was considerable overlap in the diets of both koaro and juvenile rainbow trout in the Waipehi and Omori streams, with invertebrates being consumed according to their relative abundance in the benthos. Ephemeroptera larvae were numerically the most important food item in the diet of both species. However, by weight, fish (juvenile koaro) were the most important food item in the diet of koaro and rainbow trout in the Waipehi stream. In the Omori stream in Winter, trout eggs were the most important food item in terms of weight. Terrestrial prey was found to be of relatively minor importance in the diets of koaro and rainbow trout in the Waipehi and Omori streams.

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CHAPTER ONE

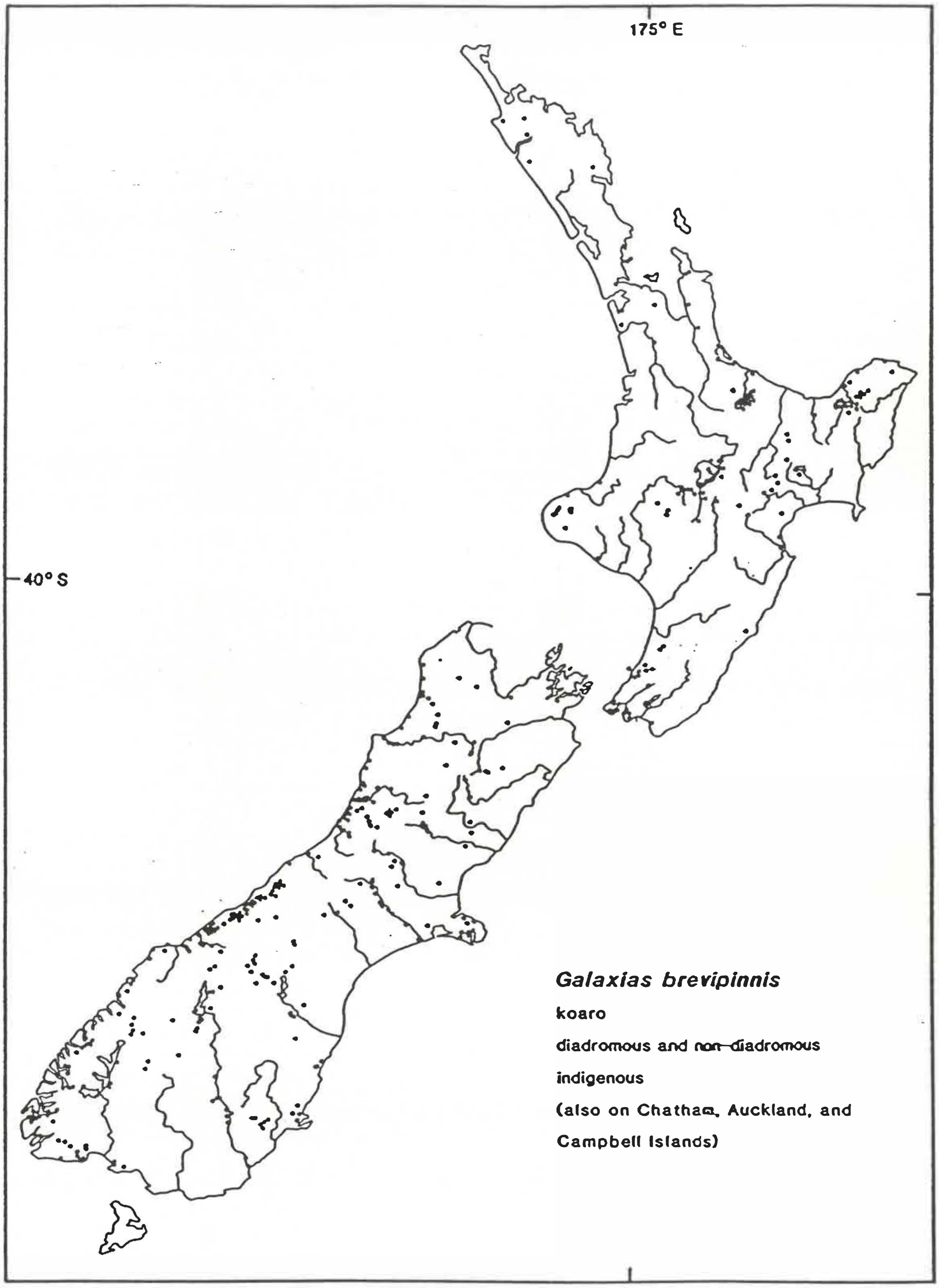
GENERAL INTRODUCTION

1.1 Introduction to the Koaro (*Galaxias brevipinnis*)

The koaro (*Galaxias brevipinnis* Gunther, (1886)) is a native freshwater fish belonging to the family Galaxiidae. The thirteen species of Galaxiidae found in New Zealand are divided into 2 genera, *Galaxias* and *Neochanna*, which have 10 and 2 species respectively. Like the inanga (*Galaxias maculatus*), the koaro is not endemic to New Zealand and is also found in south-eastern Australia and in Chile, South America (McDowall, 1978).

The koaro is widely distributed throughout New Zealand in both the North and South Islands (Map 1.1) and is present in both coastal streams and rivers and in headwater streams situated considerable distances inland - koaro have been reported to inhabit headwaters of the Wanganui river up to 250km from the ocean (McDowall, 1978). In addition to diadromous populations, 'land-locked' lacustrine populations of koaro are present in many lakes in the central volcanic region of the North Island and in the alpine and sub-alpine lakes of the Southern Alps in the South Island (McDowall and Whitaker, 1975).

The koaro is a small (fork length 230mm), negatively buoyant, slender fish almost tubular in shape (Frontispiece). The head is large and flattened and the fins are thick and fleshy. The pelvic and pectoral fins face downwards and give the koaro the ability to climb waterfalls upto 20-30m in height, and are also used as supports when the fish is resting on the substrate (Moffat and Davison, 1986). The widespread distribution of koaro in New Zealand is most probably attributable to the exceptional climbing ability of the juvenile koaro which gives the species accessibility to distant headwater streams (Green, 1979). Koaro have no scales and are covered in mucus. Colour varies considerably between individuals with irregular markings along the back and sides of the body. Koaro are usually olive-brown on top with a light fawn coloured belly. The koaro commonly grows up to 160-180mm in length, although specimens exceeding 250mm have been found in the Rotorua lakes and Pirongia streams (D. West, Personal communication 1989). Little is known of the biology and ecology of koaro in the North Island except that it occurs in riffle habitats and is common in forested streams (McDowall, 1978). Studies in South Island streams have been carried out by Main (1988), who examined the diet of koaro in some South Westland rivers, and Moffat (1986) who assessed the critical swimming speed of koaro in the laboratory and the micro-habitat of koaro and brown trout in the Ryton river, Canterbury. Spawning is thought to occur in or near the normal adult habitat during summer and autumn, and the larvae are probably washed downstream to the lake or sea, returning during the Spring months (McDowall, 1978).



Map 1.1: Distribution of koaro in New Zealand. Each point represents a record of presence, (McDowall and Richardson, 1986)

1.2 History of koaro and trout in Lake Taupo

Some uncertainty exists concerning the origin of koaro in Lake Taupo and many of the Rotorua lakes. Burstall (1980) suggested that given the recent geological history of the region (the Rotorua region in particular), it would not be unreasonable to assume that in most of the lakes there were no fish present when they were first discovered by the Maori. McDowall (1980) believed that koaro probably entered the Lake Taupo watershed from the headwaters of the Wanganui river system to the south. Koaro were plentiful in the lake prior to the introduction of trout and constituted an important source of food to the Tuwharetoa people who were the original inhabitants of the region (Fletcher, 1919). The koaro population in Lake Taupo is isolated from the sea and the entire life cycle is carried out in freshwater. The high abundance of koaro in the lake before the introduction of trout was probably mainly due to the virtual absence of competition and predation pressure, with only two other native fish species being present in the lake (Stephens, 1983).

The trout fishery in Lake Taupo is of both national and international reputation, two species of trout the rainbow and brown are present in Lake Taupo and its tributaries. Brown trout were first liberated into Lake Taupo in 1895, but these fish proved hard to catch and an alternative sporting game fish was sought. There is some uncertainty on the exact date of the release of rainbow trout fry, but it appears that they were brought from Okoroire to Taupo by Reverend Fletcher and released into Lake Taupo in 1903 (Burstall, 1983). By 1907 rainbow trout had become the dominant fish species in the lake, and by 1911 anglers were coming to fish Lake Taupo from all over the world. The diet of trout consisted largely of koaro, and trout soon

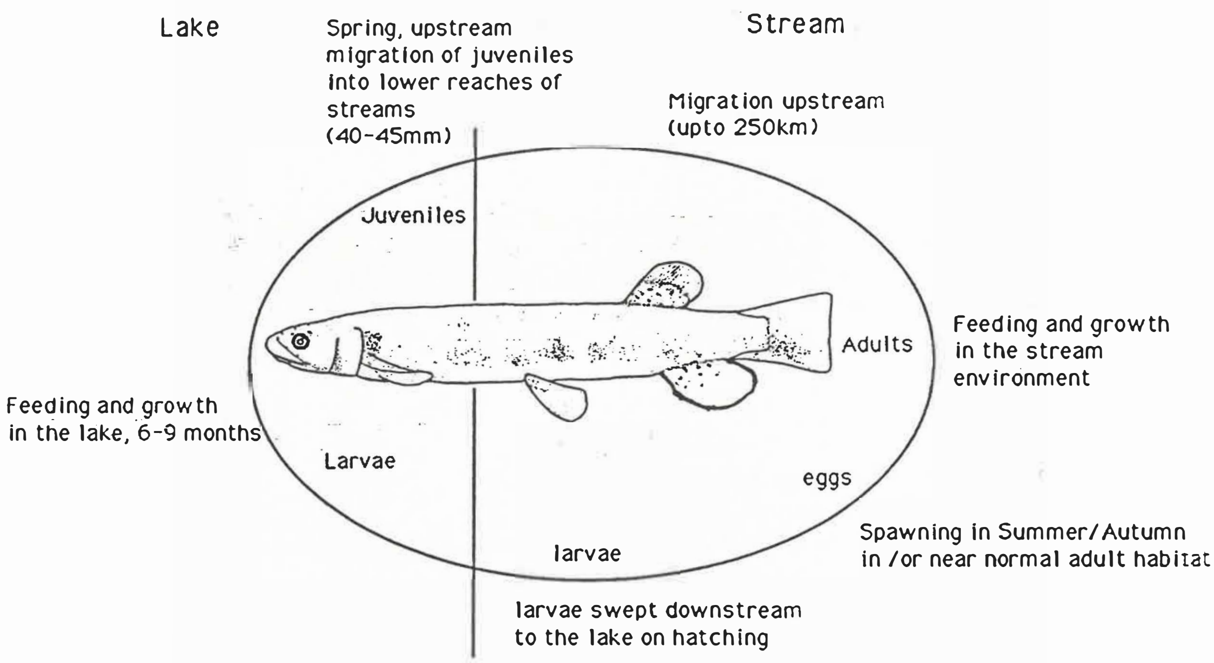


Figure 1.1: Life-cycle of koaro (*Galaxias brevipinnis*)

grew to a large size. However, by 1912 excessive predation pressure by trout resulted in a marked decline in the size of the koaro population. Trout were subsequently netted from the lake in 1913-1917 to reduce the size of the lake population to match the available food resource, and by the early 1920's this lead to a temporary recovery in the trout fishery. Around 1927 the size and quality of the trout once again began to decline and in 1934 an alternative forage fish, the common smelt, was introduced from the Rotorua lakes (Burstall, 1983). Today koaro are still present in the lake but in much reduced numbers compared to before the introduction of trout. Smelt are now the most abundant and important forage fish in the lake for rainbow and brown trout (Stephens, 1983).

1.3 Other fish species in Lake Taupo

Native fish species

Apart from the koaro the only other native fish species present in Lake Taupo are the common bully (*Gobiomorphus cotidianus*) and common smelt (*Retropinna retropinna*). Although eels have been liberated in Lake Taupo, a viable sea-going population has never become established, with the migration of elvers from the sea being prevented by the Huka falls and the construction of hydro-dams on the Waikato river.

Although the establishment of smelt in the lake in the 1940's reduced the predation pressure on the koaro population it appears that smelt in the lake are effectively competing with koaro for food in the form of zooplankton (Stephens, 1983). Stephens (1983) suggested that smelt and koaro avoid direct competition for food by utilising the same food resources in different areas and times. The ability of smelt to withstand the predation pressure of trout is probably due to a life history strategy which has evolved to cope with predation pressure (Stephens op. cit.).

Also present in Lake Taupo is the common bully, which is a result of the inter-breeding between bullies of river origin accidentally released with original lake-dwelling bullies (Stephens, 1983). The common bully is relatively abundant in Lake Taupo and is thought to be an important food item in the diet of rainbow and brown trout, particularly the latter. Bullies spawn in the lake between August and January when they are approximately 40-60mm long. Competition for food and space most probably exists between koaro and common bullies in Lake Taupo since both are benthic feeders. Naylor (1983) found that the diet of a lacustrine population of koaro overlapped with that of common bullies in Lake Alexandrina, Canterbury. However, koaro were able to feed in the water column more efficiently and hence reduce direct competition for food.

1.4 Study Objectives

There is little information available on the general biology and life-history of koaro in New Zealand. The main aim of this study was to investigate the biology of koaro populations present in tributary streams of Lake Taupo, which have so far not been the subject of any previous study. Also, there has recently been widespread speculation concerning the possible adverse effects of introduced species, including trout, on the ecology and conservation of native fish (McDowall, 1987b). However, there have been few studies to investigate the interactions of native and introduced fish in New Zealand (McDowall, 1987b). In this study, I aim to investigate the biology of koaro in Lake Taupo tributaries in relation to their inter-relationships with the co-existing trout populations.

CHAPTER TWO

STUDY SITES

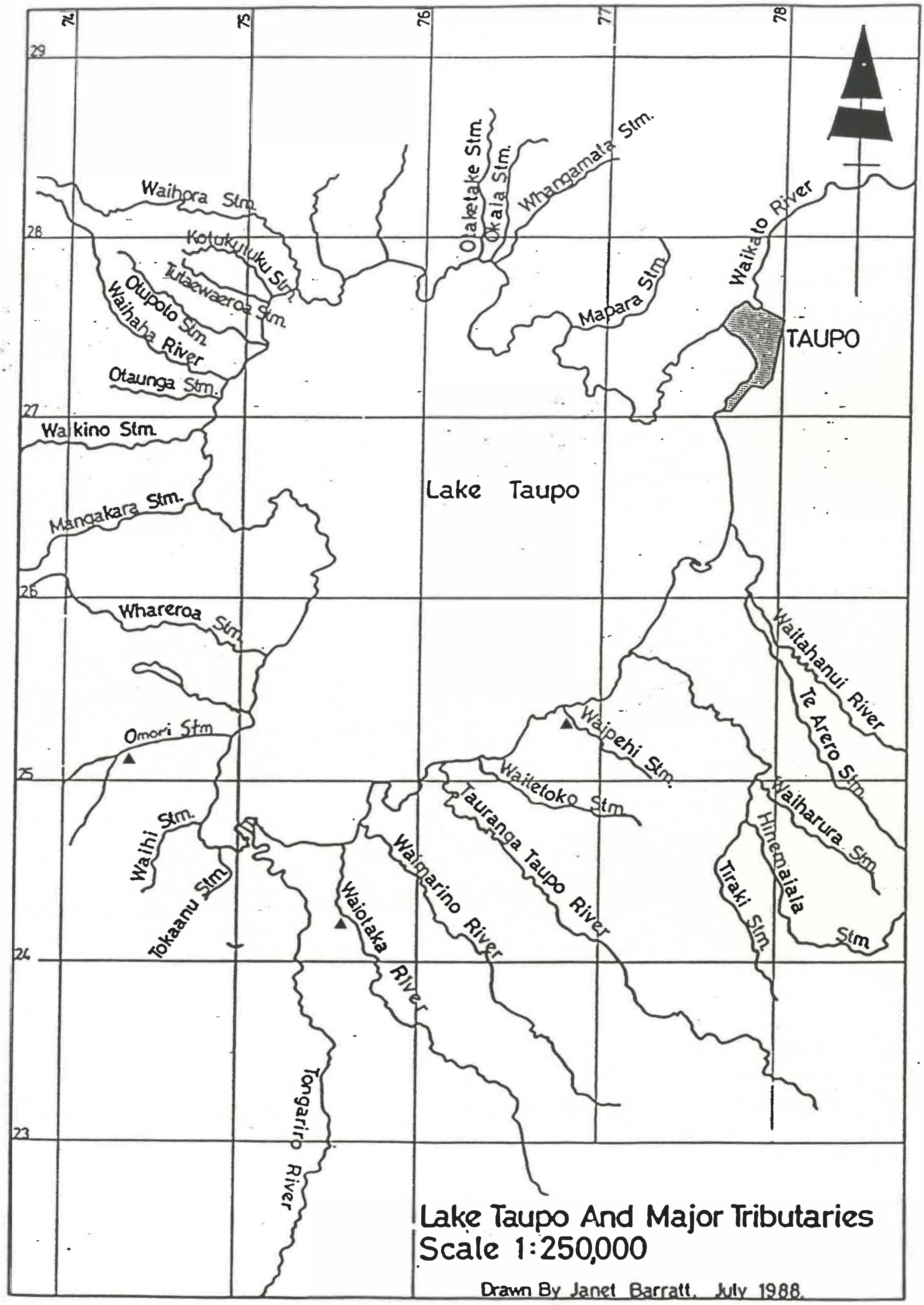
2.1 Location

The three study streams are tributaries of Lake Taupo situated in the central volcanic plateau of the North Island of New Zealand (Map 2.1). Lake Taupo is New Zealand's largest lake with a surface area of 616km^2 and an average depth of 100m. Taupo is a deep, clear, oligotrophic lake in which the surface waters are well mixed by strong south-westerly winds. The numerous tributary streams provide important nursery habitat for juvenile trout and provide spawning areas for adult trout.

2.2 Stream selection

Reconnaissance surveys were carried out from December 1987 to March 1988 using portable electro-fishing equipment to determine the distribution and abundance of adult koaro in tributary streams of the lake. A number of streams were sampled including, on the eastern shore of the lake, the Waipehi, Hinemaiaia, Waimarino, Waiotaka streams, and on the south western shores the Omori, Pukawa and Omoho streams.

Although all streams sampled contained koaro, three streams were finally selected for the study, the Omori, Waipehi and Waiotaka (Map 2.1). These streams were chosen on the basis of the following Map



2.1: Map of Lake Taupo showing the three study streams and other major tributaries.

criteria; i) they were a manageable size for electro-fishing, ii) they contained high densities of koaro, and iii) were easily accessible.

2.3 Stream characteristics

2.3.1 Waipehi stream

The Waipehi is a small stream (mean annual discharge $0.35m^3s^{-1}$) with a catchment area of approximately 26.16 km^2. The headwaters of the stream are located in the Kaimanawa ranges to the east of Lake Taupo at a height of 700m a.s.l. The stream flows for about 11.2km and discharges into the north-eastern shore of the lake at an altitude of 360m a.s.l. The stream in the upper reaches does not have a clearly defined pool-riffle pattern and consists primarily of runs. However, in the middle reaches there is a meandering pattern with a well developed pool-riffle structure.

At base flow, the stream is extremely clear but turbidity increases and water transparency decreases rapidly with rain in the headwaters, due to the extensive deposits of pumice throughout the catchment area, which results in rapid run-off from the land. The stream flows through a gorge of volcanic deposits and the substrate consists primarily of unstable pumice and gravel. The majority of the catchment area consists of exotic pine plantations (*Pinus radiata*) but the riparian vegetation is dominated by native scrub.

2.3.2 Omori stream

The Omori stream is a small stream in the south-western shores of Lake Taupo with a mean annual discharge of 0.56 m^3s^{-1} and a catchment

Plate 2.1: Waipehi stream

Plate 2.2: Omori stream

area of 27 km^2. The headwaters of the stream are situated at approximately 1067m a.s.l in native forest and the stream flows 9.1km into the south west shores of lake Taupo. The stream channel is entrenched in volcanic deposits with a gravel/ pumice substrate. The unstable bedload of the stream is constantly shifting, leading to slight turbidity even during baseflow.

The headwaters of the stream flow through podocarp/hardwood forest while in the middle reaches the riparian vegetation is dominated by scrub and some exotic pine and eucalyptus plantations. The stream flows through the small residential area of Omori and in the lower reaches the riparian vegetation is dominated by scrub.

2.3.3 Waiotaka stream

The Waiotaka is a moderately sized stream with a mean annual discharge of $2.4m^3s^{-1}$. The headwaters are situated in beech and some podocarp forest in the Northern Kaimanawa ranges at approximately 1524m a.s.l. and flows about 32km into the South eastern shores of the lake. The catchment in the middle reaches is dominated by exotic pine plantations, pasture and scrub. The upper reaches of the Waiotaka flows through a steep gorge consisting of ignimbrite banks with a rocky base. The middle reaches of the Waiotaka pass through the Hautu prison farm where the stream flows through alluvial deposits, with a substrate of gravel and sand. The stream has a well developed pool-riffle structure with extensive gravel bars.

In the lower reaches the stream flows through an extensive wetland area, mainly of willow (*Salix* spp.) and flax (*Phormium tenax*) species.

Plate 2.3: Upper reaches of the Waiotaka stream

Plate 2.4: Lower reaches of the Waiotaka stream

2.4 Site characteristics

All the sites chosen for study were representative of a particular section of stream eg. upper, middle and lower reaches. Before the sampling program commenced it was necessary to clear overhanging vegetation, such as blackberry to allow easier access to the stream for sampling. The major characteristics of each site are summarised in Table 2.1 and Table 2.2.

2.5 Temperature regime

In the Waipehi stream the temperature ranged from a low of 7°C in June to a high of 15°C in December. In the Omori stream the temperature ranged from a minimum of 9°C in June to a high of 14°C in November. Water temperature generally increased with distance downstream (Fig. 2.1).

Table 2.1: Waipehi and Omori site characteristics.

	Waipehi (top site)	Waipehi (lower site)	Omori (top site)	Omori (middle site)	Omori (lower site)
Length (m)	50	50	50	50	50
Width (m)	2.5	2.5	3.0	2.0	3.0
Depth (m)	0.14	0.14	0.187	0.28	0.37
Mean annual Flow ($m^3 s^{-1}$)	0.35	0.35	0.56	0.56	0.56
Water Temperature ^oC	7-15	7-15	9-14	9-14	9-15
pH	7.4	7.4	7.6	7.6	7.7
Conductivity (µS/cm)	72.7	69.7	78.6	77.8	75.6
Dissolved oxygen (mg/l)	11.6	11.6	11.6	11.2	11.0
Substrate	gravel, cobble	gravel, sand, cobble	gravel, boulder	cobble, grave	sand, gravel
Flow Regime	riffles,runs	riffles, runs, plungepool	torrents, riffles,pools	pools, runs, riffles	pools, runs
Riparian vegetation	native scrub	blackberry, native scrub	native scrub, manuka	manuka, gorse blackberry	willow, grass blackberry

Table 2.2: Waiotaka and Hinemaiaia site characteristics.

	Waiotaka (top site)	Waiotaka (middle site)	Waiotaka (lower site)	Hinemaiaia (Top site)
Length (m)	50	50	50	50
Width (m)	6	4	6-8*	3-4
Depth (m)	0.4	0.6	1.0*	0.5
Mean annual Flow ($m^3 s^{-1}$)	2.40	2.40	2.40	1-2.0
Water Temperature ^oC	5-16	6-16	8-18	5-18.5
pH	7.7	7.7	7.7	8.3
Conductivity (µS/cm)	69.4	67.5	63.3	No result
Dissolved oxygen (mg/l)	11.8	11.3	11.0	9.8
Substrate	gravel, boulder	gravel, sand	sand, silt	cobble, gravel
Flow Regime	riffles,runs ,rapids	riffles,pools	pools, runs	pools, runs, riffles
Riparian vegetation	native scrub	blackberry, grass, willow	blackberry, willow	native scrub, manuka kanuka

* The depth and width of this site was dependent on the fluctuating lake level

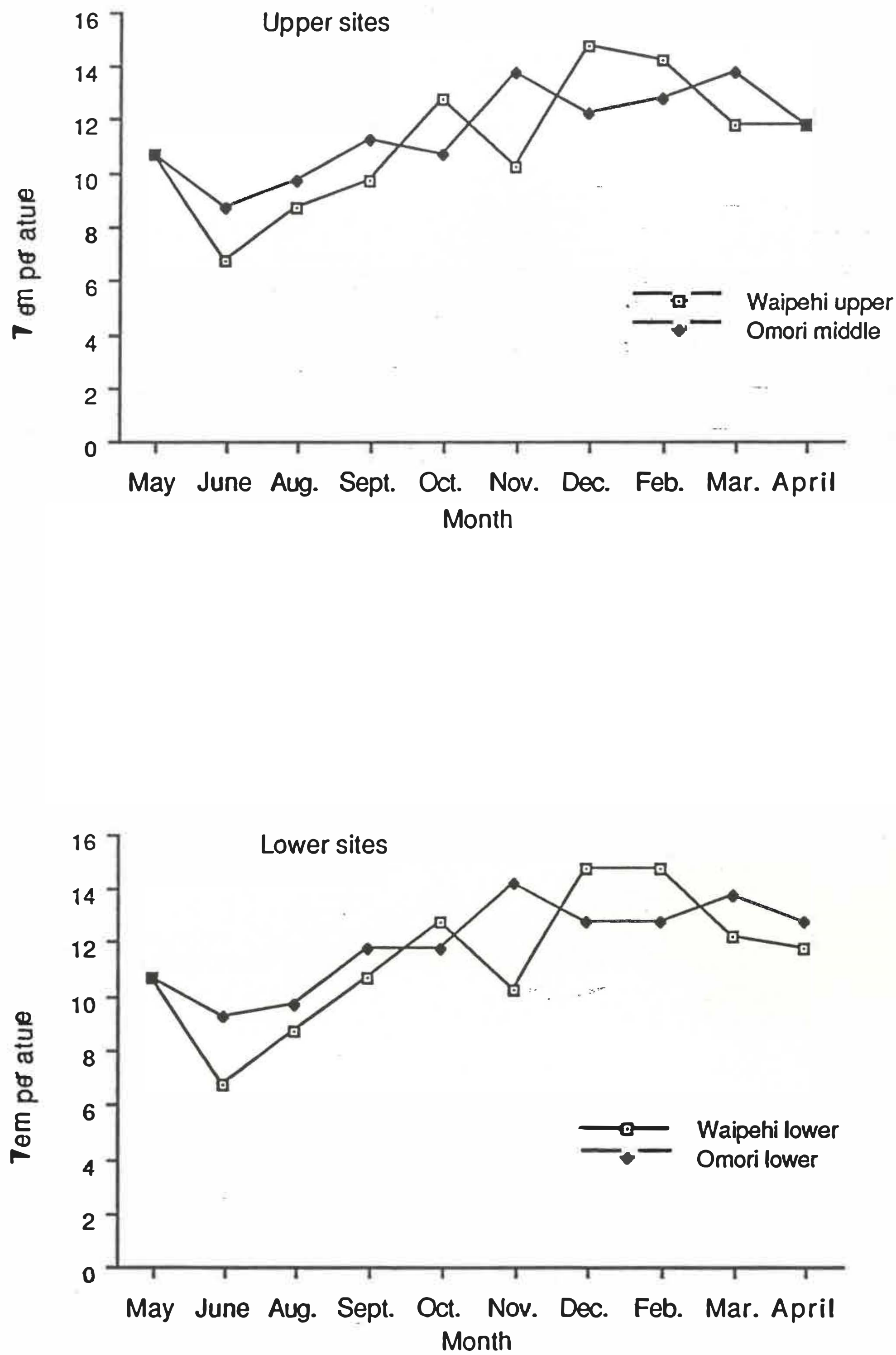


Figure 2.1: Monthly mean temperatures of the Omori and Waipehi streams during 1988-1989.

CHAPTER THREE

POPULATION DYNAMICS OF KOARO AND JUVENILE TROUT

3.1 Introduction

The population dynamics and general ecology of galaxiid species in New Zealand are poorly documented. Previous studies have investigated the migratory movements of *Galaxias maculatus* (Burnet, 1965; Benzie 1968; McDowall, 1968) and the home-range and movements of the river-resident *Galaxias vulgaris* (Cadwallader, 1976a).

Also, little research has been carried out on the abundance of galaxiid populations and factors affecting population dynamics. Recently, Glova (1988) examined variations in the densities of bullies, torrentfish, eels, brown trout and the common river Galaxias in the braided channel Ashley river, South Island. There appears to have been no previous studies on the population dynamics of koaro in New Zealand.

The population dynamics of koaro and juvenile trout in the study streams were studied during 1988 and 1989 to investigate the patterns of abundance between and within streams and the temporal and spatial variability of koaro and juvenile trout populations. It was hoped that estimates of the relative abundance of koaro and trout would provide some insight into the present distribution patterns of both koaro and rainbow trout in Taupo tributary streams. The effects of introduced salmonids on the survival of native fishes in New Zealand and Australia is not clear but recent declines in several native fish species in New Zealand have been linked to predation and competition with introduced salmonids (McDowall, 1987a).

3.2 Methods

3.2.1 Electro-fishing

Electro-fishing using generator and backpack-powered electro-fishing equipment was used to sample the fish populations in the Omori and Waipehi streams. Electro-fishing was chosen as the principal capture method due to its effectiveness in estimating fish densities in sections of small streams and also because it is one of the least selective fish sampling methods (Boccardy and Cooper, 1963).

The successive removal method can be used to provide reasonably accurate estimates of fish density in sections of small streams (Bohlin and Sundstrom, 1977). However, estimation of the entire stock of fish in a particular stream is usually not possible due to large spatial variations in population density (Bohlin op. cit.). Consequently, population estimates were made over small reaches of stream which were selected to be representative of specific reaches of the stream.

3.2.2 Sampling procedure

Electro-fishing was carried out at two sites on the Waipehi and three sites on the Omori streams (Chapter 2) were electro-fished from May 1988-April 1989. All sites were 50m in length. Stopnets were installed at the upper and lower limits of each section to restrict movement of fish in and out of the sampling site. Electro-fishing was carried out using either a MAF backpack or generator-powered electro-

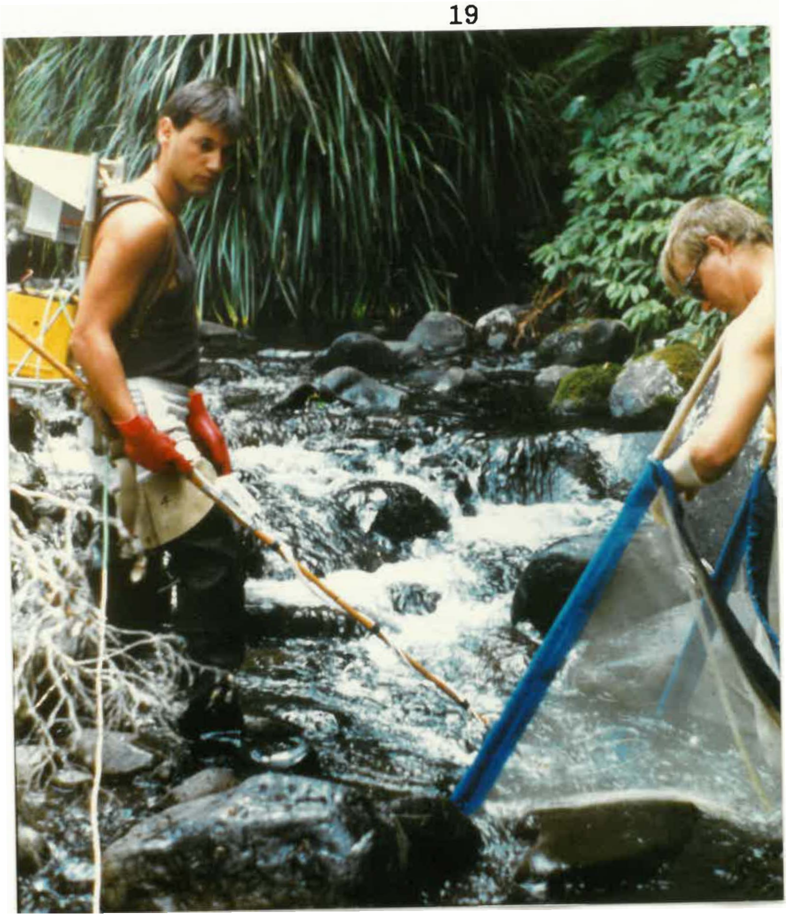


Plate 3.1: Electro-fishing using the MAF backpack set.

Plate 3.2: Electro-fishing using the generator-powered unit in the lower Waipehi stream.

Plate 3.3: Seining at the Waipehi stream mouth.

Plate 3.4: Trapping using 'minnow' traps in the lower site of the Waiotaka stream.

shocking unit. The sampling procedure involved the anode operator gradually moving upstream from the lower to the upper stopnet, with stunned fish collected using a dipnet and pole-seine stopnet.

Electro-fishing was found to be a very effective fish capture technique in the Waipehi and Omori streams, where the channel is reasonably shallow (mean depth of 0.5m) and of moderate velocity. Electro-fishing was however generally limited to shallow areas where water depth was less than 1 metre. The effective stunning radius of the anode was about 0.5m for fish greater than 65mm in length. Fish smaller than this were generally less susceptible to capture than larger fish. The number of successive removals varied depending on the catch size, with three removals being carried out when large numbers of fish were taken and two removals when catches were low. Catch data was then substituted into the removal formula, of Junge and Libosvarsky (1965), in the case of three removals, and that of Seber-LeCren (1973) for two removals.

<u>Two sample method</u> (Seber-LeCren, 1973)

$$N = \frac{C_1^2}{C1 - C2}$$

and the standard error is estimated from the formula

$$S.E.(N) = \frac{C1 * C2}{(C1 - C2)^2} * (C1 + C2)^{*0.5}$$

where;

N = estimated population number

S.E (N) = the standard error

C1 = the number of fish caught in the first removal

C2 = the number of fish caught in the second removal

Three-sample formula (Junge and Libosvarsky, 1965)

$$N = \frac{6X^2 - 3XY - Y^2 + Y * SQR\ Y^2 + 6XY - 3X^2}{18\ (X-Y)}$$

Where;

X = 2C1 + C2,

Y = C1 + C2 + C3

and the standard error is estimated by the formula;

$$S.E. = SQR \frac{N\ (1-Q^3)\ Q^3}{(1-q^3)2 - 9p^2q^2}$$

Where; X = 2C1 + C2,

Y = C1 + C2 + C3

Where q = 1 - p

$$p = \frac{3X - Y - SQR\ Y^2 + 6XY - 3X^2}{2X}$$

Population estimates using electro-fishing are based on the assumption of equal catchability. Bohlin and Sundstrom (1977) tested the accuracy of the removal method on juvenile rainbow trout populations of known size, and reported under-estimations ranging between 11.1 and 22.0 % of the total population size after 4 removals (Bohlin and Sundstrom, 1977). Marking experiments revealed unequal catchability among individuals, thus partly accounting for the observed under-estimations in population estimates.

Fish mortality through electro-fishing appeared to be negligible, although some fish (trout or koaro less than 50mms long) mortality occurred during processing of large numbers of fish in hot summer conditions. Koaro were better able to survive in low oxygen conditions.

Trapping using baited 'Gee' traps was also carried out at the three sites on the Waiotaka on a bi-monthly basis and on the Hinemaiaia overflow channel in February 1989 (when flow conditions allowed). At each site on each sampling trip, recordings were made of weather conditions, water level, water temperature and pH. Samples of fish for stomach content and fecundity analysis were also obtained from the Waipehi stream on each sampling trip.

Fish were anaesthetised with MS222 or benzocaine. The fork length of all fish was measured to the nearest 1mm using a measuring board. Wet weight of koaro and trout was also recorded using a NDA EK-120A portable electronic balance accurate to the nearest 1mg.

3.2.3 Marking

To provide information on the movements and home range of koaro a number of fish were individually marked in the Omori and Waipehi streams from November 1988 to February 1989 (Table 3.6-3.9). Acrylic paint was injected subcutaneously in various colours and combinations on the body, with marks being visible for up to 6 months. Fish smaller than 70mm were not marked due to handling difficulties. A total of 103 fish were marked in the Waipehi stream and 56 in the Omori stream. After marking fish were released back into the sections from which they were taken.

3.3 Results

3.3.1 Population densities

Waipehi stream

Lower site

Population density estimates of koaro were made for two separate length-groups so that variations in the population density of adults and juveniles could be made. Large variations in population density of koaro during the study period suggest that there are two main migrations of koaro into the Waipehi lower site (Fig.3.1). A migration of juvenile koaro from Lake Taupo appears to occur from August to March, peaking in December with a population density of approximately 12 fish m^{-2} (Table 3.1, Fig. 3.1). Catches of juvenile koaro from seine-netting around the stream outlets suggest that the peak period of migration into the stream occurred in the months of September and October (Fig. 3.2). However, difficulties in netting around the lake margins in high wind and lake level conditions at this time may have affected the size of the koaro catches. Population estimates of koaro juveniles in the lower reaches of the Waipehi stream made by electro-fishing are probably the most accurate indication of upstream migration.

Population density estimates suggest that there is an immigration of spawning koaro into the lower reaches of the stream from February to May, peaking in February with a density of approximately 2 fish m^{-2} (Fig. 3.1, Table 3.1).

Tables 3.1, 3.2: Population density estimates (Nm^{-2}) of koaro adults, koaro juveniles and rainbow trout in the Waipehi stream, 1988-1989.

Table 3.1 Waipehi lower

Month	Koaro adults	Standard error	Koaro juveniles	Standard error	Rainbow trout	Standard error
May	0.9943	0.0747	1.4687	0.1080	1.0783	0.0582
June	0.5498	0.0490	0.4653	0.0405	0.5119	0.0220
July						
August	0.5982	0.0459	4.2629	0.1546	0.2102	0.0165
Setember	0.5440	0.0521	6.3657	0.1889	0.4529	0.0235
October	0.2480	0.0300	6.7010	0.1368	0.5664	0.0247
November	0.5982	0.0459	8.9650	0.2607	0.3174	0.0209
December	0.5797	0.0217	14.198	3.8631	0.4772	0.0623
January						
February	1.9617	0.2287	2.1739	0.3232	1.8050	0.3577
March	1.3456	0.2981	1.5152	0.0922	1.2014	0.9298
April	0.9856	0.0882	1.1137	0.0270	1.1756	0.3420

Table 3.2 Waipehi top

Month	Koaro adults	Standard error	Koaro juveniles	Standard error	Rainbow trout	Standard error
May						
June	0.8273	0.0642	0.5553	0.0053	0.1389	0.0179
July						
August	0.5565	0.0178	0.2808	0.0249	0.1131	0.0075
September	0.4529	0.0234	0.1481	0.0143	0.1175	0.0143
October	0.3935	0.0414	0.1412	0.0187	0.1902	0.0146
November	0.4019	0.0151	0.3174	0.0209	0.1133	0.0237
December	0.3675	0.0718	1.0376	0.0595	0.1633	0.1032
January						
February	0.2776	0.0337	0.4734	0.0409	0.6480	0.1037
March	0.2578	0.0237	0.3612	0.0839	0.0200	0.0000
April	0.3219	0.0164	0.1066	0.0140	0.0530	0.0099

No samples were obtained in July 1989 and January 1988.

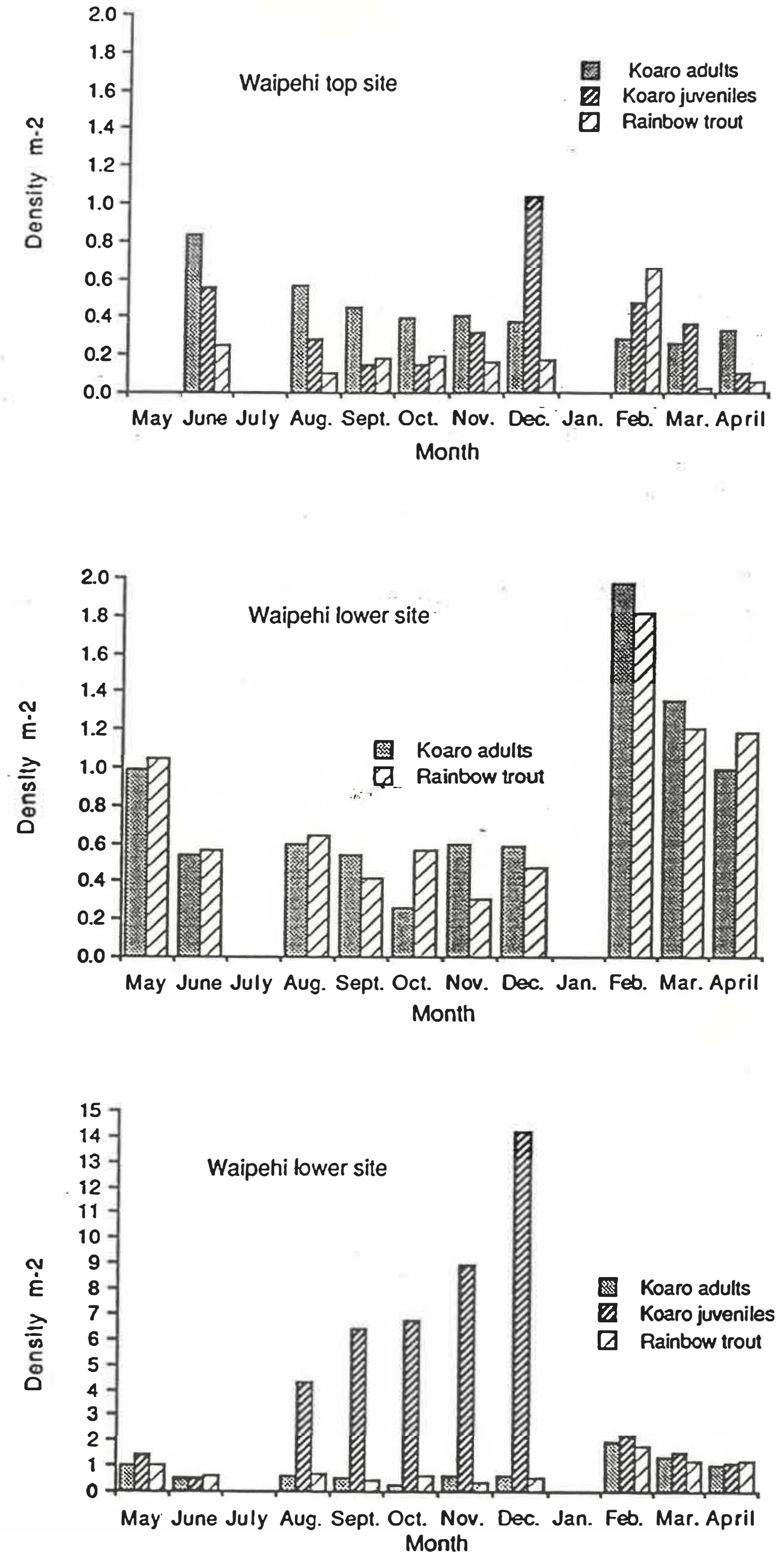
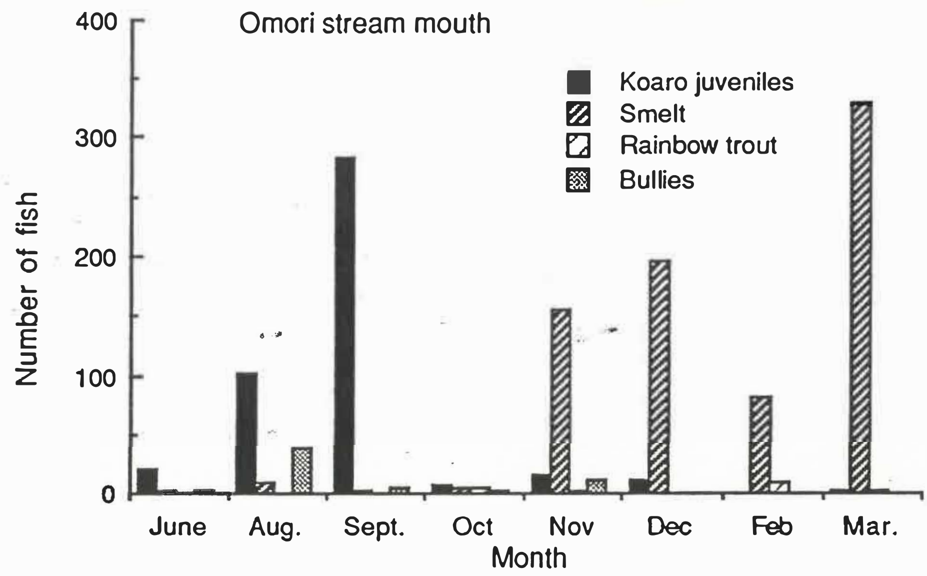


Figure 3.1: Population density estimates of koaro adults and juveniles and juvenile rainbow trout in the Waipehi top and lower sites from 1988-1989.



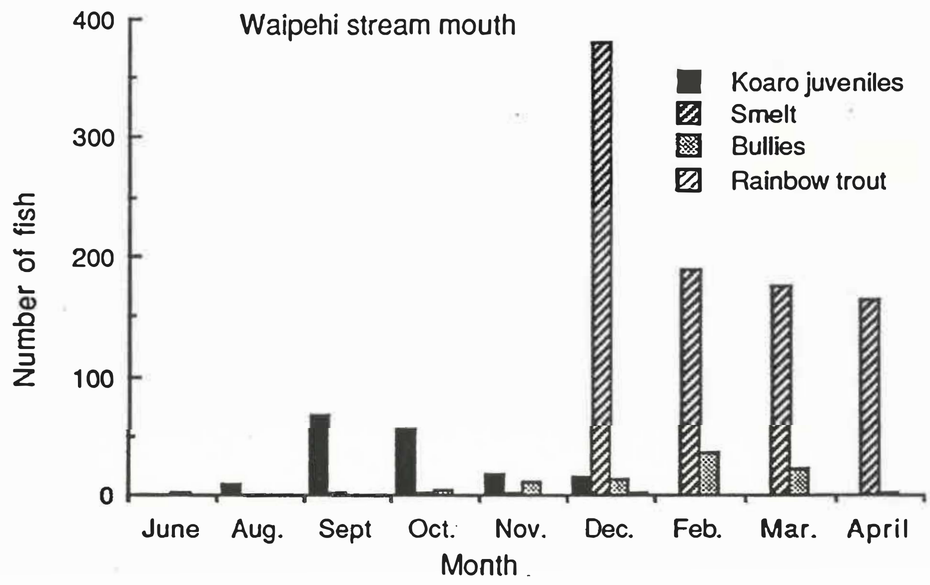


Figure 3.2: Catches of native fish and trout in seine-nettings at the Waipehi and Omori stream mouths 1988-1989.

Population length-frequency distributions also indicate that there is an influx of larger age-groups in March and April (Chapter 4, Fig. 4.1). This increase in population density may be due to a downstream migration of spawning adults. However, few ripe fish were found in the lower sites during these months. Alternatively, the influx of large adults may be due to the return of spent adult koaro from the upper reaches of the stream where spawning may have taken place.

Variations in the population density of juvenile rainbow trout appeared to follow a similar pattern to that shown by adult koaro, with an influx of juvenile trout from February to May. These movements appear to be associated with an out-migration of juvenile parr from the stream into the lake. Population density estimates of juvenile trout peaked in February (1.8 fish m^{-2}) (Fig. 3.1, Table 3.1). The population density estimates of adult koaro and juvenile rainbow trout in the Waipehi lower site (Fig. 3.1) were generally very similar, with the densities of both species being at a maximum in February-May.

Top site

The population densities of koaro at the upper Waipehi site showed much greater variations than populations at the lower site. During most of the year the upper site generally had lower densities of koaro than the lower site with a maximum density of 1.0 fish m^{-2} in February (Table 3.2). The size of the juvenile koaro population reached a maximum in December, when the densities of juvenile koaro in the lower site were also at a peak. This suggests that from November onwards juvenile koaro gradually move upstream from the lower site to the upstream reaches. The size of the adult koaro population density was low in February and March, when adults were at their peak density at the lower site, suggesting that adult koaro may migrate to downstream sites for spawning in the Summer months.

The highest densities of juvenile trout recorded at this site were in December (1.0 m^{-2}), when juvenile trout densities in the lower site in December were low (0.5 fish m^{-2}). The increase in juvenile trout density at the lower site in February suggests that a migration of juvenile trout from the stream to the lake takes place at this time (Table 3.1).

Waterfall Site

In February 1989 reconnaissance electro-fishing was carried out above a series of 3 small waterfalls (approximately 4kms from Lake Taupo) on the Waipehi stream. It was thought that these waterfalls may possibly exclude trout from the upper reaches of the stream. The ability of koaro to climb such barriers (Green 1979) suggested that koaro populations may possibly exist in isolation above these falls. However, both migratory and resident rainbow trout were found to be present above the waterfalls, with juvenile rainbow trout and adult koaro being captured in almost equal numbers. However, population densities appear to be considerably lower than at the downstream sites and may be associated with poor quality habitat (the stream flows through a steep gorge has an unstable pumice substrate with little over-hanging and instream cover).

Omori stream

Population density estimates of koaro in the Omori stream were much lower than in the Waipehi stream (Table 3.3). The koaro population in this stream was not separated into juvenile and adults as few juveniles were captured.

Omori upper site

The population density estimates of koaro at the top site of the Omori were lower than in the upper and lower sites of the Waipehi stream (Table 3.4 and Fig 3.3). There was a general increase in the population density of koaro at this site from April to June with a sharp decrease in density in August to December (Fig. 3.3). This decline appears to correlate well with changes in the size of the juvenile rainbow trout population, which also decreased during this period (Fig. 3.3, Table 3.4). The population densities of both trout and koaro were found to be very similar during most of the year (Fig 3.3, Table 3.4).

Omori middle site

The density of koaro at the middle site was similar to the density of koaro at the upper site (Table 3.5, Fig. 3.3), and followed the same general pattern of slow decline over the year as was seen at the top site. The density of juvenile trout at this site was higher than that in the top site. The increase in koaro numbers at this site in February is most probably due to the immigration of juvenile koaro.

Tables 3.3, 3.4, 3.5: Population density estimates (Nm^{-2}) for koaro, common bullies, rainbow and brown trout in the Omori stream, 1988-1989.

Table 3.3 Omori lower site

Month	Koaro	Standard error	Rainbow trout	Standard error	Brown Trout	Standard error	Common bully	Standard error
May								
June	0.2576	0.0435	0.3910	0.0312	0.0900	0.0013	1.8410	1.1124
July								
August	1.4060	0.0746	0.3462	0.0193	0.1600	0.0032	0.6848	0.0725
September	0.7421	0.0574	0.2001	0.0156	0.0533	0.0010	1.5021	0.2947
October	0.3036	0.0367	0.1440	0.0226	0.0200	0.0000	1.1203	0.1750
November	0.6945	0.0432	0.3392	0.0535	0.0000	0.0000	1.1243	0.1708
December	0.2500	0.0509	0.3008	0.0471	0.0500	0.0000	1.2100	0.0920
January								
February	0.1157	0.0122	0.6676	0.0603	0.0914	0.0049	1.4826	0.2362
March	0.0720	0.0063	0.4537	0.0252	0.0700	0.0000	1.1250	0.0750
April	0.3025	0.2042	0.9257	0.3077	0.0200	0.0000	1.2931	0.5631

Table 3.4 Omori top

Month	Koaro	Standard error	Rainbow trout	Standard error
May	0.5734	0.0505	0.5621	0.0217
June	0.3955	0.0182	0.4435	0.0070
July				
August	0.2958	0.0099	0.2704	0.0020
September	0.2090	0.0141	0.2022	0.0056
October	0.1617	0.0050	0.1115	0.0048
November	0.2256	0.0104	0.0800	0.0489
December	0.2314	0.0172	0.1200	0.0600
January				
February	0.3214	0.1175	0.2133	0.0199
March	0.2777	0.0337	0.0914	0.0049
April	0.2890	0.0583	0.3600	0.2683

Table 3.5 Omori middle

Month	Koaro	Standard error	Rainbow trout	Standard error
May	0.4357	0.0179	0.8891	0.0240
June	0.5583	0.0260	0.7566	0.0169
July				
August	0.2474	0.0119	0.2812	0.0038
September	0.0955	0.0127	0.2105	0.0026
October	0.1633	0.1032	0.1806	0.0028
November	0.1309	0.0036	0.0900	0.0000
December	0.1782	0.0143	0.0800	0.0000
January				
February	0.4033	0.0864	0.0900	0.0000
March	0.4033	0.4262	0.2813	0.0770
April	0.2223	0.0184	0.5000	0.2121

Blank spaces indicate no sample obtained.

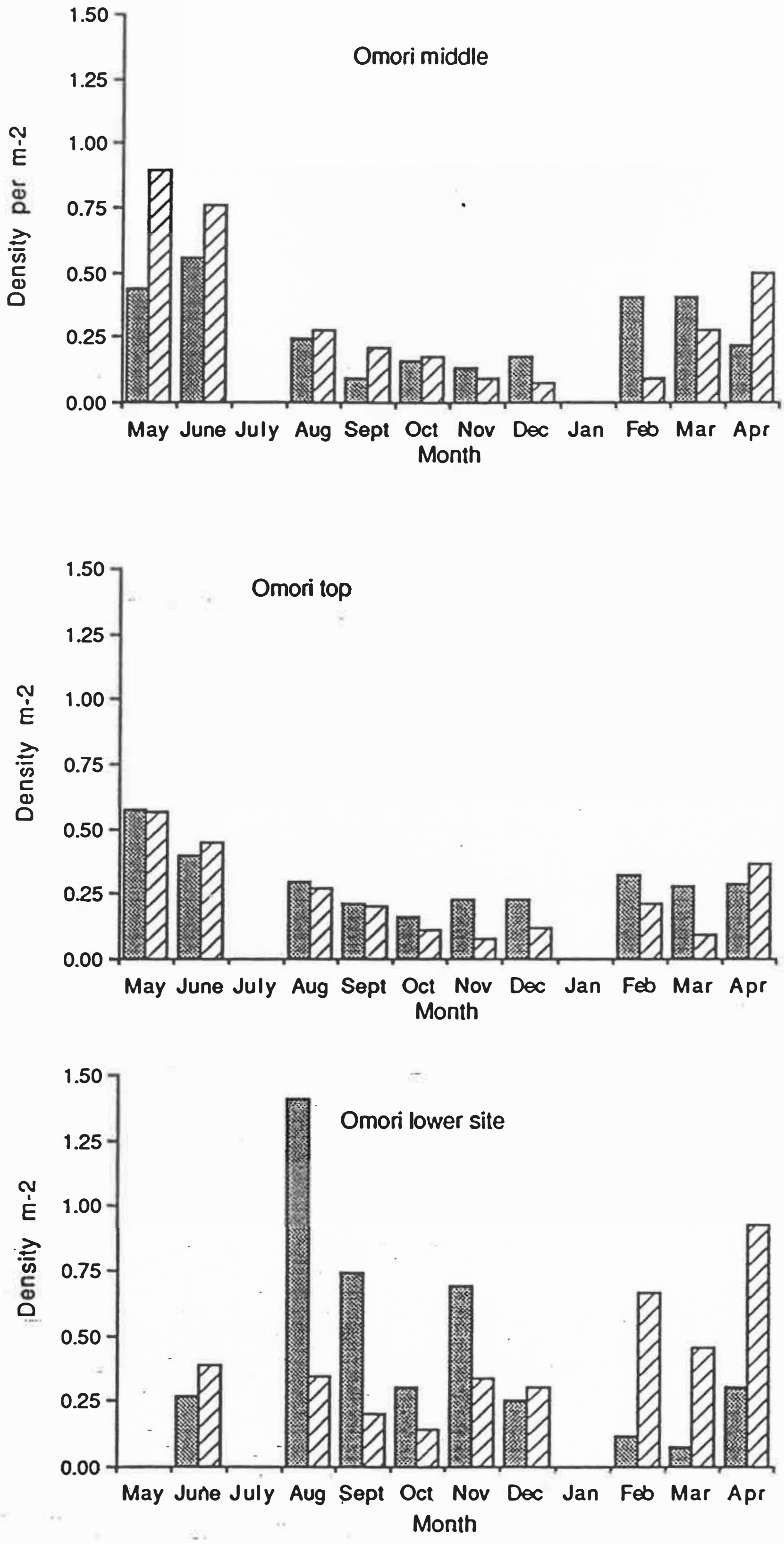


Figure 3.3: Population density estimates of koaro and rainbow trout in the Omori upper, middle and lower sites, 1988-1989.

Omori lower site

The population densities of koaro at the lower site of the Omori stream were much lower than at the upper and middle sites. A total of only 10 koaro greater than 60mm in length were found at this site during the entire sampling period (Table 3.3). The highest densities of koaro occurred during the upstream migration of koaro juveniles in August. Seine catches around the lake confluence indicated that the highest numbers of koaro juveniles were present at the stream mouth in August (Fig. 3.2). The upstream migration of juveniles in August occurred over a much shorter time-period than in the Waipehi stream. The size of the juvenile koaro migration into the lower reaches of this site appeared to be considerably lower than in the lower reaches of the Waipehi.

The population density of juvenile trout at this site was relatively high. There was a marked increase in the population density of trout from February to April, when trout appeared to be migrating out of the stream into the lake (Table 3.3, Fig. 3.3). The highest density of juvenile brown trout was recorded at this site, with a maximum density of 0.16 fish m^{-2} in August, suggesting that the peak out-migration period of brown trout may be later than the April out-migration of juvenile rainbow trout (Table 3.4).

Low catches of koaro at this lower site mean that the relative densities of adult koaro and trout in this site cannot be compared easily. The poor quality habitat conditions and limited food supply at this site (Chapter 6) may be major factors in explaining the low fish densities.

Sampling above a waterfall located on the Omori stream approximately one kilometre above the upper sampling site revealed no koaro and only a low density of resident juvenile trout. This suggests that the waterfall is an effective barrier to both koaro and migratory trout.

Waiotaka stream

Initially, the mainstem of the Waiotaka stream was sampled by electro-fishing. However, this method was found to be ineffective due to the large size of this stream, with high average water depths. Trapping using "Gee" wire-mesh traps was therefore used to provide qualitative estimates of relative abundance of koaro and rainbow trout populations at three sites on this stream. Comparison of fish catches at the top site by electro-fishing and trapping in May and June, suggested that traps captured a relatively high proportion of the adult koaro population present. Further trapping proved relatively unsuccessful however, with few koaro and juvenile trout being taken (Table 3.6), due mainly to the high water flow conditions. The low catch-per-unit-effort (C.P.U.E) of koaro and trout in traps set in the Summer of 1989 (Table 3.6) may be indicative of low population densities or that koaro showed trap avoidance. However, koaro were captured in high numbers in traps set in the Hinemaiaia river in August 1989, suggesting that the low trap catches in the Waiotaka are a true reflection of low population densities.

Table 3.6: Koaro trapping results for the Hinemaiaia and Waiotaka streams, February 1989.

Stream	Site	No. of traps	Koaro	C.P.U.E.
Waiotaka	Top	56	3	0.054
Waiotaka	Middle	52	1	0.019
Waiotaka	Lower	51	0	0.000
Hinemaiaia	Top	59	42	0.712
Hinemaiaia	Middle	58	17	0.293
Hinemaiaia	Lower	51	7	0.137

Hinemaiaia stream

A study of the ecology of juvenile trout in the Hinemaiaia river carried out at the same time as this study (Rosenau 1988) showed that koaro were also present in high densities in many areas (Rosenau, personnel communication 1989). Traps were set in the overflow channel of the Hinemaiaia river in February 1989 to compare with trap catches in the other sites, the mean catch-per-unit-effort of koaro (0.393) was found to be relatively high compared to the Waiotaka stream. It appears that the mainstem of the Hinemaiaia river supports a high density of koaro throughout the year, with relatively low densities of rainbow trout (mean C.P.U.E= 0.0920) (M. Rosenau in prep.).

3.3.2 Distribution of Recaptures

The number of koaro marked and recaptured at sites in the Waipehi and Omori streams are shown in Tables 3.7-3.10.

The recapture rate of marked koaro from the lower site of the Waipehi stream (46%) was higher than that in the middle site (33%), suggesting that koaro in the middle site are in the process of migrating to the upper or lower reaches of the stream. A high proportion (47%) of fish marked at the lower site of the Waipehi were recaptured, suggesting that the lower site provides good koaro habitat and that fish have little need to move to more suitable areas.

The marking study provides little information on the spawning migrations of koaro. However, comparison of population length-frequency distributions (Chapter 4, Fig. 4.1) and adult population estimates suggests that there is an increase in the number of koaro into the middle site of the Waipehi from April to June, and a movement of koaro into the bottom site from January to April. As the peak time of spawning appears to be from December to March (Chapter 5) it appears that there may be a downstream migration of adults at this time into the lower reaches, where spawning takes place.

The proportions of marked fish recaptured in the Omori stream and in the Waipehi stream were similar (Table 3.9, 3.10) with most fish being recaptured at the site of tagging. 29% of koaro tagged in the top site were later recaptured, compared to 42% in the middle site. Only three koaro greater than 70mm in length were marked in the lower site of the Omori stream and none were recaptured.

Table 3.7: Recaptures of marked koaro from the Waipehi lower site.

Month	Colour	Pos.	No. Fish marked	Date recaptured				Fish recaptured	
				Dec	Feb.	Mar.	Apr	Total	%Total
Nov.	orange	anal 1,3	34	3 2	3 3	1 3	0 0	7 8	44
Dec.	pink	anal 1,2	37	x x	2 3	5 1	2 2	9 6	41
Feb.	white	anal 1,3	32	x x	x x	4 2	2 9	6 11	53
Total			103	5	11	16	15	47	46

Table 3.8: Recaptures of marked koaro from the Waipehi upper site.

Month	Colour	Pos.	No. Fish marked	Date recaptured				Fish recaptured	
				Dec	Feb.	Mar.	Apr	Total	%Total
Nov.	orange	pelvic 2	38	2 0	1 0	2 0	3 0	8	21
Dec.	pink	pelvic 1	22	x x	1 0	3 0	3 1	8	37
Feb.	white	pelvic 1	18	x x	x x	5 0	3 2	10	55
Total			78	2	2	10	12	26	33

Note: the second row in the date recaptured column, indicates the number of fish caught in the other Waipehi site.

Table 3.9: Recaptures of marked koaro from the Omori top site.

Month	Colour	Pos.	No. Fish marked	Date recaptured				Fish recaptured	
				Dec	Feb.	Mar.	Apr	Total	%Total
Nov.	orange	pelvic	17	5 0	1 0	1 0	1 0	5	30
Dec.	pink	pelvic	11	x x	2 0	1 0	0 1	2	18
Feb.	white	pelvic	4	x x	x x	0 0	0 2	2	50
Total			32	5	3	2	4	9	29

Table 3.10: Recaptures of marked koaro from the Omori middle site.

Month	Colour	Pos.	No. Fish marked	Date recaptured				Fish recaptured	
				Dec	Feb.	Mar.	Apr	Total	%Total
Nov.	orange	anal	13	1	3	0	1	4	31
Dec.	pink	anal	4	x	0	4	1	4	100
Feb.	white	anal	7	x x	x x	0 0	0 2	2	29
Total			24	1	3	4	4	10	42

Note: the second row in the date recaptured column, indicates the number of fish caught in the other Omori site.

3.4 Discussion

3.4.1 Comparison of sites

The population density of koaro was higher in the Waipehi stream than in the Omori stream, where densities of juvenile trout were high. Amongst the larger Taupo streams, the Hinemaiaia river appears to have the highest densities of koaro, while numbers in the mainstems of the Waiotaka and Waimarino rivers appear to be relatively low (M. Rosenau, personal communication 1989). It appears that in general, the population density of koaro is negatively correlated with trout density and may account for the large variations in koaro population density between sites.

The pattern of migration of juvenile koaro into the Waipehi and Omori streams appears to differ, with runs into the lower reaches of the Omori stream preceding those in the Waipehi stream. I can find no obvious explanation for this occurrence, except that high flow conditions in the Omori stream may have induced an earlier migration of koaro whitebait from the lake. Flow regime has been suggested as a possible stimulus for the migration of galaxiid juveniles into coastal rivers and streams (McDowall, 1984). It has also been suggested that other factors such as water colour, turbidity, dissolved oxygen, temperature and pH could all be a stimulus for upstream migration in whitebait (McDowall, 1984).

Seasonal variations in koaro population density in the upper and lower sites of the Waipehi suggest that adult koaro may undergo a spawning migration, with a downstream emmigration of adults into the lower reaches of the stream in February to April. The high densities of adult koaro in the lower reaches of the stream may also be supplemented by lake resident adult koaro which may migrate into the cooler tributary streams during the Summer months. The population dynamics of the koaro population in the Omori stream could not be investigated in detail due to the low population densities, but densities appeared to decrease during the Winter months. The capture of spawning adults at the upper sites of this stream suggests that spawning occurs in the normal adult habitat and that an extensive spawning migration does not take place.

3.4.2 Distribution of koaro and juvenile rainbow trout

There is strong circumstantial evidence that the introduction of salmonids into Lake Taupo was responsible for the decline in the koaro population (McDowall, 1987a; Stephens, 1983; Burstall, 1983; Fletcher, 1919). The decline is also apparent from the history of the trout fishery in the lake. Also, the fact that large populations of koaro exist in lakes where trout are absent, eg Lake Rotopounamu, suggests that predation and/or competition with trout are the major factors contributing to the decline of koaro.

Although there is little direct supporting evidence, it appears that salmonids may compete directly with koaro adults and juveniles in Lake Taupo tributary streams. Juvenile koaro do not appear to be heavily predated on by trout in the lake due largely to the abundance of smelt which is the primary forage food of trout in the lake (Stephens, 1984). Moffat (1984) and Main (1988) noted that when contained in enclosures brown trout were very aggressive towards koaro.

Juvenile rainbow trout and adult koaro appear to co-exist in relatively equal densities in the Omori and Waipehi streams. This finding does not conform with results of a previous study in Australia (Jackson and Williams, 1980), which found that brown trout had reduced and in some cases eliminated koaro from streams in the Otway ranges, Southern Victoria. Other studies on galaxiids have suggested that there is little overlap in the distribution range of galaxiids and trout, with galaxiids being generally abundant only where trout are relatively low in number or absent (Cadwallader, 1979; Jackson and Williams, 1980, Tilzey, 1976).

There is little doubt that there is competition between both koaro and salmonids in tributaries of Lake Taupo for both food and space. Analysis of stomach contents of koaro and rainbow trout from the Waipehi, Omori and Waiotaka streams suggests that there is considerable dietary overlap between the two species (Chapter 6).

Observations in the field during electro-fishing and trapping operations also suggest that trout and koaro are found in the same macro habitats but not necessarily in the same micro habitats. Glova (1989) suggested that koaro and brown trout may not compete directly with each other due to behavioural differences. Koaro are also mainly a nocturnal fish while trout are more active during the day (Glova, 1989).

The population density of juvenile rainbow and brown trout was much higher in the Omori stream than in the Waipehi stream. The reasons for this are not obvious but may be related to the high quality trout habitat in the Omori stream. The habitat in the Omori stream is also of higher quality for koaro but the population density of koaro is much lower than in the Waipehi, with the higher population densities of trout possibly reducing the abundance of koaro through inter-specific competition.

The relatively low population densities of rainbow trout in the

Waipehi stream may reflect the scarcity of suitable spawning gravels in this stream and as a result koaro densities are higher than in the Omori and Waiotaka.

The present distribution pattern of koaro in the small tributaries of Lake Taupo overlaps significantly with that of trout. However, koaro are found in much lower densities in the mainstems of the larger waterways such as the Waimarino and Waiotaka where juvenile trout predominate. Main (1988) also found that there was little overlap between the distribution of brown trout and koaro in the mainstems of South Westland streams, but koaro and trout were found to co-exist in the small tributaries. This distribution pattern may be due to the fact that mainstems of rivers are the preferred habitat of adult trout while galaxiids prefer smaller streams.

Similar distribution patterns have been documented in a Wairarapa stream in the North Island (Hopkins, 1971) and in an Australian stream (Frankenberg, 1966; Jackson and Williams, 1980; Cadwallader, 1979) where galaxiids were abundant in areas where trout were not present. Glova (1989), using a stream simulator, observed that juvenile salmonids are generally behaviourally dominant over various galaxiid species, including koaro. There is now good evidence to suggest that juvenile salmonids are territorially active only in the day while koaro are more active at night (Glova, 1989). The koaro, like other galaxiids, becomes active at dusk, and at dawn retreats to hiding places in the substrate, under-cut banks or in woody debris, where they remain buried in day-time (Glova, 1989). Therefore, temporal resource partitioning may be occurring with direct competition between koaro and trout being limited to the dusk and dawn periods.

If such behavioural differences do occur in the wild then populations of both koaro and trout can co-exist successfully.

However this infers that indirect competition for resources may be more important in determining distribution patterns. The two main forms of indirect competition may be the mere presence of territorially dominant trout (interference competition) and the use of a very similar and limited food resource (exploitation competition).

CHAPTER FOUR

AGE AND GROWTH OF KOARO

4.1 Introduction

The age structure, growth and mortality of koaro populations in New Zealand have not been studied in detail. Age and growth studies within the galaxiid family have been carried out on the following species: *G. fasciatus* (Hopkins, 1979), *G. divergens* (Hopkins, 1971), *G vulgaris* (Cadwallader 1975a) and *G. maculatus* (Burnet, 1965; McDowall, 1968; Benzie, 1968; Pollard, 1971;). The absence of scales in galaxiid species means that other methods of age determination must be used. McDowall (1968) found that otoliths and length-frequency analysis could not be used to determine the age of *G. maculatus* because of the prolonged spawning season of this species. Pollard (1971) investigating a landlocked population of *G.maculatus*, successfully used length-frequency analysis to age fish, but found otoliths of little use. Hopkins (1971) used both length-frequency analysis and otoliths to age populations of *G. divergens*, but did not validate the use of otoliths for this species. Cadwallader (1975a) used a combination of both otoliths and length-frequency analysis to age *G. vulgaris* from the Glentui river, Canterbury.

In this study both length-frequency analysis and otoliths were used to investigate the age structure of koaro, enabling a more complete investigation of the age structure, growth and mortality of koaro populations in the study streams to be made.

4.2 Methods

Koaro in the Waipehi and Omori streams were collected by electro-fishing as this is one of the least selective of all sampling methods (Chapter 3). The fork length of all fish captured was measured to the nearest 1mm and fish were weighed using a NDA EK-120a portable electronic balance accurate to the nearest 0.1mg.

Samples were taken at approximately monthly intervals from May 1988 to April 1989. No sampling was carried out in July 1988 and January 1989 due to adverse weather conditions.

4.2.1 <u>Age Determination</u>

There are a number of methods which can be used to age fish (Jearld, 1983), but three general methods predominate:-

i) the recovery of marked fish of a known age. This method is time consuming and was found to be unsuitable for this study.

ii) The Peterson method involving plots of length-frequency distributions of fish population samples (Tesch, 1971). This method involves the comparison of a large number of fish in a population and is based on the assumption that the lengths of fish in a particular age class will be distributed normally around a mean (Calliet et al, 1986). When length-frequencies are plotted a series of normal curves for each age group become apparent, enabling segregation of age-groups. This method is most reliable in ageing fish which have short spawning seasons and in the younger year classes since older fish grow in length more slowly and age-groups overlap (Calliet et al, 1986). Further complications arise with the different growth rates of individuals, and between the sexes in a population, which also leads to overlap amongst age-groups.

iii) The third method is an anatomical approach based on ageing individual fish from hard structures such as scales, bones or otoliths (Jearld, 1983). Otoliths were deemed the most useful hard structure for this study due to the absence of scales in koaro.

Otoliths are hard, calcarous structures in the paired labyrinth systems of teleosts (Tesch, 1971). The saggita is the largest of the 3 types of otolith and the most useful in determining age (Calliet et al, 1986). The basis of most ageing is the annulus or year mark, which is the result of a slowing in growth rate and subsequent reduction in the rate of calcium deposition, in response to such factors as the lowering of water temperatures in Winter. The use of otoliths to age fish depends on changes in the seasonal rate of growth or metabolism which are reflected in the otoliths as alternating bands of opaque and translucent material (Cadwallader, 1975a). Due to uncertainty over the cause or the time involved in deposition of calcium bands in otoliths and other hard structures of fish, caution must be exhibited in their interpretation and validity (Calliet et al, 1986).

Both sagittal otoliths were carefully removed from behind the brain using a scalpel and tweezers. Only fresh fish or fish preserved in 40% isopropanol were used. (Formalin was found to degrade the surface layer and thus create difficulties in interpreting the rings). Otoliths were observed under a stereo microscope at 80x magnification, mounted in glycerol, and viewed with reflected light against a black background. If interpretation was difficult the otolith was attached to a glass-slide using 'superglue' and ground down on jewellers sandpaper (1200 grade) using slow, circular movements.

In many cases it was difficult to distinguish between rings laid down on a regular seasonal basis, and those which resulted from non-periodic variation in growth, ie. secondary rings, resulting from spawning or flooding. Therefore, only otoliths with the most clear and distinctive rings were used to validate length-frequency analyses. The rings distinguished as annuli were more distinct, uniformly spaced and extended around the whole otolith. Otoliths were used to assist in determining the age of the older fish and to validate the results of ageing using length-frequency distributions. Daily growth rings on the otoliths were apparent but were not investigated as they were not clearly visible.

4.2.2 Methods for Studying Growth

There are four main methods for investigating the rate of growth of fish (Tesch, 1971):-

i) Direct observation

ii) Growth of fishes may be studied experimentally by direct measurement of fish of known size and age in tanks or ponds.

iii) Tagging and Marking

Tagging is often used to study growth, by recapturing fish of a known size. Only those marking techniques which do not affect the health, behaviour and mobility give accurate results (Tesch, 1971).
In this study tagging was used to investigate movement but not growth as electro-fishing may affect the survival and growth rate of fish (Sharber & Carothers 1988).

iv) Back-calculation of lengths at earlier ages

Back calculation of lengths from scales, otoliths and bones of individual fish are often used to determine age and growth history.

Many fish studies have investigated the growth rates of fish using growth curve models ie. von Bertalanffy, Gomptertz, and Logistic (Tesch 1971). The von Bertalanffy model is the most widely used, and has generally found to accurately describe the growth of most fish species.

4.3 Results

4.3.1 Age Structure

The length-frequency distributions of large samples of koaro captured from the Waipehi stream during the study period are shown in Fig. 4.1. In addition a length-frequency distribution of koaro taken from the top site of the Waipehi stream in February 1989 (Fig. 4.2) was plotted. Using these length-frequency distributions, five age-groups can be distinguished, corresponding to 0+, 1+, 2+, 3+ and 4+ age-groups (Fig. 4.2).

When length-frequency distributions of koaro populations from sites are compared (Fig. 4.3), it can be seen that sample sizes in the Omori stream were not large enough to obtain accurate age-group separation. However, it does appear that the age structure of koaro population in the Omori stream is similar to that in the Waipehi. Therefore, all further estimates of growth were based solely on koaro from the Waipehi.

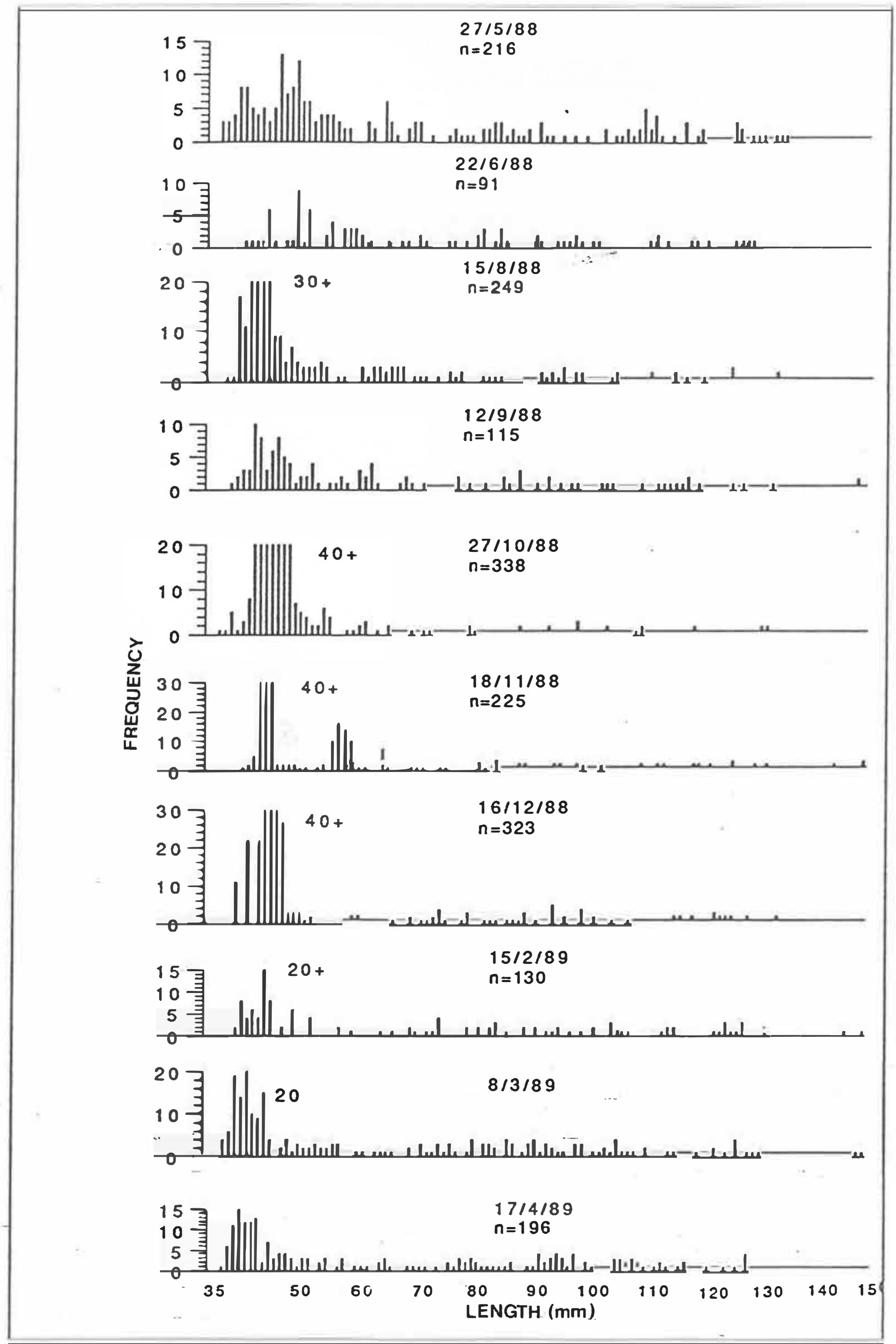


Figure 4.1: Length-frequency distributions of koaro sampled in the Waipehi stream 1988-1989.

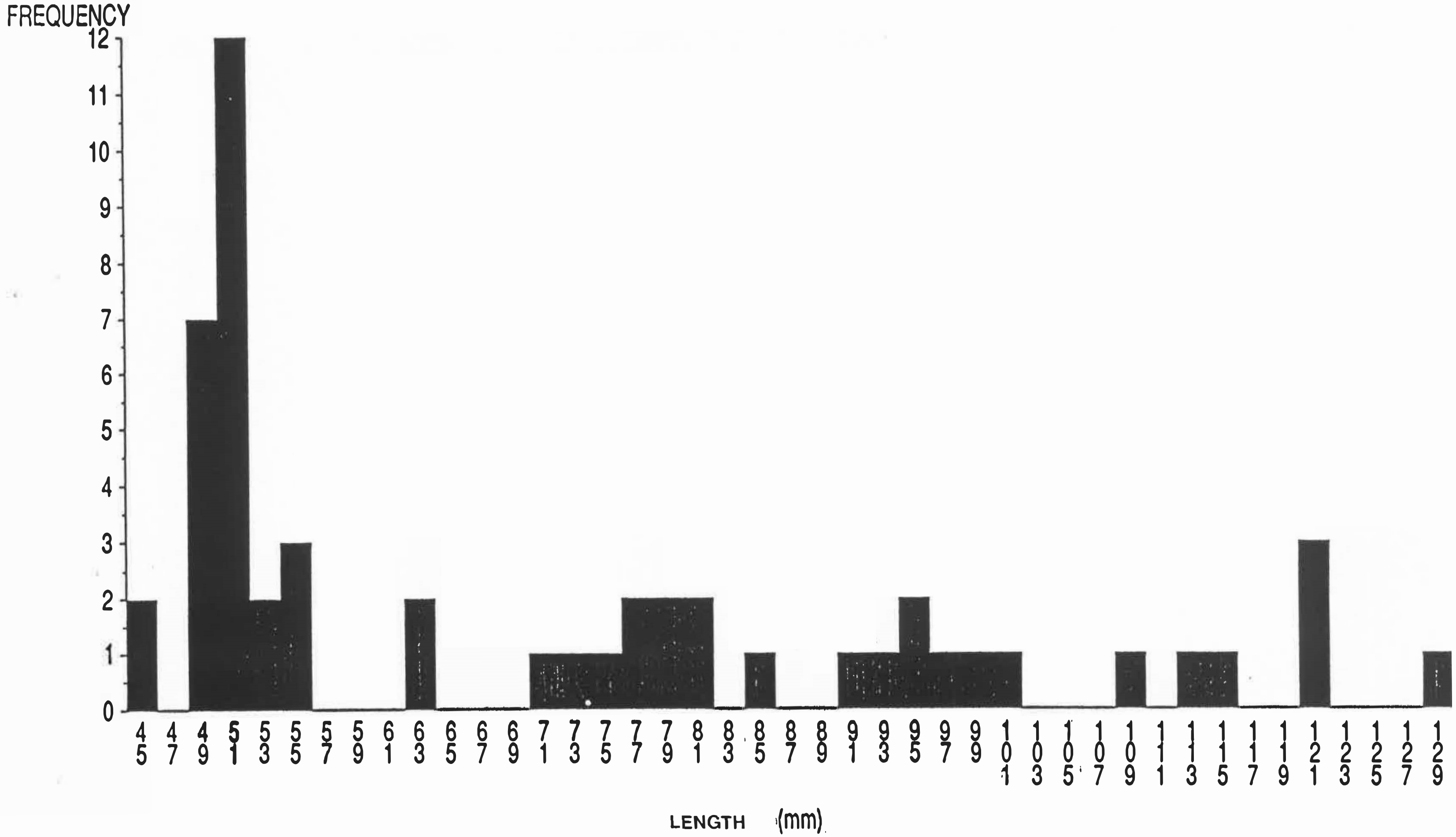


Figure 4.2: Length-frequency distribution of koaro in the Waipehi stream (upper site) February 1989.

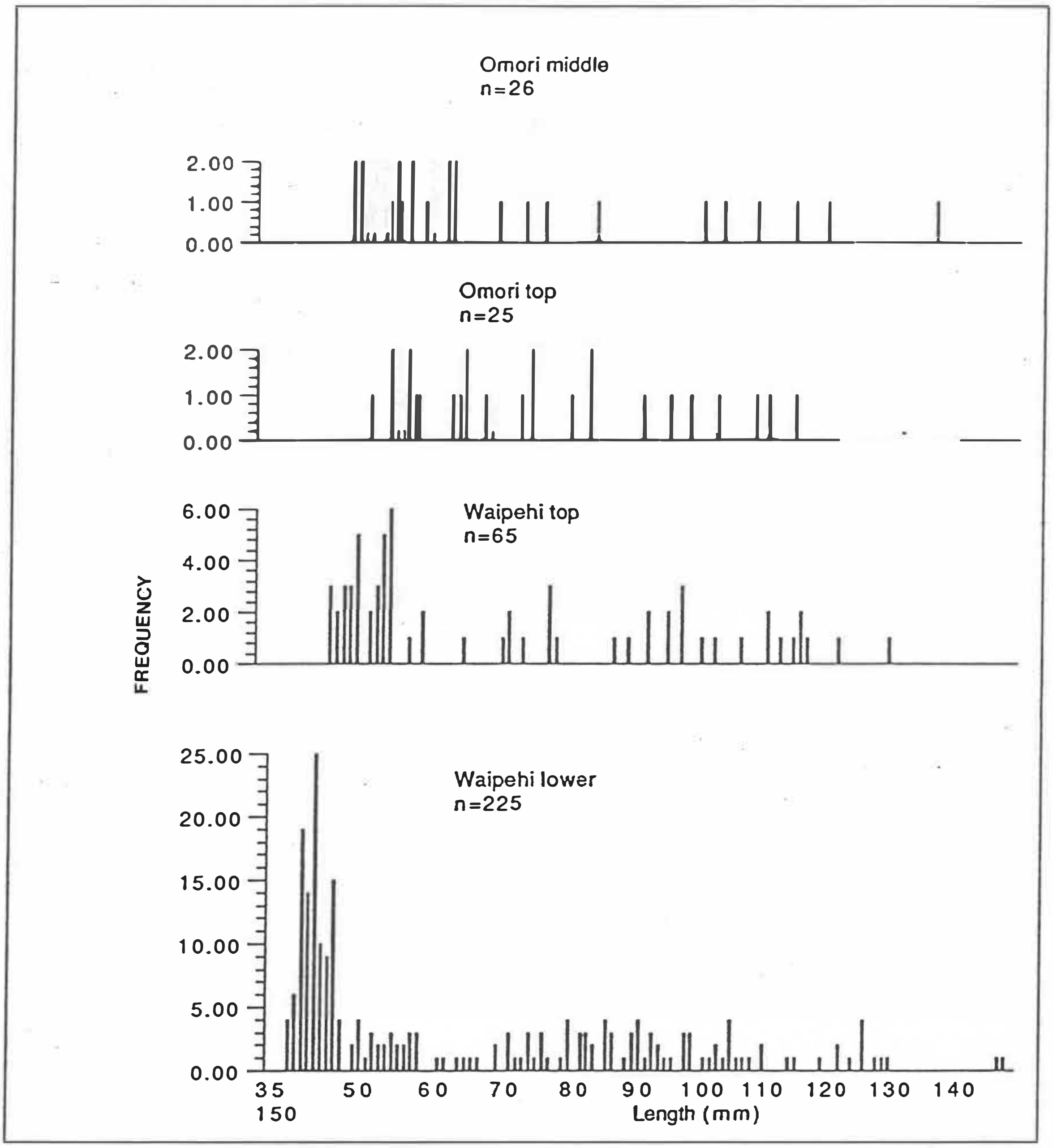


Figure 4.3: Comparison of length-frequency distributions of koaro in the Omori and Waipehi streams, March 1989.

The separation of age-classes in the length-frequency distribution was often difficult due to a number of factors:-

i) It is known that juveniles of diadromous galaxiids such as Koaro, inanga and kokopu undergo slight reductions in length upon entry into freshwater (Woods, 1968, McDowall, 1968). As a result, the pattern of growth during the first year of life is likely to differ from that in later years. This shrinkage may also occur in koaro populations in Lake Taupo, with whitebait entering the Waipehi and Omori streams at a mean length of approximately 45mm and reducing to 40mm upon entry to the streams. As a result, it was often difficult to separate 0+ and 1+ age-groups.

ii) Further complications arose due to differences in growth rates between individuals and possibly between the sexes. Hopkins (1979) found that female *Galaxias fasciatus* grew significantly faster than males, and this may also occur in koaro populations. It is not possible to distinguish the sex of koaro externally and fish had to be returned to the laboratory for internal dissection.

The use of length-frequency distributions to age koaro was validated by comparison with results obtained using otoliths. Examination of otoliths from koaro taken in June 1989 indicated that koaro ranging in length from 89-110mm were 2+ to 3+ years of age (Plate 4.1, plate 4.2). These ages agreed with those predicted from length-frequency analysis (Table 4.1, Fig. 4.1). It was assumed that the age composition of the koaro population in the Omori stream was similar to that in the Waipehi stream. Comparison of length-frequency distributions suggests that the age structure of the populations were similar (Table 4.1).

Table 4.1: Age composition of Waipehi koaro using length-frequency distributions, February 1989.

Age class	Mean length (mm)	Length at t+1 (mm)
0+	50	77
1+	77	95
2+	95	115
3+	115	129
4+	129	

Table 4.2: Age composition of koaro in the Waipehi stream using otoliths, June 1989.

Length (mm)	Estimated age (years)
55	0 +
55	0 +
73	1 +
75	1 +
88	2 +
89	2 +
90	2 +
105	3 +
110	3 +
111	3 +
116	3 +
121	3 +
146	4 +

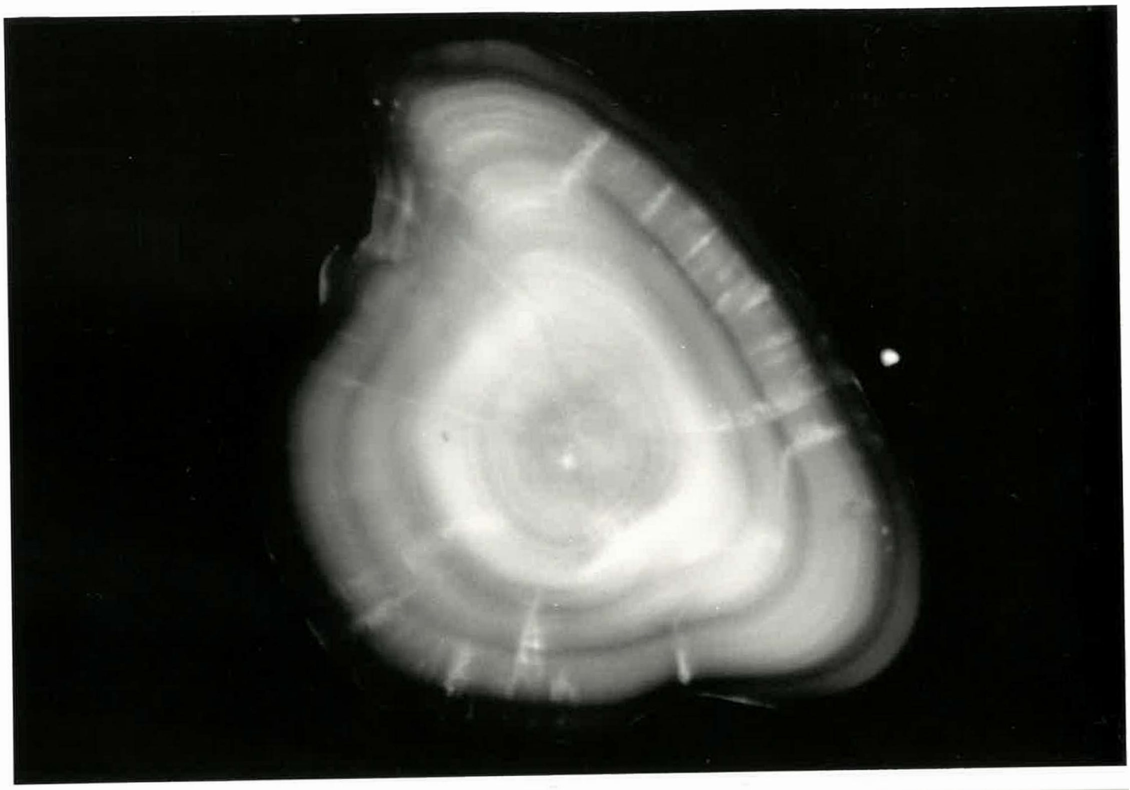


Plate 4.1: Otolith of 89mm koaro with an estimated age of 2+ years.

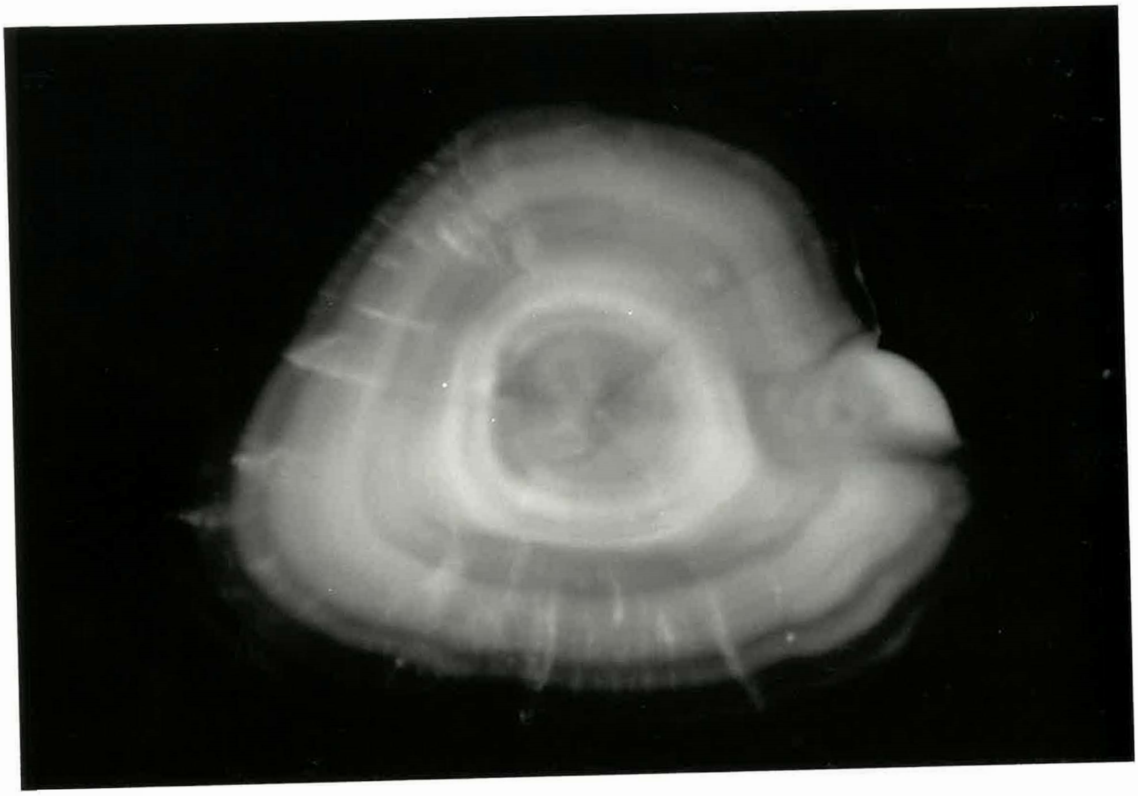


Plate 4.2: Otolith of 103mm koaro, with an estimated age of 3+ years.

4.3.2 Growth

Annual Growth in Length

The von Bertalanffy equation (von Bertalanffy, 1938) is one of the most widely used growth curve models and was used to establish the annual growth pattern of koaro in the Waipehi stream from May 1988 to April 1989. As the growth rate of koaro smaller than 55mm does not conform to that of later years, all age 0+ koaro were excluded from the annual growth estimates.

The length-frequency data used for calculating the annual growth of koaro was obtained from a koaro sample taken from the Waipehi top site in February 1989. The age-group composition of the population determined from the length-frequency distribution was found to be very similar to age classes obtained from otoliths.

The von Bertalanffy growth equation as described by Tesch (1971) is expressed as;

$$l_t = L_\infty (1-e^{-k(t-t0)})$$

Where;

l_t = the length at age t

L_∞ = the asymptotic length predicted by the equation

e = the base of the natural log

t = age in years

t_0= a time when length would theoretically be zero

K= The growth coefficient (instantaneous rate)

The mean lengths of the various age groups were used to estimate the parameters L_∞, K, and t_0. These parameters were obtained graphically using a Walford plot (Walford, 1946) which is a plot of of mean length at time t1 against time at t2 etc. (Fig. 4.4). The following procedure was used to obtain the von Bertalanffy parameters.

Step 1. A Ford-Walford plot was plotted for the length-frequency distribution of koaro from the Waipehi in February 1989 (Fig. 4.4, Table 4.1).

Step 2. L_∞ was determined by solving the equation;

$$L_\infty = \frac{\text{y intercept}}{(1 - k)}$$

where k = the slope of the line in the Walford plot.

Therefore substituting gives;

$$L_\infty = \frac{34.846}{(1-0.82082)}$$

L_∞ = 194 mm

Step 3. The parameter t_0 was determined from the equation;

$$t_0 = \frac{\text{y intercept} - \log_e L_\infty}{K}$$

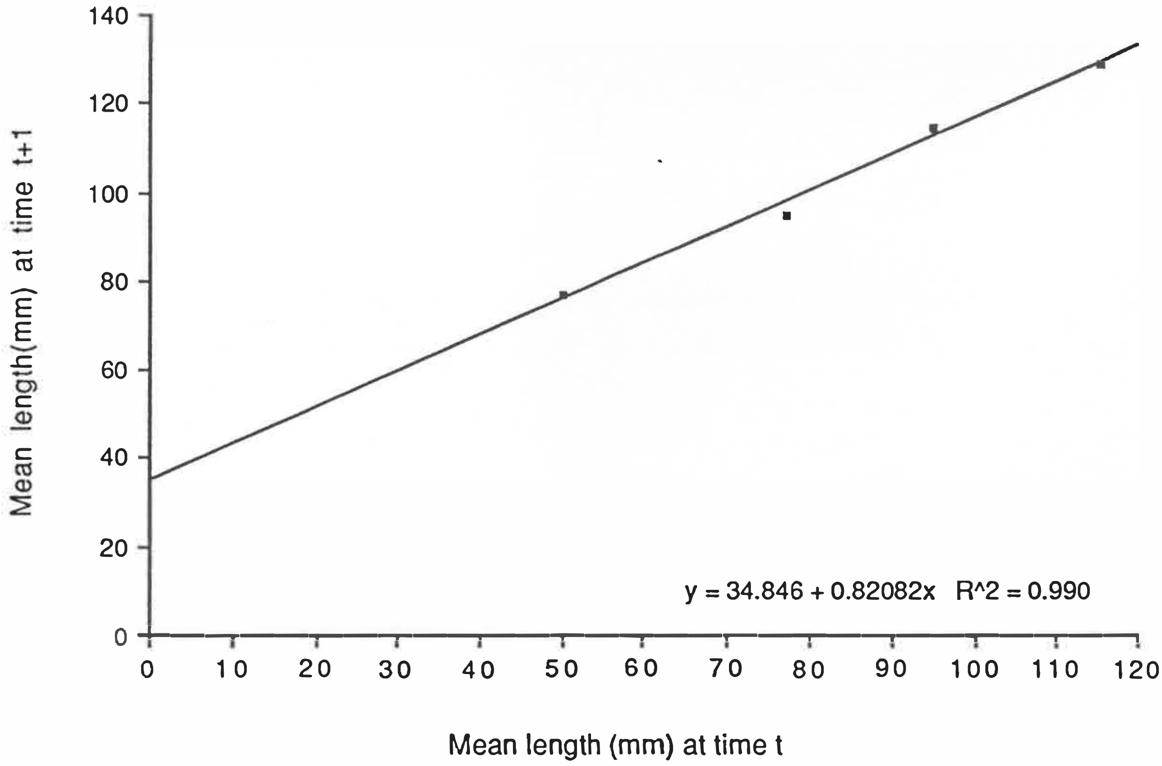


Figure 4.4: Ford-Walford plot for Waipehi top site koaro in February 1989.

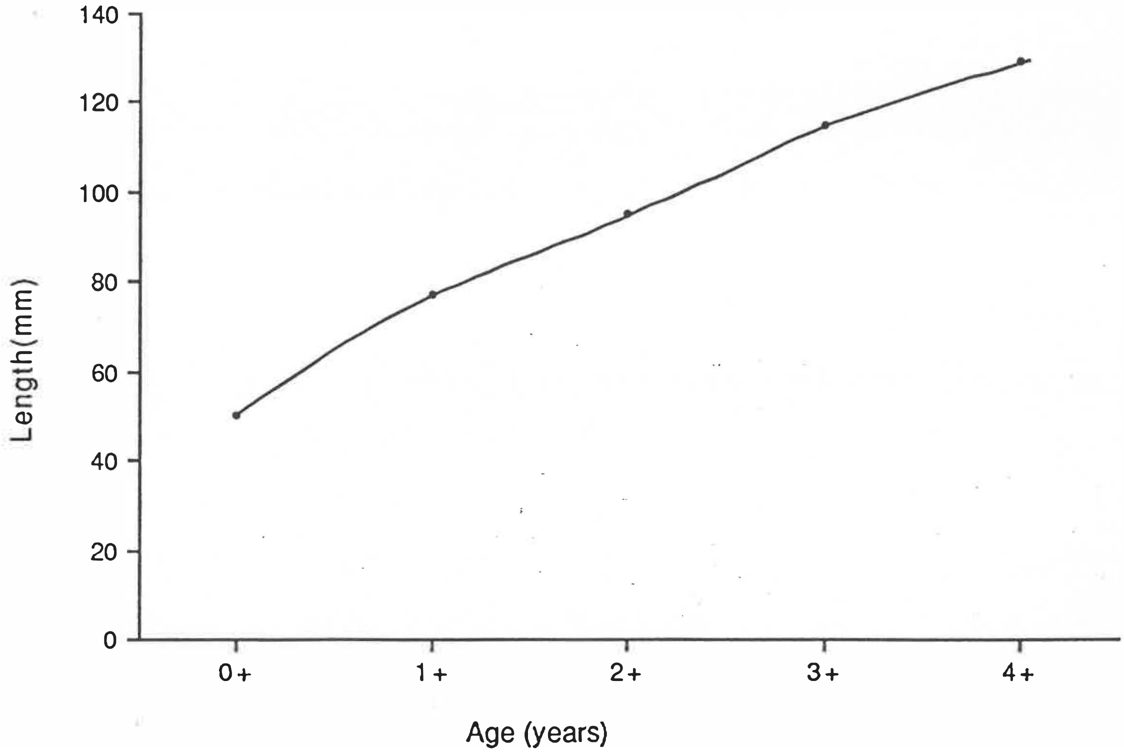


Figure 4.5: Age-length plot for Waipehi koaro, February 1989.

$$t_0 = \frac{34.846 - 5.2703}{0.82082}$$

t_0 = 36.03

Therefore, the annual growth of koaro in the Waipehi stream is described by the von Bertalanffy equation as;

$$Length_t = 194.47 \; (1 - e^{-1. (t + 36.03)})$$

Where:

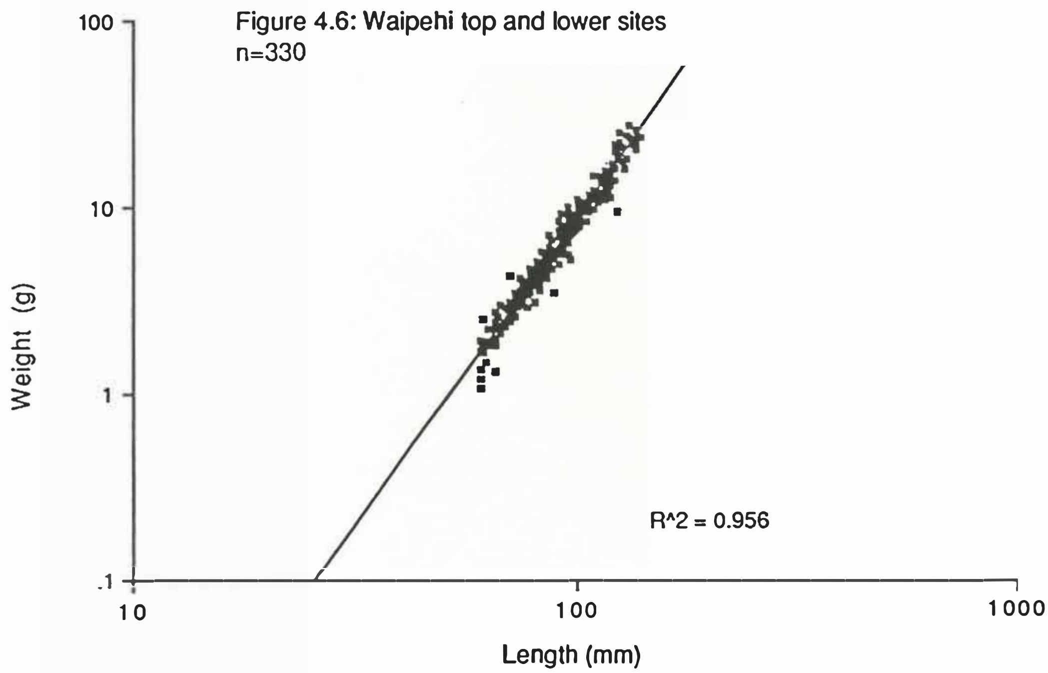
$L\infty$ = 194.47 mm

k = 0.82082

t_0 = 36.03

4.3.3 Length-Weight Relationship

The length-weight relationship of koaro in the Omori (Fig. 4.6) and Waipehi (Fig. 4.7) streams was calculated from length and weight data obtained from June 1988, December 1988 and February 1989. It was hoped that length weight data obtained from different months could be combined to give a general expression describing the relationship between length and weight for the Waipehi and Omori koaro populations. The length-weight expression is usually described by the relationship:



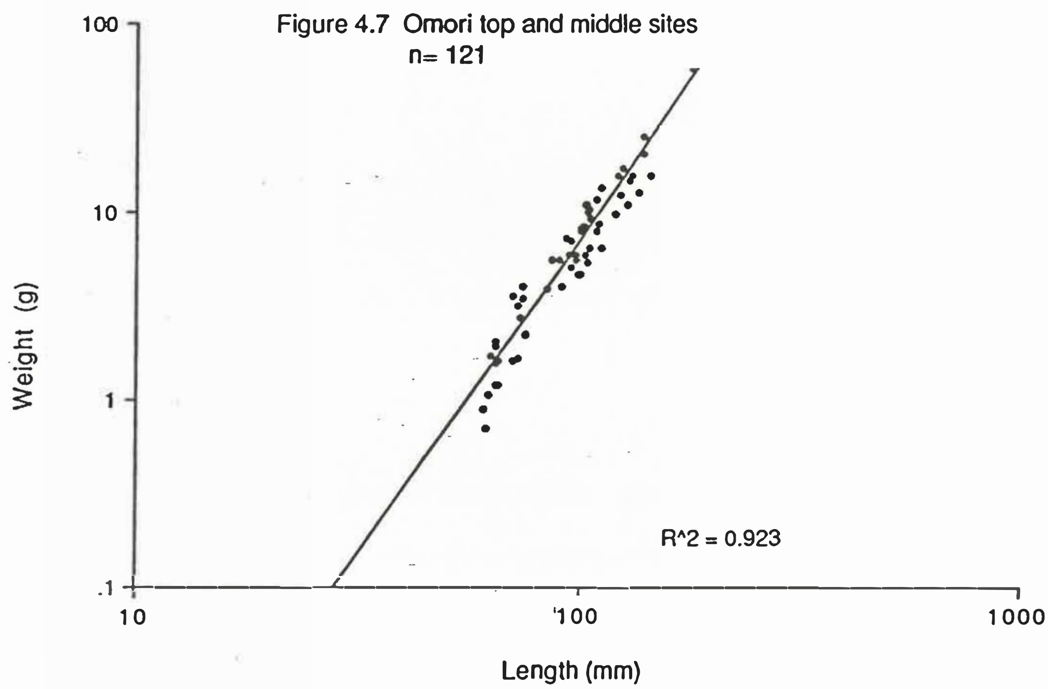


Figure 4.6, 4.7: Log_{10} plot of length against weight of Waipehi and Omori koaro.

$W = a * L^b$ (Tesch, 1971)

where;

W = weight

L = length

a & *b* = constants

Alternatively, the length-weight relationship can be transformed to;

Log W = Log *a* + *b* * Log (L)

It is often more convenient to plot $\log_{10}$ weight against $\log_{10}$ length and calculate the regression line by the method of least squares (Fig 4.6, Fig. 4.7). The regression coefficient is *b*, while log*a* is the intercept of the line with the *y* axis.

This gave the following general length-weight relationship expressions for the Waipehi and Omori koaro populations;

Waipehi koaro;

Log W = 3.2537 log l - 2.1641 R^2 = 0.961

and Omori koaro;

Log W = 3.3419 log l - 2.4474 R^2= 0.923

LeCren (1958) stated that the exponent *a* commonly lies between 2.5 and 4.0. A cube relationship has been assumed between length and weight, a situation which arises if a fish maintains a constant shape as it grows ie. isometric growth. The length-weight relationship equations obtained from the koaro in the Waipehi and Omori streams, indicate that weight increases slightly greater than the cube of length.

Table 4.3: Regressions of weight on length for Omori and Waipehi koaro (W = weight(g), L = length (mm)).

Site	Month	n	Regression equation	Correlation
Omori middle	December	10	log W = 3.631 log L - 2.343	0.989
	February	25	log W = 3.150 log L - 1.950	0.981
	June	22	log W = 3.486 log L - 2.269	0.985
Omori upper	December	19	log W = 3.327 log L - 2.310	0.978
	February	13	log W = 3.299 log L - 2.285	0.994
	June	32	log W = 3.444 log L - 2.179	0.971
Waipehi lower	December	51	log W = 3.396 log L - 2.428	0.939
	February	58	log W = 3.355 log L - 2.386	0.952
	June	100	log W = 3.295 log L - 2.274	0.961
Waipehi upper	December	29	log W = 3.376 log L - 2.328	0.972
	February	24	log W = 3.274 log L - 2.200	0.950
	June	105	log W = 3.217 log L - 2.210	0.968

The weight-length regression equations for June 1988, December 1988 and February 1989 (Table 4.3) generally show that the *b* exponent is highest in Spring, decreasing during the spawning season (February). The *b* exponent for koaro in the Omori stream appears to increase more quickly in comparison to the Waipehi stream. Coefficient *a* cannot be used as a measure of relative condition unless the *b* coefficient is the same for all groups of fish whose condition is being compared (LeCren 1951).

4.3.4 Seasonal growth in length

Seasonal patterns of growth in length were complicated by the high degree of overlap in age classes. Growth of the age 0+ age class is also deceptive as juveniles undergo shrinkage upon entry to the stream and the mean lengths of the 0+ age class are hence liable to inaccuracy. Therefore, seasonal growth rates for this age group are not easily estimated. The wide overlap between the various age classes, and differences between the growth of the sexes, meant that it was difficult to estimate accurately the mean lengths of each year class, making investigation of seasonal growth patterns very difficult.

There was insufficient data to accurately record the seasonal growth in length of koaro in the Omori stream. However, individual tagging of fish in the Omori stream revealed that the age 3+ fish grew on average from 2-3 mm in length between December and March.

4.3.5 Condition

Seasonal differences in condition were examined by deriving condition factors for koaro in the Waipehi and Omori streams during the months of June 1988, December 1988 and February 1989 (Table 4.4). Fulton condition factors were determined using the formula;

$$CF = \frac{W}{L^3} \times 10^5 \quad \text{(Tesch, 1971)}$$

The condition of koaro in the Omori stream was relatively low in Winter and high in Summer. In comparison, condition factors derived for Waipehi koaro show that there was little variation throughout the year, with condition being close to 1 in both Winter and Summer. Generally, condition factors for both the Waipehi and Omori koaro populations peak in Spring and decrease slightly during February, coinciding with the peak time of spawning.

Diet studies showed that in the spring months a high proportion of koaro contained extensive yellow fat dèposits, suggesting that fish are in peak condition during these months.

Site	Month	N	Mean length (mm)	Mean weight (g)	Condition factor
Waipehi top	June	68	85.82	6.558	1.0375
	December	29	93.69	8.387	1.0198
	February	24	95.58	8.708	0.9972
Waipehi lower	June	100	92.82	7.476	0.9349
	December	51	92.96	8.602	1.0708
	February	58	93.17	7.488	0.9258
Omori top	June	32	98.09	6.625	0.7019
	December	19	94.63	10.21	1.2050
	February	13	100.15	12.03	1.1970
Omori middle	June	22	91.25	5.000	0.6088
	December	7	90.86	9.570	1.2761
	February	24	92.33	9.217	1.1710

Table 4.4: Fulton's condition factor, mean length and weight of koaro.

4.3.6 Mortality

Mortality estimates were complicated by the high degree of overlap of the age classes and the upstream movement of juvenile koaro and the movements of koaro adults at all sites. Juveniles koaro were also represented in the Spring months during their upstream migration.

It appears from the length frequency distributions that koaro undergo size selective or 'J' shaped mortality whereby, after the initial high mortality in the first year of life, the rate of mortality decreases lower and remains relatively constant for the other age groups of the population (Fig 4.1).

4.4 Discussion

Age classes determined from length-frequency distributions and otoliths show a close degree of correlation. Koaro otoliths required intensive preparation however, and in an environment where growth is constant throughout the year, annual rings are difficult to read and therefore may not be entirely accurate. The length-frequency distributions of koaro populations in both the Waipehi and Omori streams showed a considerable overlap between age-classes, which increased with age. Factors which may be implicated include the extended spawning season (Chapter 7), the continual recruitment of koaro juveniles, different growth rates of males and females, competition for food, and inherent differences in the rate of growth of individual fish. The extensive overlap between age classes makes age determination difficult. However, a combination of both techniques was found to be a satisfactory age determination method.

It appears that koaro in the Waipehi and Omori streams are in peak condition in the Spring months, but condition factors vary considerably between the two streams. The high condition of koaro in the Waipehi stream may be related to the fact that this is a productive stream with a rich benthic fauna and low numbers of trout (Chapter 3). Results indicate that koaro in the Omori stream have low condition factors in the Winter and high condition factors in the Summer. Since water temperatures were similar in both streams (Chapter 2) the differences in condition of koaro between the streams could be a reflection of intense competition with trout in the Omori stream for a limited food resource in Winter. The high condition factors of Omori koaro in the Summer months may reflect an abundant food supply which is sufficient to sustain both trout and koaro. Therefore the limiting factor in the growth and survival of koaro in the presence of trout may be the Winter months when both species are competing for the same limited food resource (Chapter 6).

The condition of koaro in the Waipehi stream does not appear to show great seasonal variation and peak condition factors were generally lower than in Omori koaro. The relatively constant condition of koaro in the Waipehi stream could be due to the low numbers of trout present in the stream over the Winter months and therefore reduced competition for food. The higher densities of koaro in the Waipehi stream could be due to the absence of trout and reduced competition for food over the critical winter period when food is scarce.

Length-weight relationships of koaro in the study streams appear to be typical of many species of galaxiids in New Zealand. Cadwallader (1975a) found that for *Galaxias vulgaris* the value of the b exponent varied from 3.084-3.376 while Hopkins (1979) found that

Galaxias fasciatus in two streams, b exponents varied between 3.29-3.36.

The growth rate of koaro was found to be reasonably slow and similar to that seen in other galaxiid species. A koaro fry captured during benthos sampling in February in the Omori stream was approximately 6mm in length. Koaro juveniles rear in the lake for 6-9 months and return to the tributary streams at approximately 45mm in length. Thus during the period from hatching to re-entry into the stream there is a growth in length of approximately 30-40mm. The juveniles then undergo shrinkage (the reason for this reduction in length is not known but it could be due to a physiological change or a result of the decrease in water temperature from the lake to the stream) before assuming positive growth (Woods, 1968). For the older age groups growth appears to be fairly continuous throughout the year and is slowest in the Winter months. Cadwallader (1975a) found that *G.vulgaris* grew most quickly in spring and summer and slower in Autumn and winter. The annual growth rate of *G.vulgaris* is not as quick as koaro, with 1+, 2+, 3+, 4+ *G.vulgaris* reaching 61, 82, 98, and 110mm respectively. Results of this study suggest that koaro reach a mean fork length of 95mm by three years of age. The difference between the two species may be related to the severity of the autumn and winter seasons in the South Island streams where the study was conducted. Cadwallader (1975a) observed that most growth occurred when water temperature was maximum, and growth ceased when temperatures were low.

The growth of *G.fasciatus* was much faster than koaro in Taupo, with the former reaching a mean fork length of 86mm at age 1+, and 122 mm at age 2+ (Hopkins, 1979). The largest koaro in this study (186 mm) was captured from the top site on the Omori stream, while the largest koaro recorded from the Waipehi stream was a 175mm long gravid female. These fish were most probably 5-6 years of age. There is little information on the maximum life-spans of other large galaxiid species in New Zealand. Hopkin's (1979) found that *G. fasciatus* survived to 9 years of age. Of the smaller galaxiids *G .maculatus* females are known to survive to 3 years (Burnet, 1965), *G. vulgaris* and *G. divergens* are thought to survive to 3 years of age (Benzie, 1968; Hopkins, 1971). Hopkins (1979) found that the growth rates and longevity of male and female *G. fasciatus* differed considerably, with females generally growing faster and living longer than males. Furthermore, marked differences were found in the growth rates of fish from two different stream populations. This difference was attributed to competition with koaro and eels for food. Unfortunately, as koaro can not be sexed externally males and females were combined into the same age groups.

The high mortality rate of koaro during their first year of life is similar to other New Zealand fish e.g. *Galaxias divergens* (Hopkins, 1971), *Gobiomorphus cotiadianus* (Stephens 1982) and *Gobiomorphus breviceps* (Staples, 1975). Staples (1975) attributed much of the mortality of younger fish to intraspecific predation, and Stephens (1982) suggested that high mortality of older fish was due to stresses associated with spawning, high water temperature and low food availability. The relationship between egg size, fecundity and life history pattern in New Zealand galaxiids has been discussed by Benzie (1968) and McDowall (1970). Diadromous and lacustrine populations of koaro have an r-selected life-history strategy, producing numerous (3000-19000) small eggs (1.0mm in diameter)(Chapter 6). McDowall (1970) suggested that the high fecundity was related to high larval mortality, due to predation, dispersal related and a plentiful supply of plankton in the lake or ocean environment. McDowall (1970) suggested that food reserves are more important to the larval stages of such species as *G.vulgaris* which develop in running water, since this gives them a better chance of resisting downstream dispersal and also compensates for the poorer food supply in the freshwater environment. The results of diet analyses suggest that intraspecific and interspecific predation may be an important factor in juvenile mortality (Chapter 6).

CHAPTER FIVE

REPRODUCTION

5.1 Introduction

The reproductive biology of the koaro is not well known. The koaro is one of the five diadromous galaxiid species which generally produce large numbers of small eggs, with the newly hatched eggs being carried downstream to the sea where the juveniles develop during the Winter. The following spring, the juvenile whitebait ascend the rivers in large shoals. However, the koaro populations in Lake Taupo and some of the other central North Island lakes are landlocked and the spawning and reproductive cycles of these populations have not been extensively researched. Populations of koaro are found in many inland South Island and North Island lakes (McDowall, 1970). Landlocking occurs in several galaxiid species including - *G. gracilis* which is thought to be a landlocked derivative of *G.maculatus*, (McDowall, 1967).

The few studies carried out on galaxiid species in New Zealand indicate a diverse range of spawning habitat. *G.maculatus*, is probably the most well known of all the galaxiidae species, and spawns over tidal flats and river banks, with eggs hatching upon reimmersion by spring tides (McDowall, 1970). *G.fasciatus* however, spawns among flooded terrestrial vegetation along the margins of a stream (Mitchell and Penlington, 1982). Of the non-diadromous species, *G. divergens* probably scatters small batches of eggs on stones on the stream bed (Hopkins, 1971) and *G. vulgaris* excavates a nest in the stream gravel (Cadwallader, 1976b). The ova of *Neochanna apoda* develop in damp, pool-side vegetation (Eldon, 1971). The life-cycles of *G. brevipinnis*, *G. fasciatus*, *G. postvectis* and *G. argentus* have been inferred mainly from the occurrence of juveniles in samples of migrating whitebait. McDowall (1970) considered it unlikely that spawning migrations occur in diadromous galaxiids as the ripe adults have been found in or close to normal adult habitats.

The aim of this study was to describe the reproductive cycle of a lacustrine population of koaro where the life-cycle is restricted to freshwater. The fecundity, gonadosomatic ratios, sex ratios and egg size, were investigated.

5.2 Methods

Fish were collected by electro-fishing (backpack and generator powered) at approximately monthly intervals from December 1987 to April 1989. Koaro were assessed for reproductive condition during routine sampling trips. Gentle pressure was applied to the flanks of the fish to see if milt or ova were extruded. In addition, fish samples were taken and gonads were examined in the laboratory. No method was found to distinguish between males and females externally in the field unless sexual products were released. Fish samples were preserved in either 10% formalin or 40% isopropanol. The preserved samples were examined in the laboratory and their sex and stage of maturity recorded.

Seven stages of maturity are recognised, using the classification of Nilkosky (1963).

1) Immature - Fish sexes indistinguishable.

2) Resting - Developing virgin or resting adult. Eggs visible under 25x magnification.

3) Maturation stage 1 - Developing/ eggs visible to the naked eye.

4) Maturation stage 2 - Gonads filling body cavity. Testes white, ovaries yellow, eggs 1mm in diameter.

5) Reproduction- Ripe, eggs/ milt excluded by light pressure.

6) Spent - gonads in spent condition.

Gonadosomatic ratios (GSR) were calculated using the formula

$$GSR = \frac{\text{Wt of gonads} \times 100}{\text{Wt of fish}}$$

The gonads were weighed (including the weight of the seminal vesicles) separately to the nearest one milligram using a Mettler AC100 electronic balance. Egg counts were made from ovaries at stage *E* and also from ripe fish in the field. Ovaries were removed and fixed in Gilsons fluid (Simpson, 1951) to preserve and break down the ovarian tissue and to release the eggs. Samples of approximately 10% of the total number of eggs were separated and placed in small glass dishes. The remaining ovaries were then dried at 80 °C for 24 hours or until they were dry. The total number of eggs was then estimated from the formula:

$$\text{Total no. of eggs} = \frac{\text{No. of eggs in sample X Total weight of ovary}}{\text{Wt of sample}}$$

The diameters of eggs from ovulated fish were then measured under a stereo microscope, using an eye piece graduated with an Olympus objective micrometer. Egg diameters in mature and ripe fish were also recorded.

5.3 Results

5.3.1 Spawning

The time-period over which mature koaro were captured suggests that spawning occurs over an extended period with, ripe fish in the Waipehi and Omori streams being captured from November through to April. Spawning appeared to be at a peak from December through to March (Fig. 5.1).

The presence of tagged fish (Chapter 3) spawning in their normal adult habitat, where they were marked, suggests that lengthy spawning migrations do not take place. The results of fish tagging (Chapter 3) and analysis of length-frequency distributions (Chapter 4) do however suggest that there may be short localised movements within the home-range of koaro to areas of suitable spawning substrate.

No fish were actually observed in the act of spawning, but the presence of ripe males with running milt and gravid females releasing eggs at some sites suggests that spawning was either occurring or was

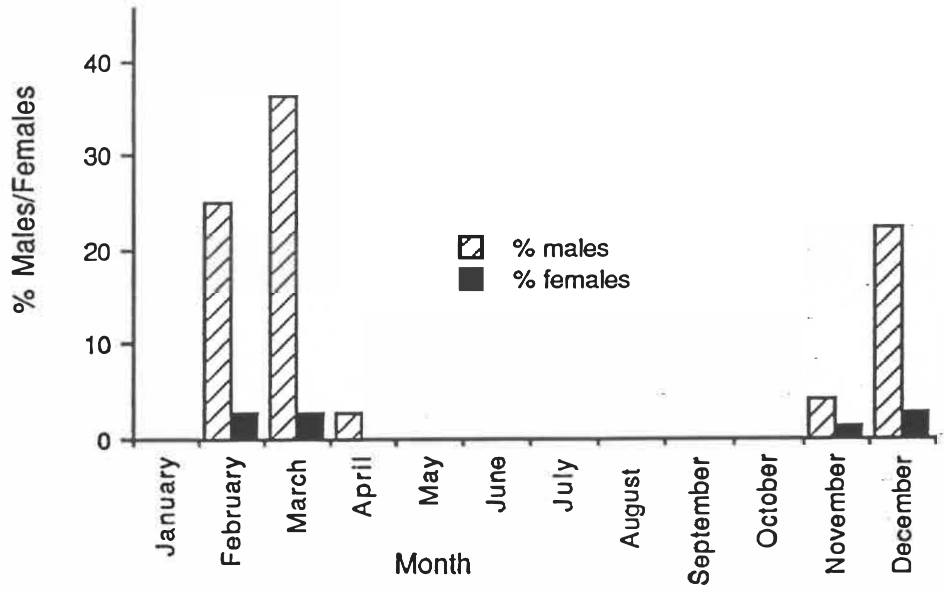


Figure 5.1: Ripe koaro found in the Waipehi stream during sampling.

very close. A search for eggs in the substrate and on the river banks was unsuccessful, but to find such small eggs would be fortuitous. However, a juvenile koaro measuring 6mm in length was captured in a benthos sample from the middle site on the Omori stream in February 1989, suggesting that spawning occurs in the stream itself either in/ or near the normal adult habitat. The presence of these gravid fish at periods of normal flow suggests that spawning may not necessarily be related to flooding. This differs from observations on *G. fasciatus* made by Mitchell and Penlington (1982) when *G. fasciatus* were seen spawning during flooding.

5.3.2 Fecundity

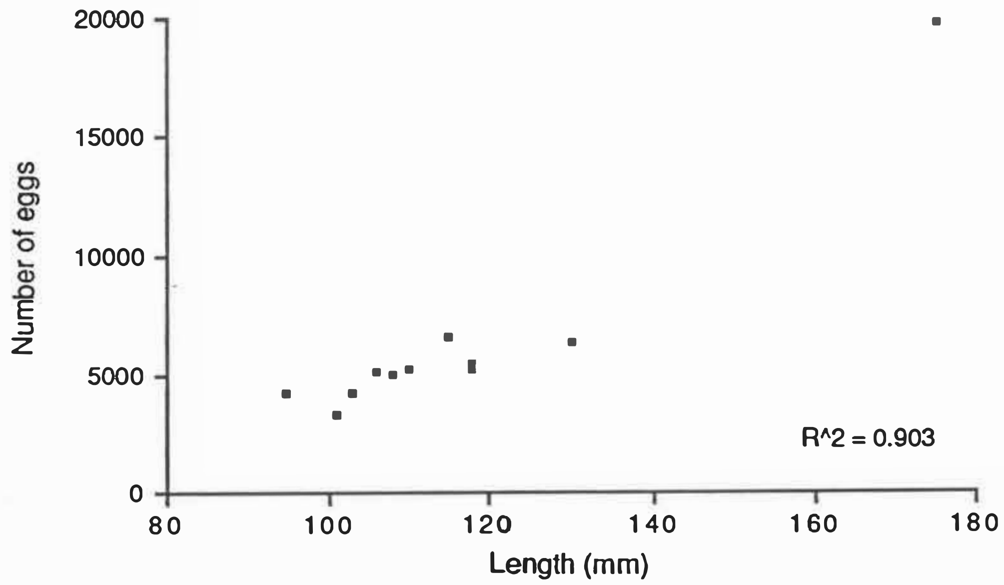
Ovaries were removed from 8 mature or ripe females between

December 1988 and April 1989. The fork length of the fish ranged from 101mm to 175mm and fecundity estimates were made for each fish. Only mature or maturing eggs greater than 1.0mm in diameter were counted and any eggs smaller than this were not included. Mature egg diameter ranged between 1.0mm and 1.25mm. Fecundity estimates ranged from 3,613 (fish length, 103mm) to 19,830 (fish length, 175mm). It appears that there is a general increase in fecundity with increasing weight and length of female koaro (Fig. 5.2, Fig. 5.3). The relationship between egg number and length appears to be approximately linear (Fig. 5.3). However, as this was based on a small sample size, a mathematical expression could not be fitted to the relationship.

5.3.3 Sex ratio

Approximately half of a total sample of 412 koaro were sexed. In this sample there were 110 (52%) males and 102 (48%) females (200 immature fish all less than 60mm in length were not sexed).

The sex-ratio of males to females (Fig. 5.4) seems to declined in May and may have been due to male mortality during spawning. The proportion of ripe males in the field was much higher than that of gravid females (Fig. 5.1). The sex ratio did not vary between individual sites and there was no general tendency for one sex to predominate.



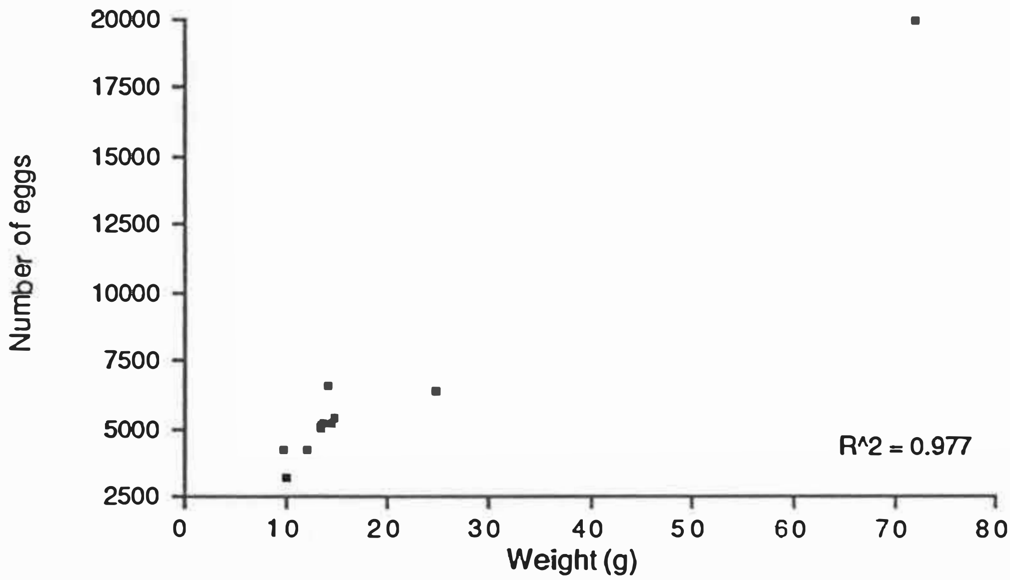


Figure 5.2 and Figure 5.3: Fecundity versus weight and length for Waipehi koaro.

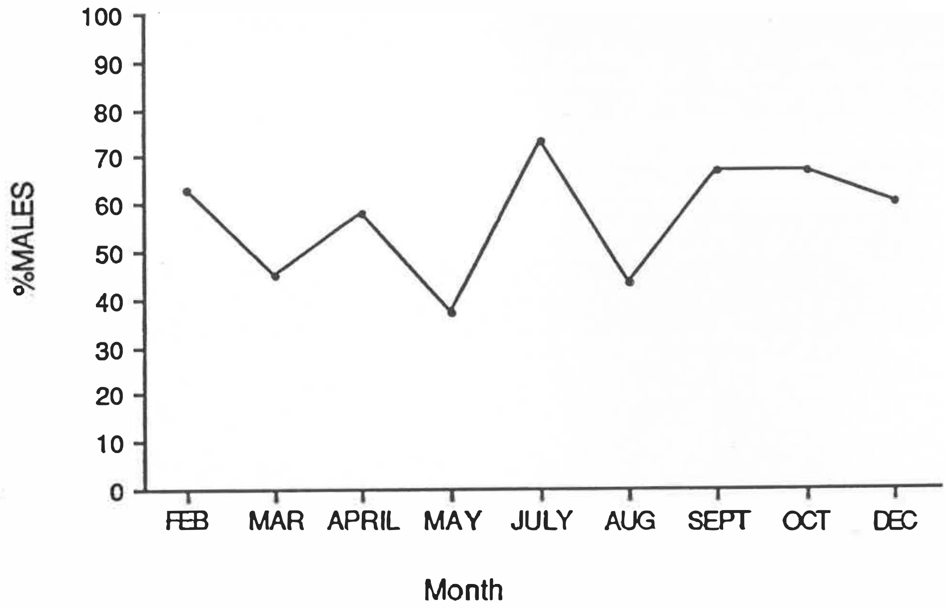


Figure 5.4: Sex-ratio of Koaro at the Waipehi lower site, 1988-1989.

5.3.4 <u>Gonadosomatic ratios</u>

The gonadosomatic ratios (GSR) of ripe male koaro were found to be much lower than for ripe females (Fig. 5.5). The maximum GSR for one female koaro was 27.757, with a mean index of 5.67. The maximum GSR for one male was 23.293 and the mean index was 3.04. Mean GSR values for both males and females dropped sharply in Winter, reflecting the end of spawning activity. The gonadosomatic ratio of female koaro was at its highest in Spring. This time-period agrees with the dates when ripe fish were captured.

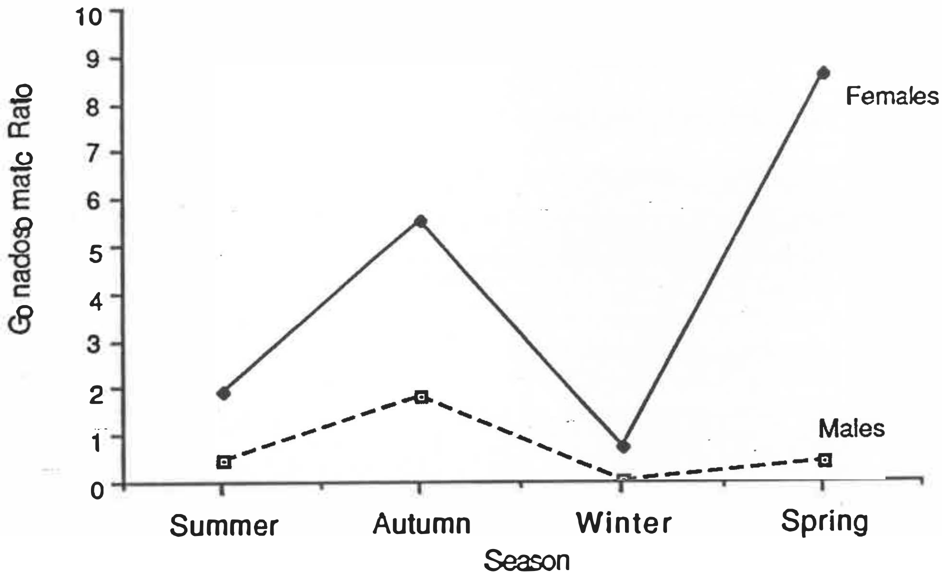


Figure 5.5: Mean gonadosomatic ratios for male and female koaro in the Waipehi, 1988-1989.

5.4 Discussion

Although there is little information on the reproductive biology of diadromous populations of koaro to compare with these results, it appears that lacustrine populations of koaro have retained a similar reproductive cycle. This lifecycle involves the adults spawning in the lake tributaries in Summer and early Autumn, with the larval koaro being washed downstream to the lake where they rear for 6-9 months, before migrating back into tributary streams in Spring to assume stream existence.

The results of this study indicate that the koaro has an extended spawning season, with the greatest spawning activity occurring in late Summer and Autumn. This is consistent with the breeding seasons of most other New Zealand galaxiids. *G.maculatus* may spawn at any time between September and June (McDowall, 1968) while *G.vulgaris* was found to spawn from July to September (Cadwallader, 1976b). However, *G.fasciatus* was found to spawn over a sharply defined spawning period between late April and mid-June (7 to 8 weeks) (Hopkins, 1979a).

It seems that koaro in Lake Taupo tributaries spawn earlier in the year than most other galaxiid species. The spawning of koaro is poorly documented. McDowall (1980) suggested that koaro probably spawned in late Autumn and early Winter. Koaro in other lower Waikato tributary streams streams have been found to spawn in Late Autumn and early Winter (D.West, personal communication 1989). It is interesting to speculate on the apparent difference between landlocked and sea-going populations. The earlier spawning of Taupo koaro could be related to cooler winter water temperatures, (minimum 6°C). In comparison, water temperatures in Pirongia streams seldom fall below 10°C (D.West, personal communication 1989). Another possible reason could be that in the less productive freshwater environment juvenile koaro may need to spend more time rearing in the lake to attain a minimum threshold size before migrating upstream to assume stream residence.

Due to the extended spawning period and the presence of fish at different stages of sexual maturity it was difficult to monitor the development of the gonads in koaro throughout the year. It appears however that the GSR is highest in the Spring just before spawning in the late Summer and lowest in the winter at the cessation of spawning. Females typically had much higher GSR values than males, which is consistent with other galaxiid species such as, *G.vulgaris* (Cadwallader, 1976b) and *G.fasciatus* (Hopkins, 1979a). It also appears that the number and size of eggs increases with increasing fish length although sample sizes were small.

More ripe males were found than females throughout the year, although the sex ratio of non-spawning males and females was approximately equal. This is most probably the result of some males not reaching maturity at peak spawning time, due to the excess of ripe males over ripe females. Cadwallader (1976b) found a similar situation in *G.vulgaris*, while Hopkins (1979a) found that the value of the GSR remained higher in male *G.fasciatus* over a longer period than in females. Cadwallader (1976b) suggested that the the significance of such a mechanism was to ensure that there are always enough ripe males to fertilise the eggs.

Gravid koaro were found in the middle site on the Waipehi stream where there is little or no instream vegetation. It is possible therefore that koaro do not spawn in water-logged debris as in spawning *G. fasciatus* (Hopkins, 1971). Abrasion around the ovipositor of female koaro suggested that spawning occurs in or on, the substrate. Spawning in koaro may be similar to *G. vulgaris* which spawns in the the most turbulent parts of riffles where a small nest is excavated in the stream gravel (Cadwallader, 1976b). The presence of gravid fish at the top site on the Omori stream, and the capture of a larval koaro at this site, implies that spawning occurs in or near normal adult habitat. However, it is unclear whether any spawning migration takes place. Tagging results suggest that koaro in the Waipehi and Omori streams do not undergo any extensive spawning migration, but remain in or close to their normal adult habitat. This conclusion was based on population density estimates and the high number of marked fish that were recovered in the same study site over a 6 month period (Chapter 3). There may however be a movement of spawning adult fish into the lower reaches of the Waipehi stream

(Chapter 3). However, this movement could be complicated by the migration of gravid lake-resident koaro into the lower reaches of tributaries.

A search for eggs within the streams was carried out in January and February 1989 but was unsuccessful. However a larval koaro was found in a benthos sample from the middle site of the Omori stream. The presence of a larval koaro and ripe running adults up to 4-5km from the lake indicates that spawning almost certainly occurs in the lake tributary streams.

Mortality during spawning may be high, with some spent koaro being infected with white-spot in the Waipehi stream in Autumn. Three injured fish were also captured during sampling, one being a 175mm ripe female with 2 bites of approximately 15mm in diameter. This wound was most probably inflicted by a water rat, suggesting that predation during spawning could be a cause of mortality. *Anguillia dieffenbachii* are also known to prey on spawning *G.fasciatus* and this may have some effect on the survival of juveniles (Mitchell and Penlington, 1982).

CHAPTER SIX

THE FOOD OF KOARO AND JUVENILE RAINBOW TROUT

6.1 Introduction

The main purpose of this study was to investigate the diet of the koaro and juvenile rainbow trout present in Lake Taupo tributary streams. The benthic invertebrate populations in the study streams were also investigated to determine the relationship between prey abundance and feeding in koaro.

The possible detrimental effects of trout on the abundance and distribution of galaxiid species in New Zealand is a controversial subject (McDowall, 1987a). It has been suggested (McDowall, 1987a) that trout not only prey on the juvenile stages of koaro but also that young trout compete for both food and space with stream-resident koaro. The secondary purpose of this study was to determine whether the diets of juvenile trout and koaro are similar, and if so to what extent. The high population densities of koaro in some Taupo tributary streams, such as the Waipehi, where rainbow trout and koaro co-exist appears atypical for North Island streams in general (eg. Waikato tributary streams, personal observation 1989).

There is little information available on the diet of koaro in North Island lakes or streams. It is known that the diet of diadromous koaro in the South Island does not contain a high proportion of terrestrial food items compared to other large galaxiids, such as banded kokopu (Main, 1988). As a result, koaro may not have been affected by the clearance of riparian native forest as severely as other galaxiids (McDowall, 1987a). Koaro found in non-forested South Island streams were found to utilise aquatic prey exclusively (Sagar and Eldon, 1983). The minor contribution of terrestrial prey reported in the diet of koaro in South Island streams is similar to that of other New Zealand galaxiids such as the common river galaxias *Galaxias vulgaris* (Cadwallader, 1975b; 1975c; 1975d), inanga *Galaxias maculatus* (Allen, 1951; McDowall, 1968), dwarf galaxias *Galaxias divergens* (Hopkins, 1971), and Canterbury mudfish *Neochanna burrowisus* (Eldon, 1979). The diet of these species consists largely of aquatic invertebrate larvae.

Main (1988) carried out a comprehensive study of the diets of koaro, giant kokopu, short jawed kokopu and banded kokopu in some South Westland streams using gut content and stable isotope analyses. Rounick and Hicks (1985) also used stable isotope analyses to investigate the diets of six koaro from the Waikanae river in the South Island. Naylor (1983) studied the diet of a lacustrine population of koaro in Lake Alexandrina, South Canterbury, and found that koaro in the lentic zone fed primarily on zooplankton. Sagar and Eldon (1983) analysed the stomach contents of seven koaro from the Rakaia river and found that the diets consisted mostly of benthic invertebrates.

Studies on large galaxiids such as the shortjawed kokopu and giant kokopu (Main, 1988; Jellyman, 1979) and the banded kokopu (West personal communication 1989) suggest that terrestrial invertebrates form an important part of their diets.

The aims of this study were to investigate the composition of the diet in koaro and rainbow trout, together with seasonal changes in diet and differences between stream populations.

6.2 Methods

6.2.1 General methods

The Waipehi, Omori and Hinemaiaia stream koaro populations were studied in 1988 and 1989 (Table 6.1). The study is based on a relatively large sample of 331 koaro and 188 juvenile rainbow trout. The majority of koaro were captured from the Waipehi stream and Omori streams in 1988 in conjunction with age, growth and reproduction studies. The diet of koaro in the Omori stream is based on a relatively small sample size, due mainly to difficulties encountered in gaining access to suitable study sites.

Fish were captured by electro-fishing as this method does not lead to excessive digestion of stomach contents (Bowen 1983). After capture, fish were anaesthetised using benzocaine or MS222 and preserved in 10% formalin or 40% isopropanol and returned to the laboratory for analysis. Benthic invertebrate samples were also collected from each study stream to estimate the availability of potential prey items, and thus to determine whether fishes were feeding selectively. Benthic invertebrates were collected in February 1989 from all sites on the Waipehi and Omori streams using a Surber sampler. A total of ten samples were taken at each site from riffle, pool, and run habitats.

Table 6.1: Sample sizes and mean lengths of koaro and rainbow trout used in diet studies.

	Koaro			Rainbow Trout		
Season	Waipehi	Omori top middle	Omori lower	Waipehi	Omori top & middle	Omori lower
Summer D,J,F						
Number of fish Mean length Range	110 65 40-175	No Sample	20 54 39-111	37 73 33-177	No Sample	No Sample
Autumn M,A,M						
Number of fish Mean Length Range	95 83 41-150	16 99 70-134	No Sample	35 83 32-138	16 105 57-152	No Sample
Winter J,J,A						
Number of fish Mean length Range	23 65 41-118	No Sample	No Sample	4 86 73-105	51 49 37-179	18 82 45-120
Spring S,O,N						
Number of fish Mean Length Range	21 78 49-136	4 63 52-88	No Sample	No Sample	5 109 63-161	11 70-105 87

Other Samples Collected

Season	Waipehi waterfall Summer		Hinemaiaia Summer	Omori lower site Summer		
Species	Koaro	R.T	Koaro	Bully	Brown trout	Catfish
Number of fish Mean Length Range	27 80 51-128	11 78 48-120	15 50 41-89	26 66 36-102	5 115 80-202	 98 85-110

6.2.2 Stomach contents

Stomach contents were examined in water in a petri dish under a low power (6-40X) binocular microscope. Prey were identified to species level whenever possible using identification keys (Winterbourne and Gregson 1981) and most incomplete prey were identified from readily distinguishable parts, such as head capsules.

Numerical and gravimetric methods were used to enumerate stomach contents. Percentage composition was used to provide an indication of the proportion (%) of each food type in the diet. The gravimetric method was based on the wet weight of individual food items present in the stomach and was expressed as a percentage of the total wet weight of all food items present. Wet weights of prey items were determined from invertebrate samples. In the case of relatively rare items which were not present in benthic samples, wet weights were determined using undigested prey found in the stomachs. The mean wet weight of each prey item was estimated by using a Mettler AC100 balance accurate to the nearest 0.001 g. Weights obtained using this method are liable to error if the size of prey items shows large variation, but this procedure does overcome the error associated with digested prey. Glenn & Ward (1968) found that wet weight correlated highly significantly with dry weight for 5 different prey species. The weights of cased trichopteran and molluscs were estimated excluding the shell.

Problems are associated with both methods, with the numerical method tending to over-emphasise the importance of small prey items whereas the gravimetric methods tends to over-emphasise the importance of single heavy items in the diet (Hyslop 1980). To obtain maximum information from the available food material, Hyslop (1980) recommended that measures of both amount (number) and bulk (weight or volume) of food should be used to overcome the bias of both the numerical and gravimetric methods.

Ivlev's (1961) index of electivity is a simple measure of the selectivity of fish for a particular prey item;

$$E = \frac{r - p}{r + p}$$

Where:

E = electivity index

r = percentage abundance in the diet

p = percentage abundance in benthos samples

6.3 Results

6.3.1 Waipehi Stream

Koaro

Approximately 276 koaro were captured from April 1988 to May 1989 and their stomach contents examined. Over the entire sampling period, Diptera and Ephemeroptera larvae were the most abundant prey items in the diet of koaro, but juvenile koaro (whitebait) comprised most of the total biomass consumed (64%) (Table 6.2, Fig. 6.1). The stomach contents of koaro were dominated by aquatic prey, measured both numerically and gravimetrically (Fig. 6.1). Of the total prey, terrestrial prey comprised only 4% by abundance and 7% by biomass of the total prey consumed by koaro (Table 6.2). The diet of koaro was examined seasonally to investigate if there were any changes or trends in the diet with time (Fig. 6.2).

Table 6.2: Relative abundance and biomass of prey items present in koaro and rainbow trout stomachs in the Waipehi stream.

	Koaro		Rainbow Trout	
	Abundance %	Weight %	Abundance %	Weight %
Aquatic Prey				
Tipulidae	0.00	0.00	0.00	0.00
Ephemeroptera	39.30	8.35	59.86	8.06
Trichoptera	13.30	3.54	6.49	0.87
Diptera	27.30	0.49	1.92	0.01
Hemiptera	0.60	0.05	0.24	0.02
Plecoptera	2.21	5.17	1.20	1.25
Fish	6.12	64.03	15.63	87.70
Fish ova	6.11	9.95	0.24	0.21
Mollusca	0.00	0.00	0.00	0.00
Neuroptera	0.17	0.62	0.00	0.00
Coleoptera	0.66	1.11	0.00	0.00
Percentage	95.77	93.31	85.58	98.12
Terrestrial Prey				
Annelida	0.43	4.46	0.24	0.54
Arachnida	0.12	0.04	0.00	0.00
Collembola	0.36	0.01	0.00	0.00
Myriapoda	0.78	0.06	0.24	0.01
Diptera	0.60	0.04	0.48	0.31
Hymenoptera	0.00	0.00	0.72	0.01
Lepidoptera	0.44	0.62	0.48	0.30
Coleoptera	0.63	0.84	0.72	0.40
Orthoptera	0.10	0.62	0.96	0.30
Percentage	3.46	6.70	3.84	1.87

Table 6.3: Ivlev's (1961) Electivity indices for koaro and rainbow trout in the Waipehi stream, February 1989.

Order	Koaro	Rainbow Trout
Tipulidae	+1.000	+1.000
Ephemeroptera	-0.625	-0.390
Trichoptera	+0.096	-0.088
Diptera	+0.064	-0.693
Hemiptera	–	-0.924
Plecoptera	–	-0.035

Table 6.4: Relative abundance (%) of invertebrate groups in benthos samples, February 1989.

	Relative Abundance %		
	Waipehi Stream (n=20)	Omori top & middle (n=20)	Omori Bottom (n=10)
Order			
Ephemeroptera	93.26	35.24	0.00
Trichoptera	2.84	18.10	29.41
Diptera	0.71	36.19	64.71
Hemiptera	0.35	3.81	5.88
Plecoptera	0.00	1.91	0.00
Neuroptera	1.77	0.95	0.00
Mollusca	0.00	2.86	0.00
Fish	0.00	0.95	0.00

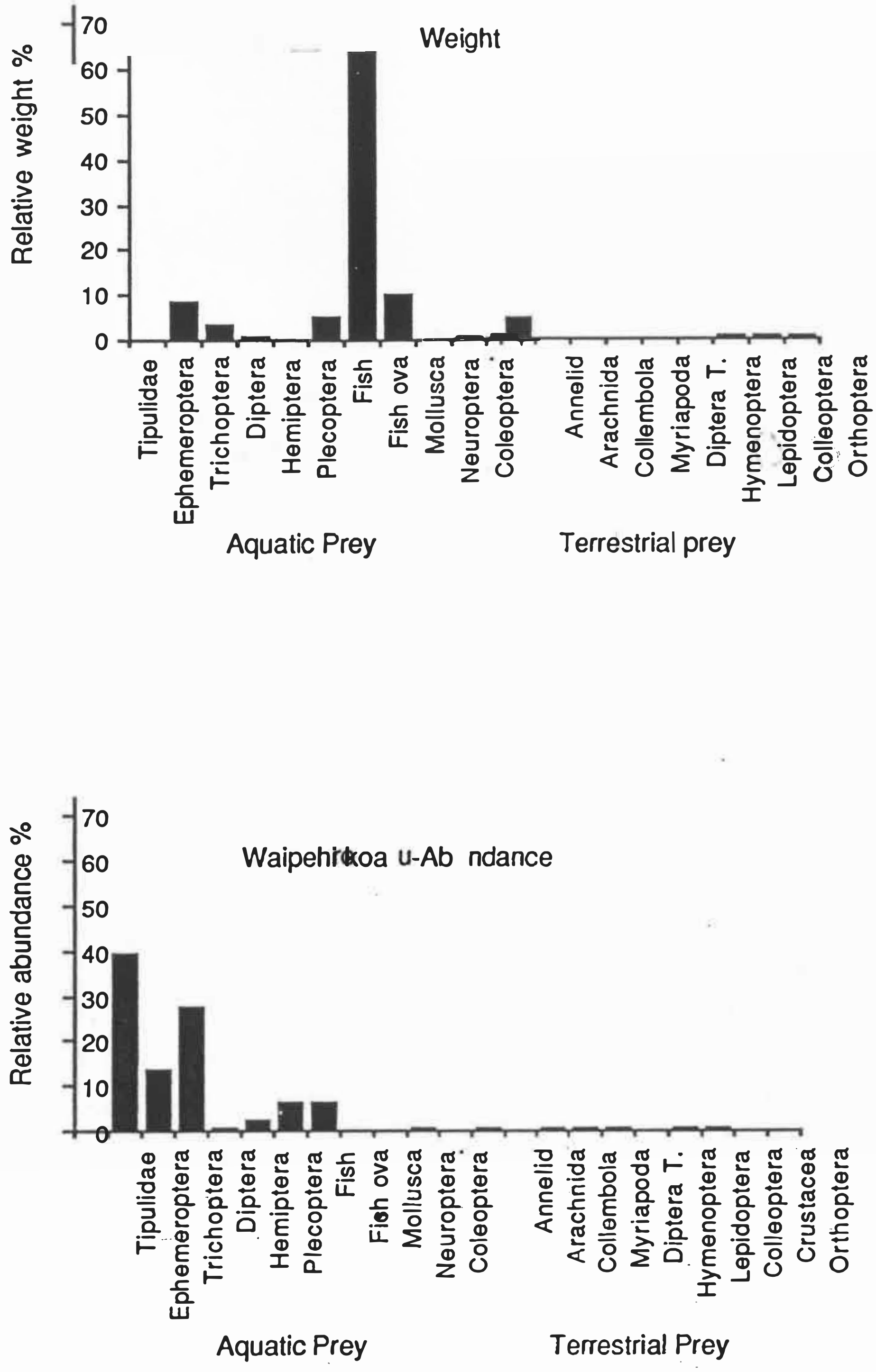


Figure 6.1 Composition of the diet of koaro in the Waipehi stream assessed by number and weight

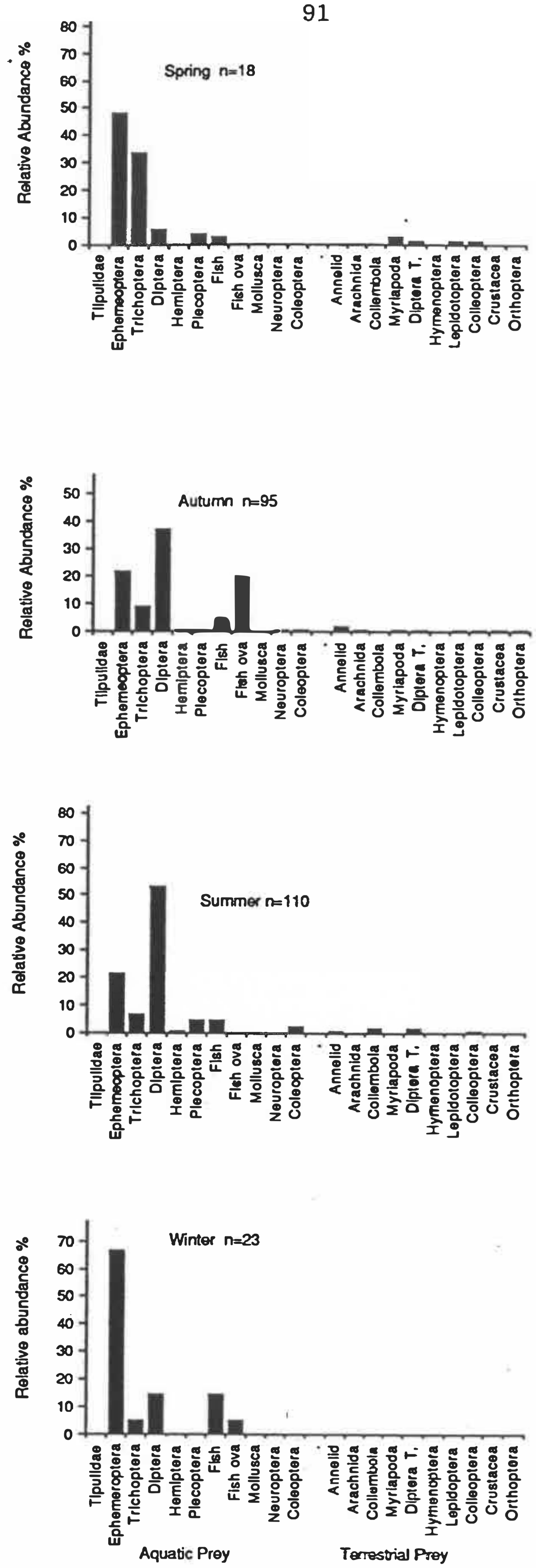
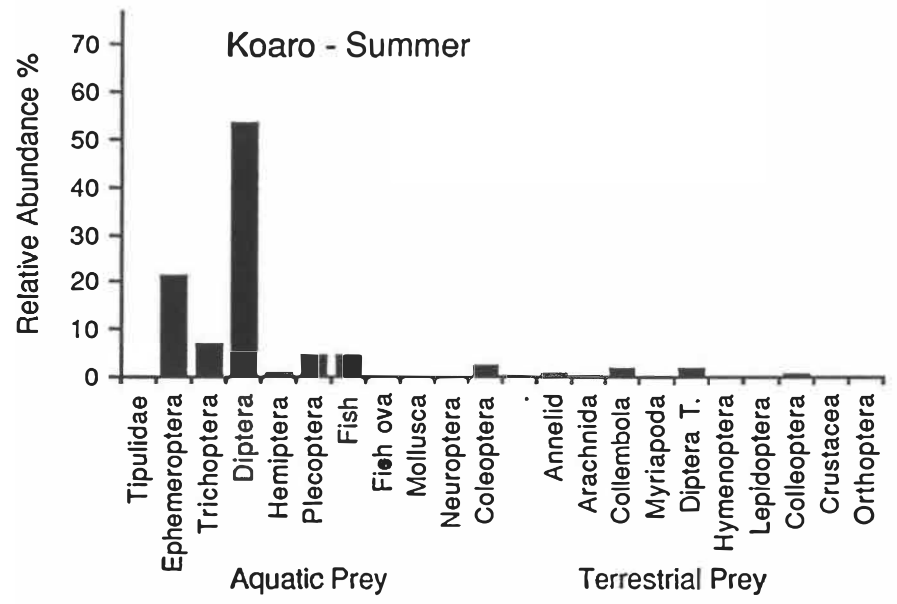


Figure 6.2: Seasonal changes in the composition of koaro diets in the Waipehi stream.



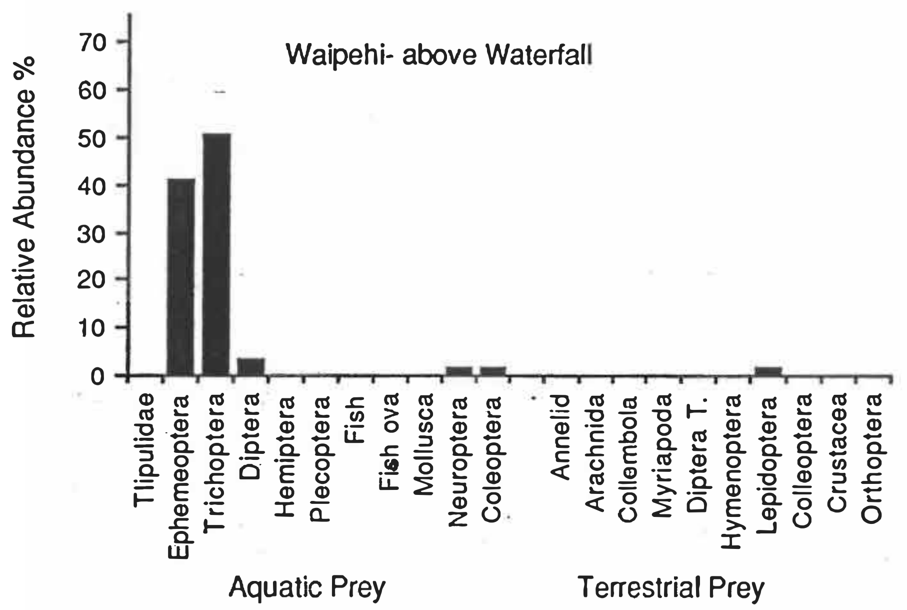


Figure 6 3: Comparison of the diets of koaro in the Waipehi stream cap ured from above and below the waterfalls

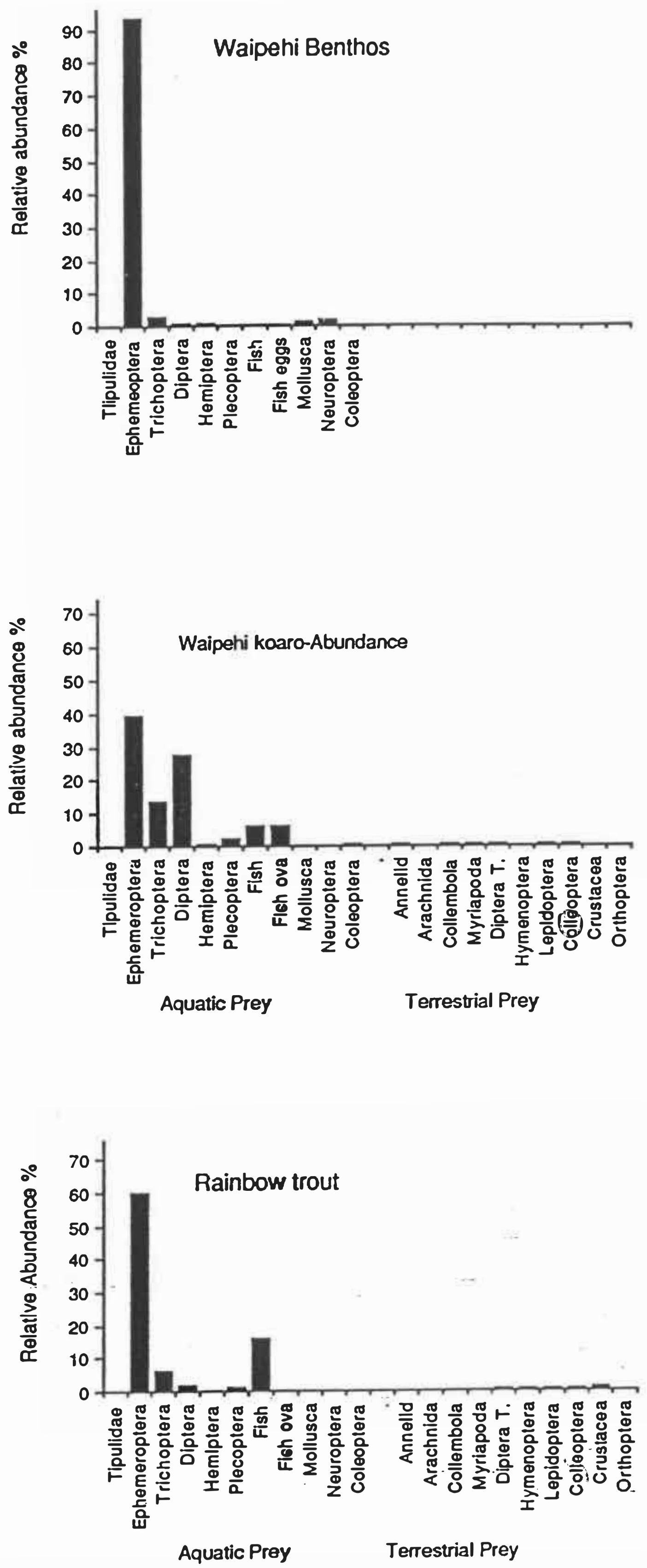


Figure 6.4: Comparison of koaro and juvenile rainbow trout in the Waipehi stream with the benthos.

Ephemeroptera larvae were numerically the most important prey item in the diet of koaro in Winter and Spring (Fig. 6.2), while in Summer and Autumn Diptera larvae were the most important (Fig. 6.2). Fish (koaro juveniles and rainbow trout fry) were the most important food items by weight throughout the year, particularly in Winter (Fig 6.2). In Autumn, rainbow trout and koaro eggs were also an important dietary component (by weight).

The diets of koaro taken from above a series of waterfalls on the Waipehi stream (approximately 5 kilometres from the lake) were dominated numerically and gravimetrically by larval Trichopteran (52%) and Ephemeropteran (41%) species (Fig. 6.3). No fish remains or fish eggs were found in the stomach contents of 27 koaro taken from above the waterfall.

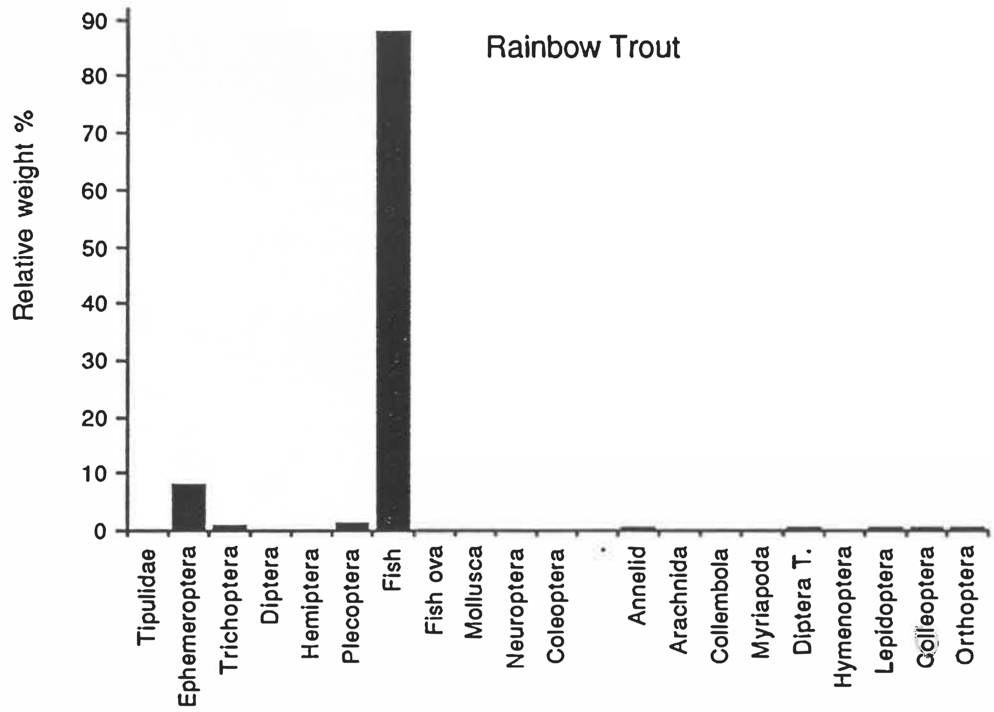
In the Summer of 1989, Ephemeroptera larvae (mainly Deleatidium species and *Coloburiscus humeralis*) comprised over 90% of the invertebrate species present in substrate samples taken from the Waipehi (Table 6.4). However, this is not reflected in the stomach contents of koaro captured over the Summer period, when Diptera larvae were the dominant prey consumed (Fig. 6.4). This indicates that selectivity is occurring, with koaro selecting large prey items such as koaro juveniles. Ivlev indices calculated for koaro and rainbow trout in the Waipehi stream showed that although Ephemeroptera were the most abundant invertebrates in the benthos they were not selected for strongly (Table 6.3).

Rainbow Trout

A total of 87 juvenile rainbow trout stomachs were examined from the Waipehi stream (Table 6.1). As with koaro, the diet consisted principally of aquatic prey (86% by number and 98% by weight) (Table 6.2). Ephemeroptera larvae (59.8%), fish (15.6%) and Trichoptera larvae (6.5%) were the most important food items numerically. However, juvenile koaro in the whitebait stage of development constituted the largest part of the diet (87.7%) (Table 6.2, Fig. 6.5).

The diet of juvenile rainbow trout was investigated in three seasons- Summer, Autumn and Winter. However, samples could not be obtained in Spring due to low trout population densities. Ephemeroptera larvae were most numerous in all seasons, and by weight in Winter (Fig. 6.6). Koaro juveniles dominated the diets of rainbow trout in Autumn and by weight in Summer (Fig. 6.6).

The diet of rainbow trout generally reflected the composition and relative abundance of the invertebrate species in the benthos. However, Ivlev indices suggest that there was a tendency for the selection of large food items, such as whitebait and Plecopteran species (Table 6.3, Fig. 6.4).



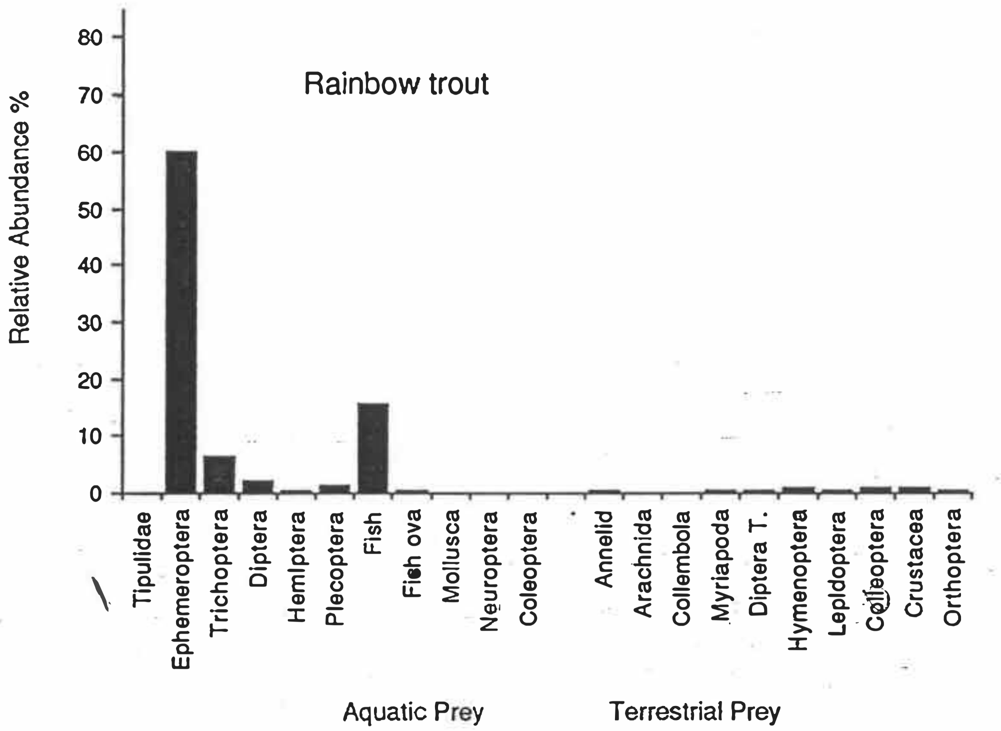


Figure 6.5: Composition of the diet of juvenile rainbow trout in the Waipehi stream assessed by number and weight.

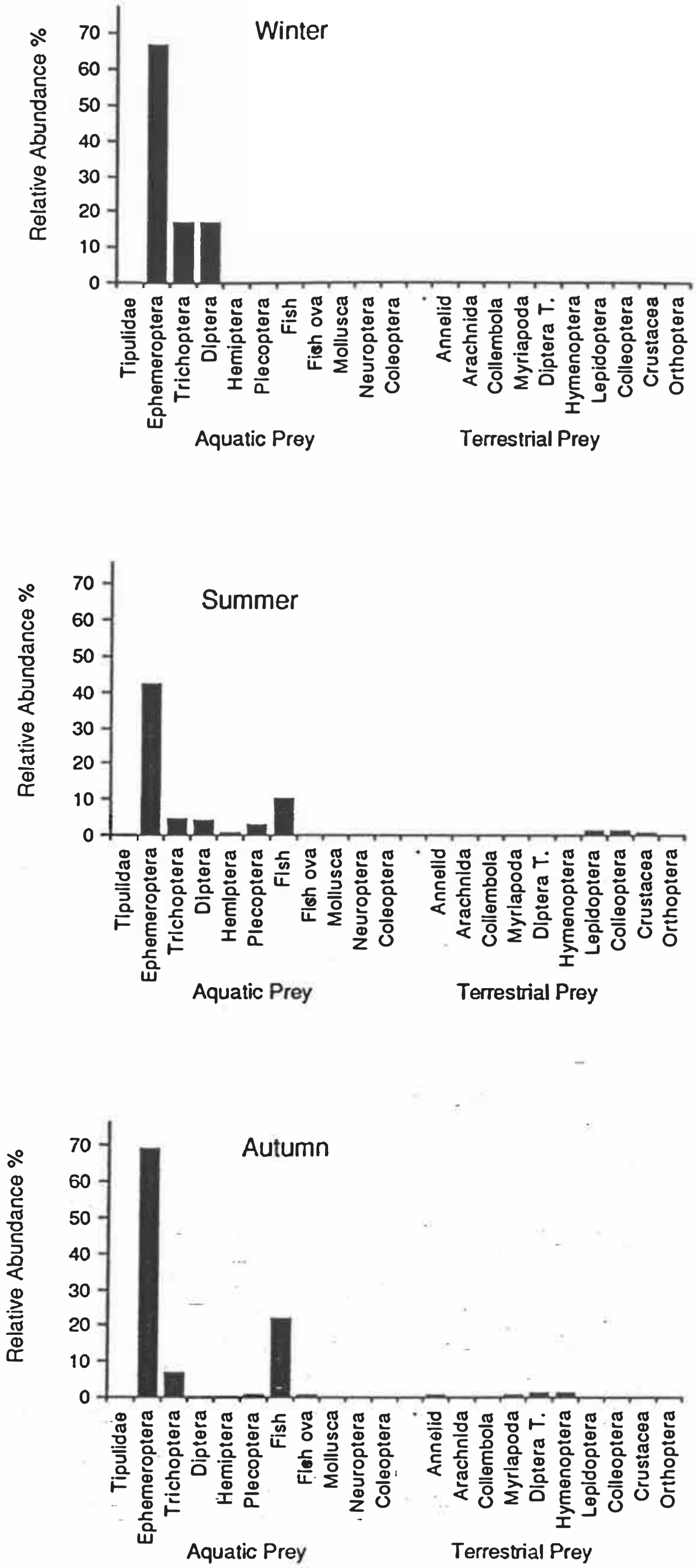


Figure 6.6: Seasonal changes in composition of the diet of juvenile rainbow trout in the Waipehi stream

6.3.2 Omori stream (top and middle sites)

No seasonal data on the diet of koaro was obtained from the Omori stream since the low numbers of koaro present meant that the study populations would have been seriously depleted through the removal of fish for diet studies (Table 6.1). Therefore, the diets of both koaro and rainbow trout have been compared during only one season, Autumn 1989, at the completion of the population density study (Fig. 6.7, Table 6.5).

As few koaro stomachs were examined and there was little variation between the diets of koaro from the two sites, results from the two sites were combined. The benthic invertebrate populations in the top sites on the Omori stream consists principally of Diptera, Ephemeroptera and Trichoptera larvae (Table 6.4).

Koaro

20 koaro stomachs were examined from the top and middle sites of the Omori stream. The majority of these fish were captured in Autumn after the conclusion of the routine sampling program.

As with the Waipehi stream koaro, the diet was dominated both numerically and gravimetrically by aquatic prey (Table 6.5). Diptera larvae were the most important prey item in numerical terms (63%), followed by Trichoptera (22%) and Ephemeroptera (8%) larvae. However. measured gravimetrically, Trichoptera larvae (47%), trout ova (22%) and Ephemeroptera larvae (17%), comprised the bulk of the food consumed (Fig. 6.7, Table 6.5).

Ivlev indices suggest that there was a tendency for koaro to select Diptera larvae and large food items, such as Plecoptera and trout ova (Table 6.6).

Table 6.5: Relative abundance and biomass of prey items in koaro and juvenile rainbow trout stomachs in the Omori stream. trout in the Omori stream.

	Koaro		Rainbow trout	
	Abundance %	Weight %	Abundance%	Weight %
Aquatic prey				
Tipulidae	0.83	5.15	0.15	0.10
Ephemeroptera	8.13	17.34	15.45	3.60
Trichoptera	21.95	46.83	15.16	3.53
Diptera	63.41	6.26	6.54	0.07
Hemiptera	0.00	0.00	0.15	0.02
Plecoptera	0.00	0.00	1.78	3.21
Fish	0.00	0.00	0.00	0.00
Fish ova	1.63	22.16	56.91	85.54
Mollusca	0.00	0.00	0.00	0.00
Neuroptera	0.00	0.00	0.00	0.00
Coleoptera	0.00	0.00	0.00	0.00
	95.95	97.74	96.14	96.07
Terrestrial Prey				
Annelida	0.00	0.00	0.89	3.46
Arachnida	0.00	0.00	0.15	0.02
Collembola	0.00	0.00	0.00	0.00
Myriapoda	3.25	2.25	1.34	0.10
Diptera	0.00	0.00	1.20	0.05
Hymenoptera	0.00	0.00	0.00	0.00
Lepidoptera	0.00	0.00	0.15	0.16
Coleoptera	0.00	0.00	0.00	0.00
Orthoptera	0.00	0.00	0.00	0.00
	3.25	2.25	2.54	3.79

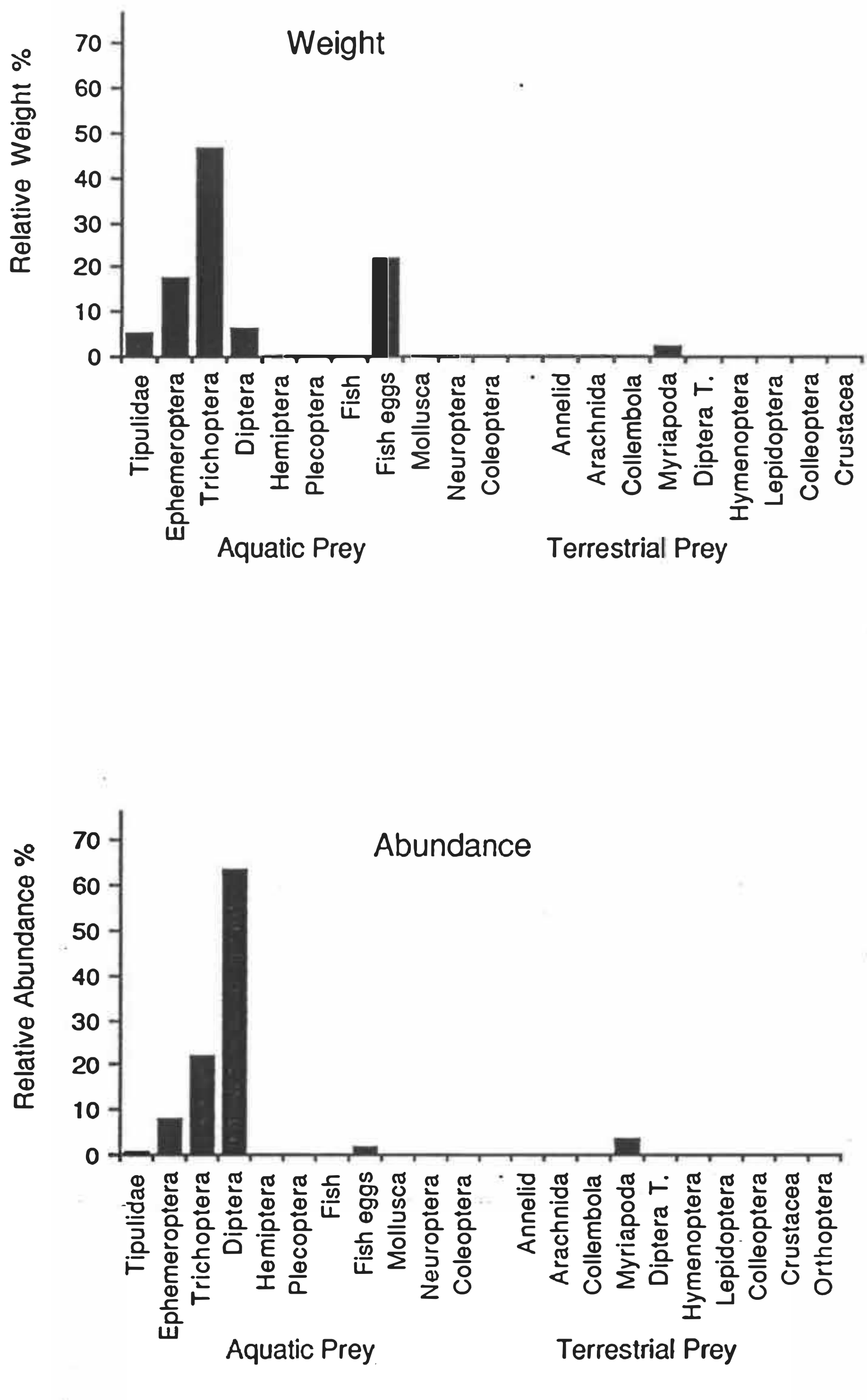


Figure 6.7: Composition of the diet of koaro in the Omori stream assessed by number and weight.

Table 6.6: Ivlev's (1961) Electivity indices for koaro and rainbow trout in the Omori stream, February 1989.

Order	Koaro	Rainbow Trout
Ephemeroptera	-0.518	-0.218
Trichoptera	+0.707	+0.391
Diptera	+0.956	+0.460
Hemiptera	+0.054	-0.186
Plecoptera	+1.000	+1.000
Neuroptera	-0.638	–
Coleoptera	+1.000	–

Rainbow Trout

A total of 72 juvenile rainbow trout were examined, with 51 of these fish being captured in the Winter months of 1988. The diet again consisted principally of aquatic prey (Table 6.5).

In comparison, trout stomachs examined from the Winter months were dominated by trout ova, both in terms of abundance (57%) and by weight (86%) (Fig. 6.8, Table 6.5).

In the Winter and Autumn, juvenile rainbow trout fed mostly on trout ova (56.91%), Ephemeroptera (15.45) and Trichoptera (15.16%) larvae (Table 6.5). By weight, trout ova dominated the diet contents of juvenile trout (85.4%). Ivlev indices suggest that large food items, such as Plecoptera larvae and trout ova were strongly selected (Table 6.6).

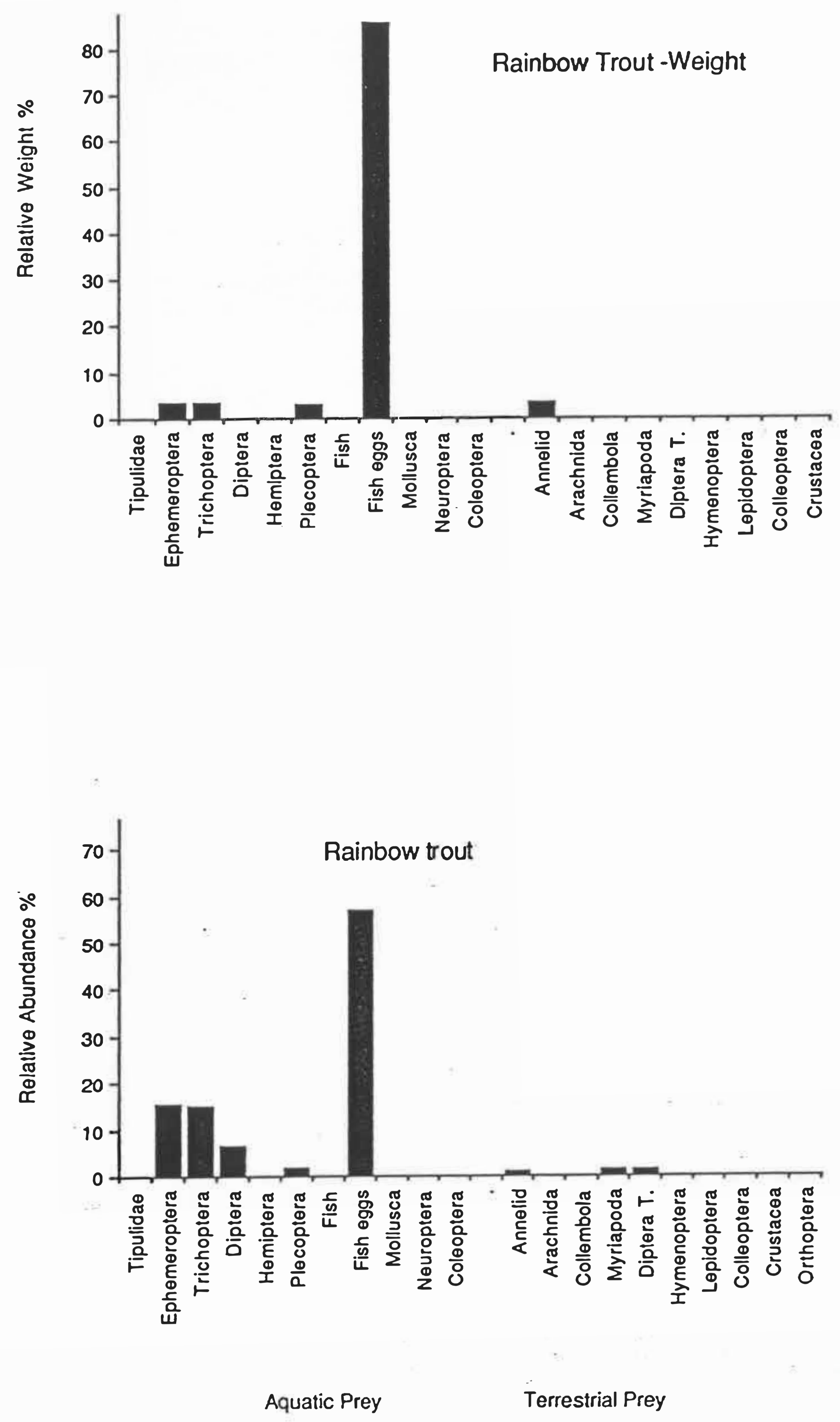


Figure 6.8: Composition of the diet of juvenile rainbow trout in the Omori stream assessed by number and weight.

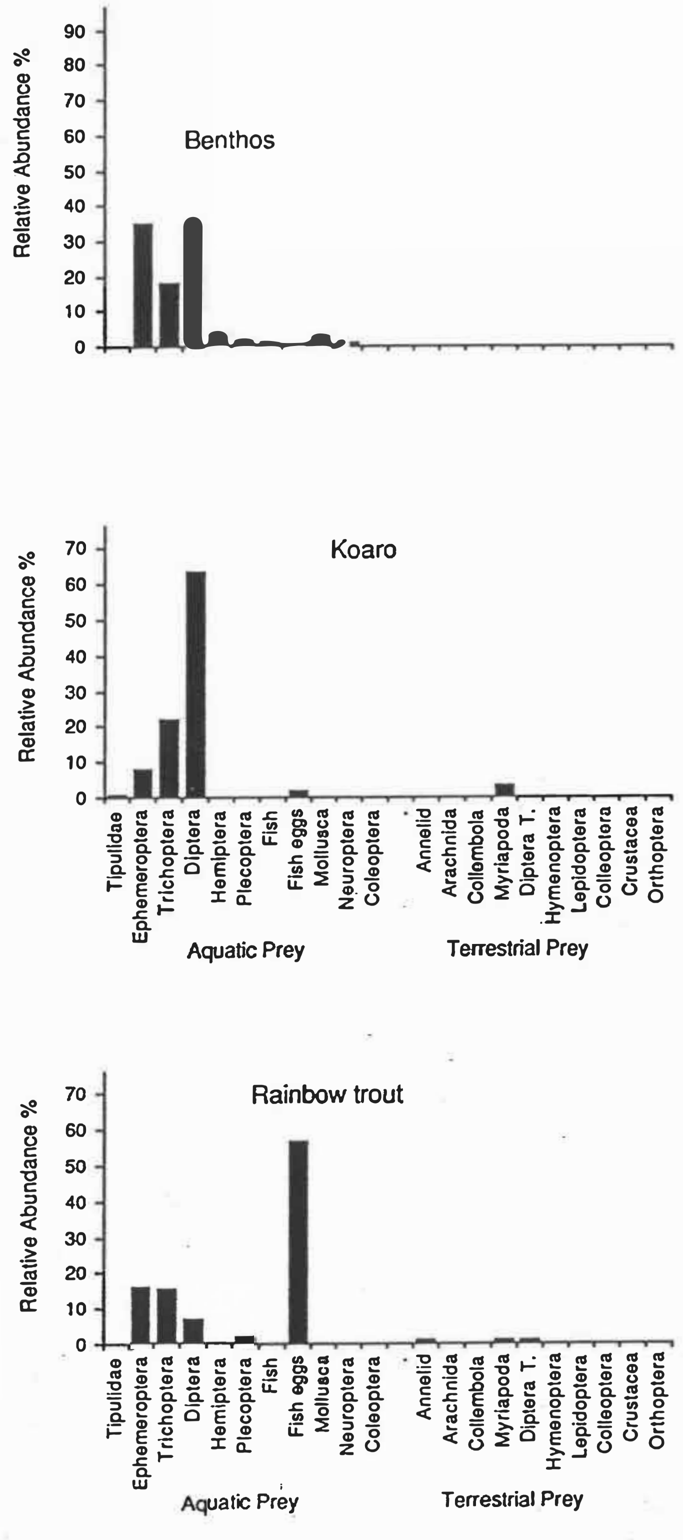


Figure 6.9: Comparison of composition of koaro and juvenile rainbow trout diets with the Omori benthos.

6.3.3 Omori stream (lower site)

Out of all the sites sampled, the lower site on the Omori stream had the most diverse range of fish species (5), including koaro, rainbow trout, brown trout, common bullies and occasional catfish (n=4 October 1988). The stomach contents of both rainbow and brown trout and koaro were dominated numerically by Diptera larvae and gravimetrically by koaro juveniles (Figure 6.10). However, The mean length of koaro sampled was relatively small (54mm) and there was also a high proportion of empty stomachs.

6.3.4 Other fish species

Koaro and rainbow trout are the dominant fish species present in the Waipehi stream, although there are also low numbers of common bullies.

The diet of brown trout (*Salmo trutta)*, and catfish (*Ictalurus nebulosus*) captured during the study could not be studied in detail due to low population densities. Four ripe female catfish were captured in October 1988, of which two had empty stomachs. Similarly, only five brown trout were retained from the Omori lower site for diet analysis. These fish were found to feed mostly on koaro juveniles and Ephemeroptera larvae. Bullies were only present in high numbers in the Omori bottom site, most of which were found to be in spawning condition. This would explain the high occurrence of empty stomachs (in a sample of 26 bullies examined, there were ten empty stomachs).

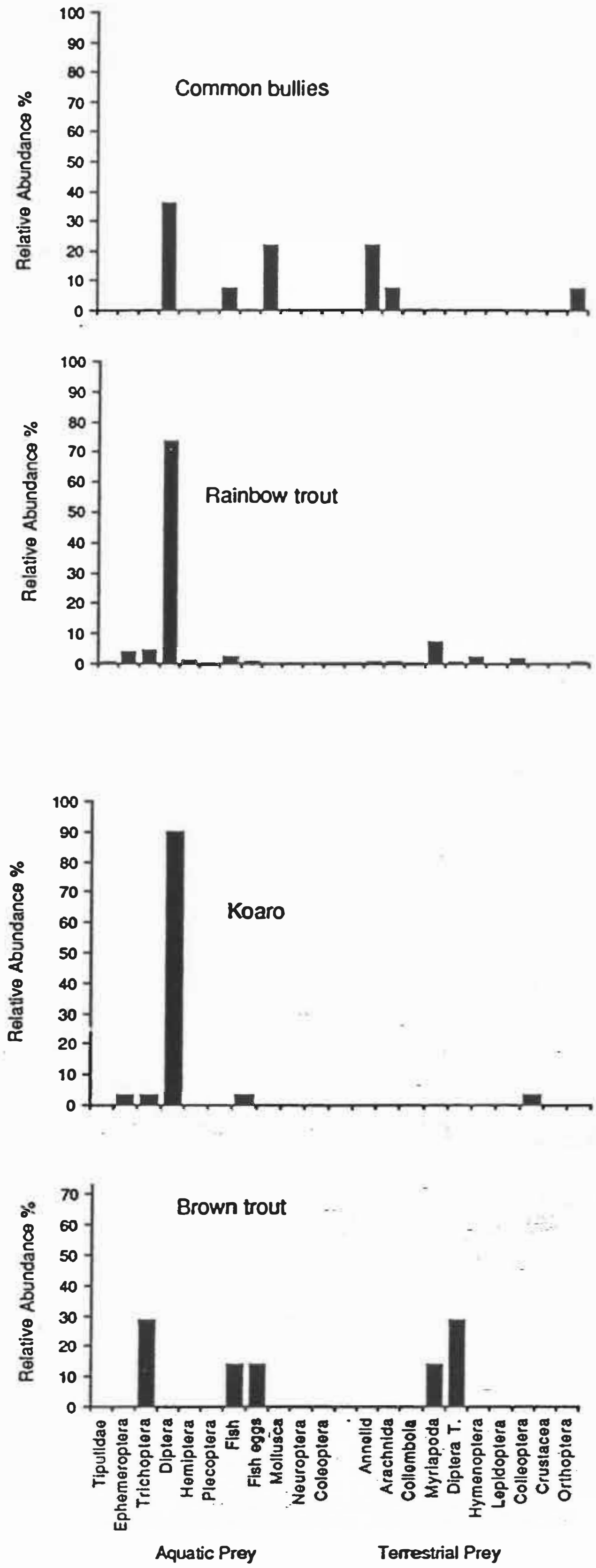


Figure 6.10: Comparison of the diet of common bullies, koaro and juvenile rainbow and brown trout in the lower Omori stream.

The diet of bullies was comprised mainly of Diptera larvae with high numbers of terrestrial prey (Fig. 6.10). As only ten adult koaro were caught in the lower site on the Omori stream, the amount of overlap between the diets of both species could not be accurately assessed.

6.4 Discussion

Koaro

The diet of koaro in the Waipehi and Omori streams was dominated numerically and gravimetrically by aquatic prey. Terrestrial prey comprised less than 5% of the total number and biomass of all the food items consumed. Numerically, benthic invertebrate larvae belonging to the orders Diptera, Ephemeroptera and Trichoptera were the most important food items. However, fish (koaro juveniles) formed a greater proportion of the dietary biomass in the lower sites of both streams. It is not clear however whether adult koaro are feeding selectively on koaro juveniles or whether, juvenile koaro are present in high densities and are therefore easily captured.

Comparison of benthos samples with the composition of the diet of koaro suggests that both large prey items and Dipteran larvae are actively selected compared to their representation in the benthos. This may reflect the high densities of large prey items in the streams or be a true indication of dietary selectivity.

Studies on the diet of koaro by Main (1988), Sagar and Eldon (1983) and Rounick & Hicks (1985) all support the conclusion that koaro feed primarily on aquatic prey. However, no previous studies have found fish and fish eggs to form such an important proportion of the diet of koaro. Main (1988) found fish to be of minor significance

in the diet of Koaro and giant and banded kokopu in South Westland streams. Sagar and Eldon (1983), found only Ephemeroptera and Trichoptera larvae in a sample of seven koaro stomachs from the Rakaia river, and considered that koaro were not selective feeders. These findings are contradictory to the results of this study.
Main (1988), using stable carbon isotope techniques, found that although koaro fed extensively on benthic invertebrates in South Westland streams a high proportion of food converted into fish biomass could be traced back to terrestrial prey.

The diet of stream-resident koaro in both Lake Taupo tributaries and in Waikato tributary streams differs greatly from that of koaro in South Westland streams (Main 1988), where terrestrial prey are more important. Also, Naylor (1983), in a study of a lentic population of koaro in Lake Alexandrina, found the diet of these fish to consist mainly of lentic invertebrates, primarily cladocera.

It is not clear whether the koaro is a benthos or drift feeder. Sagar and Eldon (1983) suggested that koaro may feed primarily on drift when occupying riffles in the Rakaia river and that most of the drifting organisms taken by the koaro came from the benthos. Main (1988) also confirmed that koaro feed extensively on benthic invertebrates and most probably on drift from the benthos. The results of my study suggest that koaro in Taupo tributaries are most probably benthic feeders. Koaro in Lake Alexandrina are primarily benthic feeders but when in competition with bullies, koaro utilised food from the water column and the lake bottom (Naylor, 1983). Therefore, the possibility that koaro do feed on food in the drift cannot be discounted. In prey selection experiments conducted in still water enclosures, Main (1988) concluded that koaro fed primarily on the benthos. Further research, is required to investigate the possibility that koaro are drift feeders in North Island streams.

Rainbow Trout

The stomach contents of juvenile rainbow trout in both streams was also found to be dominated numerically and gravimetrically by aquatic prey, with terrestrial prey being of minor importance. Juvenile rainbow trout in the Waipehi stream consumed mainly Ephemeroptera larvae but koaro whitebait comprised the greatest biomass. Juvenile rainbow trout in the Omori stream however consumed mainly rainbow trout ova. This suggests that rainbow trout juveniles, like adult koaro, may feed selectively on larger, substantial prey items. Although the Omori is a relatively small stream it holds an abundant population of juvenile rainbow trout, and adult rainbow and brown trout were often seen spawning in the study sites in Winter and Autumn. Eggs drifting downstream during spawning activities might therefore be expected to be found in the diets of juvenile trout and koaro.

It has been suggested that both predation and competition for food and habitat resources between juvenile trout and other galaxiid species is an important factor in the decline of galaxiid populations in both New Zealand and Australia. Trout are carnivores and will select the largest and most accessible prey (Tilzey, 1976). In Australia, Tilzey (1976) recorded common river galaxiids in the diet of brown trout in tributaries of the Shoalhaven River, New South Wales. However, most diet studies on adult trout in New Zealand and Australia have suggested that galaxiids are not an important source of food in trout diets (Tilzey, 1976).

However, the low incidence of galaxiids in most trout diet maybe a result of the comparative scarcity of galaxiids in the habitats where the studies were conducted. In Lake Taupo, koaro are virtually absent from the diets of adult rainbow trout (M. Cryer, personal communication 1989) where smelt are the main food source. However, in the lower reaches of tributary streams such as the Waipehi stream, juvenile koaro are an important component of the diet of rainbow trout.

Although the diets of adult rainbow and brown trout are well documented in New Zealand (Phillips, 1940; Rowe, 1984), little information exists on the feeding of juvenile trout, particularly in rainbow trout in North Island streams. Diet studies on juvenile brown trout in New Zealand suggest that they are primarily drift feeders, feeding on benthic invertebrates in relative proportion to their abundance in the benthos.

The summer diet of brown and brook trout (*Salvelinius fontinalis*) was studied in the the Dalgety stream, South Canterbury, and no partitioning of food resources was evident where these two species occurred sympatrically (Fechney, 1988). The diet of both species was found to consist almost entirely of aquatic prey, reflecting the composition and abundance in the benthos. Naylor (1986) found the diet of brown trout fry in Lake Alexandrina was also governed by the availability of food in the environment, with the diet of the young fry being dominated by aquatic invertebrates, especially cladocerans. Hopkins (1970) considered brown trout to feed to a great extent on drifting invertebrates originating from the benthos.

Species Comparison

The stomach contents of both rainbow trout and koaro in each study stream were dominated numerically by the most abundant invertebrate species present in the benthos. Fish and fish eggs were the most important prey item in the diets by weight of both rainbow trout juveniles and koaro. This is not surprising as prey size has been identified as an important factor in the selection of prey by trout (Ringler, 1979), and many fish species will select the largest prey that they can handle (Ivlev, 1961). 'Whitebait' koaro juveniles were found in high densities in the Waipehi stream lower site (Chapter 3) and would be easy prey for trout. It is somewhat surprising that koaro, a species apparently adapted to benthic feeding, would feed extensively on fish. The large number of spawning trout in the Omori stream provides an easily obtainable supply of eggs to both benthic and drift feeding fish, and explains the high proportion of trout ova found in the diet of trout and koaro.

Fish species with similar diets have been shown to co-exist in New Zealand streams (Scrimgeour and Winterbourn, 1987), and it is often assumed that inter-specific competition for food is occurring between species. However, when detailed studies of the diets and feeding habits have been conducted it has often been shown that competition is not as extreme as predicted. Direct competition is reduced by species having different feeding habits, consuming different sized prey items or feeding in different areas.

Hopkins (1970) found that in a small, nursery stream territoriality in brown trout fry reduced inter-specific competition for food. Koaro and juvenile trout were found to occupy different micro-habitats in the Ryton river so that the food resource was partitioned spatially (Moffat, 1984). In the Ashley river, torrent fish and blue gilled bullies partition their food resource weakly by consuming prey items in different proportions and sizes and more strongly by utilising the food resource at different times (Scrimgeour and Winterbourn , 1987).

Sagar and Eldon (1983) considered that due to the extensive overlap in the food niches of koaro, brown trout, bluegilled bully, upland bully and longfinned eels that there may be competition between these species. However, it was concluded that differences in preferred habitat and feeding habits would most probably reduce the possibility of interspecific competition.

It appears that resource partitioning through time and different feeding modes may also be occurring between rainbow trout and koaro in the Taupo streams, so reducing the amount of direct competition for food. Juvenile rainbow trout are mainly diurnal drift feeders occupying the middle zone of the water column (Glova, 1989), while koaro are mainly benthos feeders (Main 1988), active mainly at night (Glova, 1989), feeding primarily on the stream bottom on benthic invertebrates (Main 1988, Sagar and Eldon 1983, Rounick and Hicks 1985).

CHAPTER SEVEN

MAORI PERSPECTIVE

7.1 Introduction

Prior to the introduction of salmonids, koaro were very abundant in Lake Taupo and both adults and juveniles were an important source of food for the Tuwharetoa people. The high abundance of koaro in Lake Taupo was most probably due to very low predation pressure, lack of competition with other fish species and good habitat quality (Burstall, 1983). The absence of eels in the Taupo catchment also increased the importance of the koaro as one of the few readily available and abundant food sources in the region. Today, relatively few people fish for koaro due to their low population density in the lake.

One of the earliest documentations of koaro in Lake Taupo was written by the Reverend H.J Fletcher in 1919. There is some confusion over the naming of the fish species present in Lake Taupo at the time and this requires further clarification. Reverend Fletcher in his paper 'The Edible Fish of Lake Taupo', states that three major fish species were present in the lake at the time; the kokopu (*Galaxias fasciatus*), the inanga (*Galaxias attenuatus*) and koaro. In fact, the kokopu (*Galaxias fasciatus*) has never existed in Lake Taupo and it appears that in this case the kokopu was either confused with the koaro or the common bully.

The juvenile stage in the life-cycle has also been mis-identified as belonging to the species *Galaxias attenuatus* (which is now known as *Galaxias maculatus* or the inanga (McDowall, 1984), which has also never existed in Lake Taupo. This species of fish is most probably the whitebait stage of what is now known as the koaro (*Galaxias brevipinnis*). However, these mistakes are quite understandable considering the lack of scientific knowledge and confusion over the classification of New Zealand's freshwater fish fauna at that time (McDowall, 1978).

It must also be mentioned that the Maori often applied different names to a species of fish at different stages of its development. In addition, considerable local variation in the naming of fish occurred. For example, the koaro was also known as the kowaro, kokopu, hawai (black kokopu), kakawai (black kokopu), rawai (a large kokopu) and the inanga (Best, 1929).

7.2 Adult koaro

It is not clear whether the Kokopu mentioned by early writers was the adult form of the koaro (*Galaxias brevipinnis*) or the toitoi (common bully, *Gobiomorphus cotidianus*). However it seems likely that the 'kokopu' mentioned in many early publications is more commonly known today as the koaro. A number of statements made in the early publications have lead me to this conclusion ;

1) Only 2 species of native fish were present in the lake- the koaro and the common bully, together with a few widely dispersed eels.
2) The populations of koaro were much larger historically than the remnant populations found today. This is indicated by the nets used to catch koaro, which had a mesh size of up to 400mm (Burstall, 1983).
3) Koaro up to 200mm in length have been captured from the depths of Lake Taupo (Stephens, 1983).

4) These fish were caught in streams (few bullies are found in streams in the Taupo area).
5) They were eaten fresh without any preparation (bullies would certainly require de-scaling before being eaten).
6) Hiroa (1921), referring to the Rotorua lakes, stated that inanga, kokopu, and toitoi (common bullies) were all caught during netting operations in the lakes.
7) Best (1929) described kokopu as a widespread scaleless fish.

7.2.1 The Capture of adult koaro

Adult koaro were caught in a number of ways, the most important of which was by the use of a pouraka (Fig. 7.1), or small basket net (approximately 1 foot in diameter and 18 inches in depth) (Fletcher 1919). The net was made from flax (*Phormium tenax*). The entrance of the pouraka was at the top and the bottom portion was made so that it could be gathered in and tied fast, so that it could then be untied to empty fish captured in the trap. The trap was attached to a poito (float) and a long 30 fathom rope. The trap was then set in deep-water using small stone sinkers, with koura being used as bait. The fishing season was from November to March with the koaro captured being 'about the length of a man's hand and very fat' (Fletcher, 1919). The period of fishing is similar to the spawning period of koaro in the lake tributaries today.

Another method used for catching koaro in Lake Taupo and Rotorua was by the use of a tau, or large, dry bundles of the fully grown fern *(*Pteris esculenta*) which were anchored in the lake (Fig. 7.2). A number of these bundles were attached to a main rope which was secured

* Pteridium aquilinum

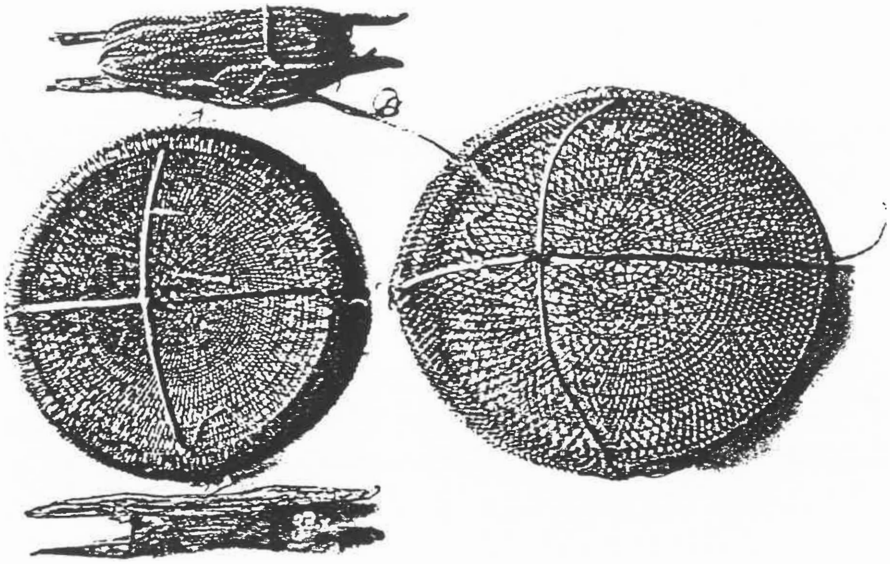


Figure 7.1: The pouraka trap - used to catch adult koaro in Lake Taupo, (From Best, 1929).

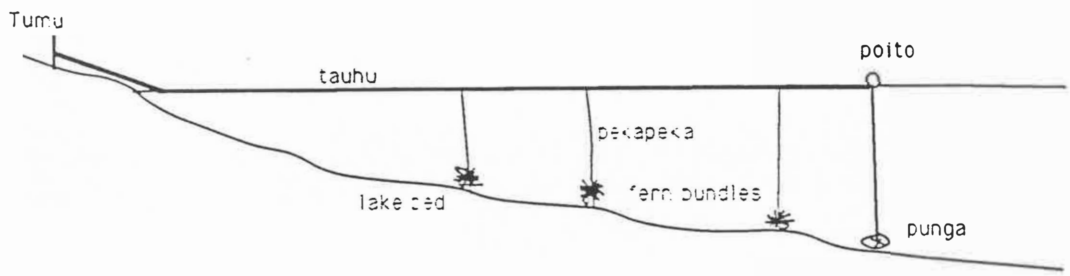


Figure 7.2: Tau method for capturing adult koaro in Lake Taupo.

to the lakeshore. The koaro would enter the tau as a source of cover. The bundles were carefully lifted the next day and the fish shaken from the fern. This method was practiced from April to the end of September (Fletcher, 1919).

Another capture technique used in the lake tributaries involved the use of a bob known as a 'kokopu-para'. A number of worms were threaded on some dressed flax and tied in a bunch to the end of a short thin rod. The fish would bite and be jerked into a canoe or onto the shore (Fletcher, 1919). However, this seems to be a highly labour intensive exercise and was most probably more of a recreational activity.

Makerita (1937) mentioned another recreational way of catching koaro on dark nights in the tributaries of lake Taupo. Hand-held hoop-nets called *kupenga kokopu* or *kupenga titoko* (Fig. 7.3) were used to snare fish using burning torches used as sources of artificial light. The fisherperson would carefully stalk the koaro and position the net behind the fish. The fish was then scared from the front and thus would turn and flee downstream into the net.

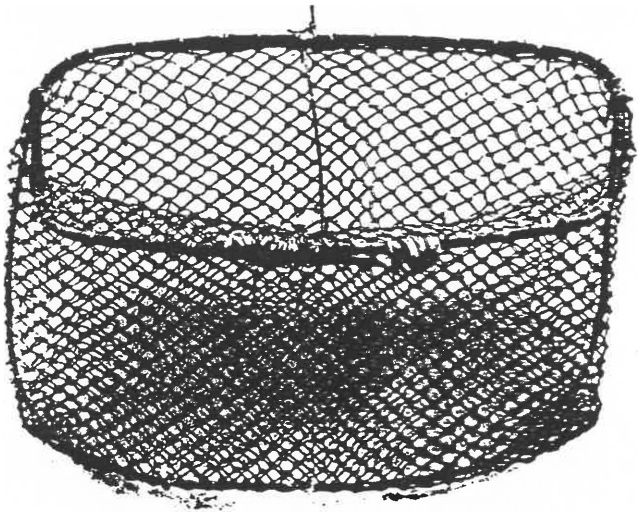


Figure 7.3: Kupenga titoki - used to capture adult koaro in the rivers and streams, (From Best, 1929).

7.3 Juvenile koaro

The juveniles of koaro, more commonly known as 'inanga', were an important food source in the Taupo and Rotorua districts (Hiroa, 1921). Koaro 'whitebait' in Lake Taupo were caught by two main methods; kupenga and hinaki.

The hinaki used were very similar in design to a 'pot' trap (Fig. 7.4) but were smaller than those used to catch eels in other parts of the country. The material used was probably the rush-like plant, *Cladium vautthiera* (Fletcher, 1919). The rush was stored in water when the traps were being constructed to preserve its malleability (Fletcher, 1919). The hinaki were positioned on the edge of a stream where the juvenile koaro migrate upstream (Fig. 7.5). A 'pa inanga' (a small barrier or weir) was erected at a slight angle to the stream by driving wooden stakes (usually manuka) into the stream, concentrating the fish and forcing them into the trap. The fisherman would examine his catch at frequent intervals. This method of catching whitebait was practiced from the beginning of September to the end of January. This correlates well with the present day migrations of juvenile koaro.

Interestingly, this method of catching koaro 'whitebait' is still used on a small scale in the Ohau channel in the Rotorua region. Fisherman have utilised the weir (which acts as a velocity barrier) to funnel small fish into small Hinakis positioned on the banks (Personal observation 1988).

The second main method of obtaining whitebait was by using a kupenga (seine nets) of various sizes along the shores of the lake. The kupenga was designed and used in almost the same way as a large modern-day seine net or drag net (Fig. 7.6, Fig. 7.7).

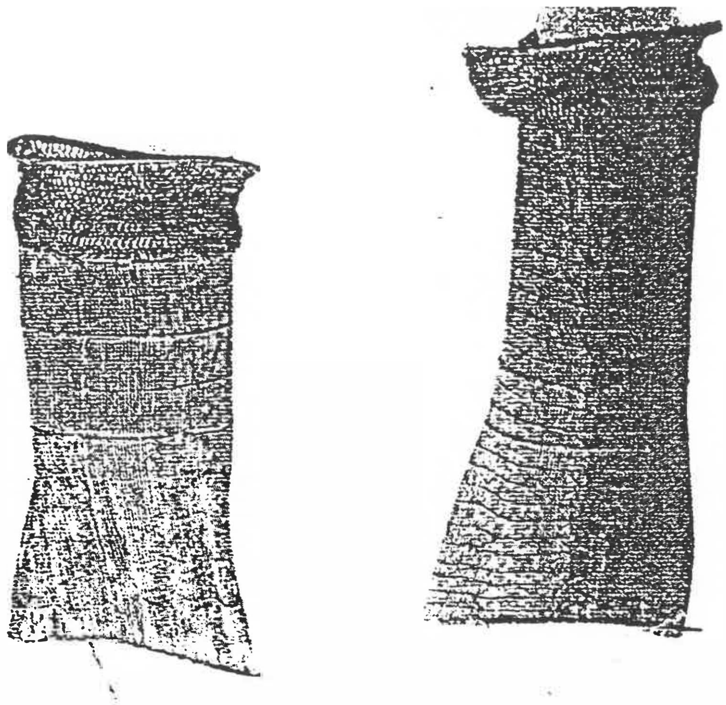


Figure 7.4: Kupenga koaro used to catch koaro juveniles in Lake Taupo tributary streams, (From Best, 1929).

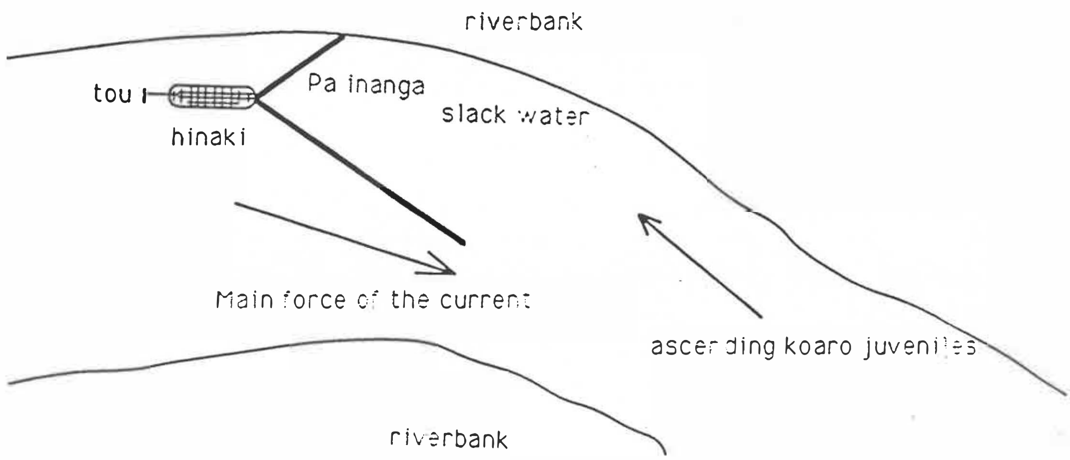


Figure 7.5: Pa inanga with Hinaki in position, (Best, 1929).

The length of the net varied from 50-100 yards, and its depth from 6 to 8 feet (Fig. 7.6).

The kupenga was composed of ;

1) The kaka or the central part of the net itself which was constructed of very thin straps of flax worked into a small mesh.

2) Kaharunga was the name applied to the rope which ran along the top of the net.

3) Kahararo was the bottom rope.

4) Poito were the wooden floats.

5) Karihi was the name applied to the stone sinkers.

There were two main methods of using the kupenga- one method involved the use of two canoes and the other the lakeshore and a canoe. The first method involved tying one canoe to a pole fixed in the lake, while the other canoe started out from the bow of the anchored canoe with 200-500 yards of rope. The canoe then returned to the stern of the anchored boat with another length of rope. The net was pulled slowly in towards the canoe (Fletcher, 1919). The same process was used in the use of one canoe but the net was fastened to a stake in the shore.

These shallow areas on the eastern side of lake Taupo, where the anchored canoe method was used, were very important and were carefully marked and jealously guarded by the various sub-tribes and families. Some of these areas are known as, Te Rimu, Nga-Parenga-Rua, Te Hohunu, Karanga- Wairua, Te Tii and Te Purakau. There were many other spots in the lake where whitebait were caught and the ownership of these areas and the rights to catch fish in them was carefully protected. Fishing was carried out using the kupenga methods from September to March.

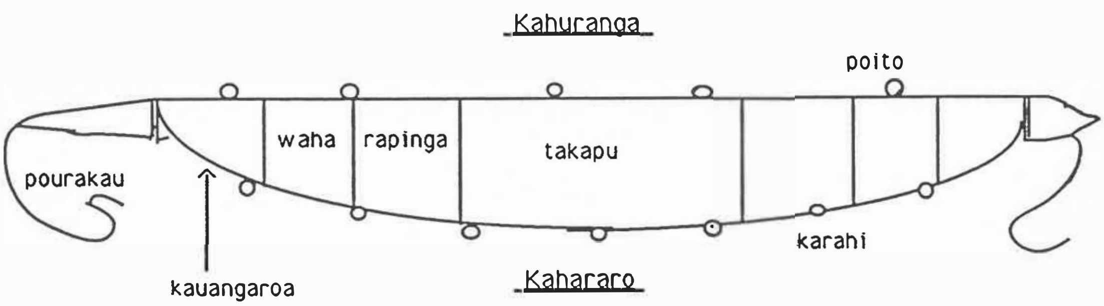


Figure 7.6: Description of the various parts of a kupenga used to capture koaro juveniles in Lake Taupo, (From, Best 1929).

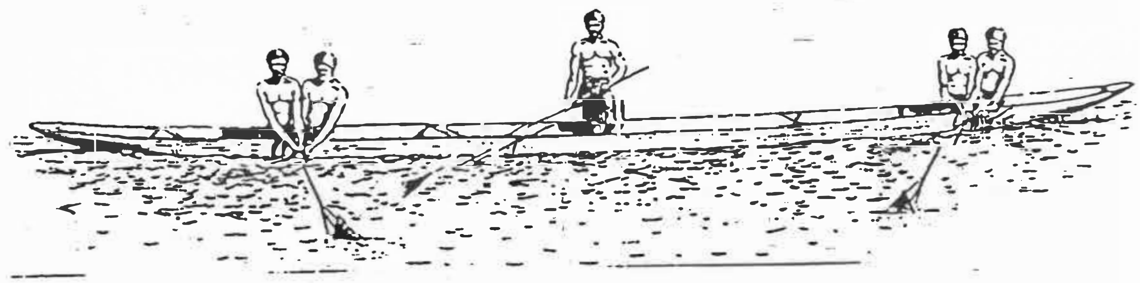


Figure 7.7: Taking koaro juveniles from Lake Taupo, (From, Best 1929).

Seining is still used today, but the fish caught are mostly juvenile smelt (*Retropinna retropinna*).

7.4 Mythology

Wi Tauri, of Taupo stated, "when the task of netting was commenced, then the principal expert took 2 fish of the first catch and deposited them at the sacred place of the village as an offering to Rongomai. When the netting was over for the day, then a ceremonial feast was held, for which a part of the catch was cooked in steam ovens. One fish for the priestly expert, one fish for the *ruahine* (a woman who took part in the tapu removing ceremony), one for the fisherman, and another for the bulk of the people. All such ceremonial performances were held to be highly necessary. If the taumaha ceremony over the offering of the two fish mentioned was neglected, then the fisherman would meet with no further success. Again, on the first day of the fishing those who remained at the village were not allowed to partake of food or cook, until the fishermen had returned and the proper ceremonies had been performed." (Best, 1929).

7.5 Modern-day utilisation

The koaro was once a plentiful and important food source to the Tuwharetoa people. Today, the koaro is found in low densities and are no longer caught in significant quantities. Methods based on traditional methods such as seining and hinaki traps are still used to capture juvenile koaro by relatively few people, but a high proportion of the catch probably consists of juvenile smelt.

In August 1894, the postmaster for Taupo, Mr G. Park, released brown trout fry in lake Taupo (Burstall, 1983). By 1898 fish were caught weighing in excess of 9kg. In 1904, a fish weighing 23.4kg was speared in the Kuratau river. 5000 Rainbow trout fry were released into Lake Taupo in 1903 by Reverend Fletcher. This actioned signalled the end of the koaro fishery in the lake, and by 1912 fishing for the koaro was unprofitable due to the low numbers of fish left (Burstall, 1983).

The Tuwharetoa people were not happy over the loss of a very important traditional fishery and restricted the introduction of trout to lake Rotoaira. However, rainbow trout also found there way into Lake Rotoaira, with a similar result for the koaro.

In 1926, with the passing of the Maori Land Claims Amendment and Adjustment act, the Tuwharetoa conceded their rights to the bed of the lake and the streams running into Lake Taupo. The Ngati Tuwharetoa Trust Board was established and the Crown agreed that the Board should receive 50% of all anglers licence fees and fines.

CHAPTER EIGHT

SUMMARY

Although koaro are no longer present in Lake Taupo in the high numbers that existed before the introduction of trout to the lake, viable populations of adult koaro still exist in many of the lake tributaries. There is no doubt that the numbers of koaro in Lake Taupo declined dramatically in the years following the introduction of trout. Although there is little documentation to show that trout preyed extensively on koaro during the early days of the trout establishment, koaro were the only abundant and easily accessible food source in the lake, and so there is strong circumstantial evidence that trout were the main cause of the decline of the koaro population in the lake.

The results of this study suggest that the decline in the numbers of koaro was probably due mainly to predation and competition with trout. Habitat alteration appears to be of minor significance as Lake Taupo and its tributaries have suffered little in the way of environmental perturbation (Stephens, 1983), especially during the early trout establishment period. The introduction of smelt has most probably had a further depressing effect on the size of the koaro population in the lake through competition for food with the juvenile stages.

Most koaro populations in New Zealand consist of stream dwelling, diadromous stocks and it is likely that lake-dwelling koaro, such as in Lake Taupo, exhibit different life-history and ecological characteristics. Consequently, it is unlikely that the findings from this study could be compared to stream-dwelling populations of koaro.

The exceptional climbing ability of koaro, particularly the juvenile stages, is probably the main reason for its widespread distribution. Koaro are generally a diadromous fish, with adults living and breeding in freshwater streams and juveniles rearing in the ocean. It is thought that Taupo koaro are derived from diadromous stock via the Wanganui river system to the south. The life-cycle of koaro in Lake Taupo is confined entirely to freshwater but it is analogous to the life-cycle of diadromous populations, with adults inhabiting tributary streams and juveniles rearing in the lake. Lake Taupo koaro were found to spawn in small tributary streams from November to April, producing large numbers of small eggs (fecundity 4000-19000). The larvae (approximately 6-7mm in length) are washed downstream into the lake, where they grow to a size of approximately 45mm. The following spring koaro juveniles ascend the lake tributaries where they settle and assume a benthic existence.

Koaro were not observed actually spawning. However, the presence of a larval koaro and gravid adults 4-5 km from the lake, in normal adult habitat, suggests that extensive spawning migration of adults do not occur. Although the sex ratio was normally 1:1, during the spawning season there was always a predominance of ripe males over females. This is probably a strategy to ensure complete fertilisation of ova. Gonadosomatic ratios in female koaro were highest in Spring before spawning and lowest in Winter after spawning. Although little information exists on the spawning biology of sea-going populations of koaro, it has been suggested that these koaro spawn in late Autumn and early Winter (McDowall, 1980; D.West personal communication 1989). In comparison, Lake Taupo koaro spawn considerably earlier (Summer/early Autumn). The reasons for this are not clear, but may be due to colder water temperatures in Winter or a poorer supply of food in the lake, requiring koaro juveniles to spend more time rearing in the lake to attain a minimum threshold size for survival.

The age structure of Lake Taupo koaro was determined from both population length-frequency distributions and otoliths, there appears to be 5 age groups 0+, 1+, 2+, 3+, 4+. However, considerable overlap between age groups for a given length often made age determination difficult. The degree of overlap increases with age, and may be due to, i) the extended spawning season, ii) the recruitment of koaro juveniles during Spring and Summer, iii) different growth rates of males and females, iv) competition for food, v) inherent differences in the rate of growth of individual fish. However, a combination of both length-frequency analysis and otoliths provided a satisfactory means of age determination. Koaro were found to grow throughout the year, with growth being maximal in Spring and Summer. Condition varied between streams, but fish were generally in poorer condition in the Winter.

The age structure and growth of other koaro populations has not been studied previously so few comparisons can be made with the findings of this study. However, it does appear that koaro in Lake Taupo do not attain the size of some diadromous koaro, for example the mean size of koaro in headwaters of some Waikato tributary streams exceeded 200mm (D.West personal communication 1989). The largest koaro captured in a Lake Taupo tributary stream during the sampling period was 184mm in length and most probably 6 years of age. However, koaro up to 200mm in length have been captured from the depths of the lake (Stephens, 1983).

Trout competition and predation

The results of population estimation studies suggest that the highest densities of koaro appeared to be negatively correlated with trout densities, that is, trout appear to have a negative impact on the abundance of koaro. The highest population densities of adult koaro were in tributaries such as the Waipehi stream and Hinemaiaia river where the number of juvenile trout was relatively low. Conversely, where trout numbers were relatively high, for example the Omori and Waiotaka streams, koaro densities were low. This may indicate competition for food and space between juvenile trout and adult koaro. Tilzey (1976) documented the invasion of rainbow trout from 1971-1974 into a headwater stream in the Lake Eucumbene catchment area, New South Wales. By 1974 the galaxiid population had completely disappeared below a barrier to trout on the stream, however, above the barrier the biomass and population structure remained relatively unchanged. Main (1988) found that there was little overlap between the distribution of brown trout and koaro in the mainstems of South Westland streams while koaro and trout co-existed in the small tributaries and headwater streams. Similar distribution patterns have been documented in a Wairarapa stream in the North Island (Hopkins, 1971) and in an Australian stream (Frankenberg, 1966; Jackson and Williams 1980; Cadwallader, 1979) where galaxiids were found in areas where trout were not present.

Studies on the food and feeding of koaro and juvenile trout in the Waipehi and Omori streams indicate considerable dietary overlap. Almost all prey was of aquatic origin, with fish and fish ova comprising an important proportion of the diet of both adult koaro and juvenile rainbow trout. When large prey items such as fish are absent or in low numbers, the diet of both fish species reflected the composition and abundance of the benthic invertebrate community. It appears that partitioning of food and feeding time (koaro feed nocturnally) may be occurring, thus reducing the amount of direct competition for food. It is unclear whether habitat segregation is occurring as adult koaro and juvenile trout were generally found in the same micro-habitat as juvenile rainbow trout, ie. riffles.

Habitat conditions do not seem to be as important in determining the distribution and abundance of koaro compared to interactions with juvenile trout. This is reflected in the low abundance of koaro in streams such as the Waiotaka, Omori and Waimarino which appear to be ideal habitat for adult koaro, but where juvenile trout were abundant. These streams are fast-flowing in areas of native vegetation, and have gravel/cobble substrate. Admittedly, little work has been carried out on the preferred habitat of koaro. However, Moffat (1984) recorded the preference of adult koaro for swiftly flowing water, and cobble substrate. ~~Other~~ Various workers have also suggested that koaro are often associated with native vegetation (McDowall, 1970; Main, 1988).

Future management

Although Lake Taupo is an internationally famous rainbow trout fishery, the native fish of the lake and its tributaries, have received little attention. Today, remnant populations of adult koaro still survive in the tributary streams of Lake Taupo but in much reduced numbers. In future, management proposals for Lake Taupo consideration should be given to the conservation of the koaro as a fish of particular historical and conservation value.

The findings of this study suggest that competition in the tributary streams between adult koaro and rainbow trout may be adversely affecting the abundance of the koaro population. The future survival and possibly enhancement of the koaro population in Lake Taupo may be achieved by the establishment of reserves where trout are excluded, for example in small tributaries such as the Waipehi. Such reserves would protect and ensure the maintenance of viable adult koaro populations.

Further research

Little is known concerning the biology of diadromous and lacustrine populations of koaro in New Zealand. Research carried out in this thesis adds to the limited amount of knowledge on the koaro. Further research is required on all aspects of diadromous koaro.

Specific areas which require further research include;

1) Feeding habits ie. do koaro feed on invertebrate drift or are they mainly benthic feeders, is feeding nocturnal or restricted to the twilight periods?

2) Habitat preferences.

3) Social interactions between koaro and juvenile trout.

4) There needs to be further investigations of lake-dwelling adult koaro as well as stream-dwelling diadromous forms.

5) It appears that some lake stocks of koaro in the North Island show very different morphological characteristics (McPhail personal communication 1989), which appear to be associated with such factors as the period of lake isolation and may be indicative of the process of speciation. This may provide a good opportunity for studies of the evolutionary biology of galaxiid fish species in New Zealand.

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