Diversity, distribution patterns and recruitment of fish in the Lake Kohangatera catchment and the implications of breaching to sea.

A thesis presented in partial fulfilment of the requirements for the degree of Masters of Science in Conservation at Massey University, Palmerston North.

Abstract

The fish fauna of a relatively unmodified coastal lake, Lake Kohangatera situated 11km south east of Wellington, was investigated as well as the impact of a large scale and prolonged breaching event that occurred in February 2004. A total of ten native species; inanga (*Galaxias maculatus*), giant kokopu (*Galaxias argentus*), banded kokopu (*Galaxias fasciatus*), koaro (*Galaxias brevipinnis*), longfin eel (*Anguilla dieffenbachii*) shortfin eel (*Anguilla australis*), common bully (*Gobiomorpus cotidianus*), redfin bully, (*Gobiomorphus huttoni*), smelt (*Retropinna retropinna*) and lamprey (*Geotria australis*) and one introduced species; brown trout *(Salmo trutta*) were found within the catchment. The majority of these fish are diadromous, spending part of their life cycle at sea. Some are able to form land locked populations while others are obligatory migrators. Lake Kohangatera occasionally breaches to sea during high flows. Historical records of the fish assemblage indicate that some of those species which depend on access to the sea periodically disappear from the fauna for periods of time, presumably when breachings do not coincide with their migratory phase. In February 2004 a severe storm caused the lake to breach for a prolonged period of time. Observed changes in the fish fauna following this breaching were the reappearance of redfin bully (*Gobiomorphus huttoni*) after an absence of several years, smelt (*Retropinna retropinna*) were recorded for the first time in the catchment, and recruitment of giant kokopu, (*Galaxias argentus*) banded kokopu (*Galaxias fasciatus*) and longfin eel (*Anguilla dieffenbachii*) improved. The diversity of fish species within Gollans Valley, the catchment of Lake Kohangatera, decreased with distance from the sea. Some species exhibited very defined distributions. Eight species were found in the lower catchment and just two or three in the headwaters. Some species were very low in abundance e.g. redfin bully or were restricted to a

particular stretch or tributary e.g. koaro and banded kokopu, while others were widespread throughout the catchment e.g. longfin eel.

General Acknowledgements.

To my supervisor Dr Mike Joy I would like to give my sincere thanks for helping me in the field, his endless patience in editing the chapters of my thesis, steering me in the right direction with my field work and helping me with the statistics. I would also like to express my gratitude to my co-supervisor Dr Russell Death for his encouragement and advice (without him I would probably never have begun studying for my Masters) and also Dr Ian Henderson for his suggestions.

Thanks to the Department of Conservation who funded this project and in particular Nadine Gibbs for her help in the field. Thanks also to the Greater Wellington Regional Council for their help, in particular Owen Spearpoint for always organising the access key to Burdens Gate for me, and his keen interest and knowledge of the area.

I an very grateful to all the people who helped me in the field; my ex-husband Robert Nicholson who was there in the beginning, Rowena Teal, Katie Paul, my daughter Holly and a special thanks to Logan Brown who did a huge amount of field work for me climbing and bush bashing, electric fishing and night spotting with great humour and enthusiasm!

Finally I would like to thank my family; my children, Adam, Todd and Holly, stepchildren James and Sophie and my mum (Janet Brend) for their encouragement and putting up with my long absences and my boring preoccupation with the computer! Most especially I would like to thank my partner Geoff who thought I was

trying to kill him when I made him climb a mountain in the dark and then go night spotting in waders two sizes too big. He has also helped me a huge amount in the field especially in the lake surveys when the trusty seagull motor broke down and he ended up rowing me and my nets all over the lake! Thanks for always being there – encouraging and positive.

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General Introduction

Introduction

Lake Kohangatera situated in East Harbour Regional Park, Wellington, along with its smaller sister lake, Lake Kohangapiripiri, occupying an adjacent valley, represents one of the few surviving lowland coastal lakes/catchments that has remained relatively undisturbed since the colonisation of New Zealand. As such it presents a valuable opportunity for the study of native fish populations and distributions in natural habitat. Situated at Pencarrow, 11kms south east of Wellington and only accessible to the public by foot, Lake Kohangatera has an open water area of about 17ha. The lake drains around 1700ha via Gollans Stream, which passes through an extensive area of undisturbed beech forest, a farm and 150 hectares of wetlands (Gibbs 2002).

The make up of New Zealand freshwater fish communities has been found to be strongly influenced by the fact that a large proportion of its fish fauna are diadromous spending part of their life cycle at sea (McDowall1998, Joy *et al* 2000, Joy & Death 2001). Consequently elevation, distance to the sea and the presence or absence of migratory barriers have a large influence on fish distribution (Joy & Death 2004, Jowett & Richardson 2003, David *et al* 2002). Lake Kohangatera and Lake Kohangapiripiri are separated from the sea by a beach barrier. While Lake Kohangapiripiri rarely breaches to sea, Lake Kohangatera has been known to breach its 420m wide beach barrier periodically during flood events. In view of the migratory habits of most of New Zealands native fish, with different species migrating at different times, the timing and frequency of these events would be expected to have huge implications on the fish assemblage of the catchment.

Historically the lakes were open to the sea allowing free access to migratory fish (Fig 1). The chart published in 1951 clearly shows both lakes with open passage to the sea. Since then the beaches have aggraded strongly (Matthews 1980) and the lakes have

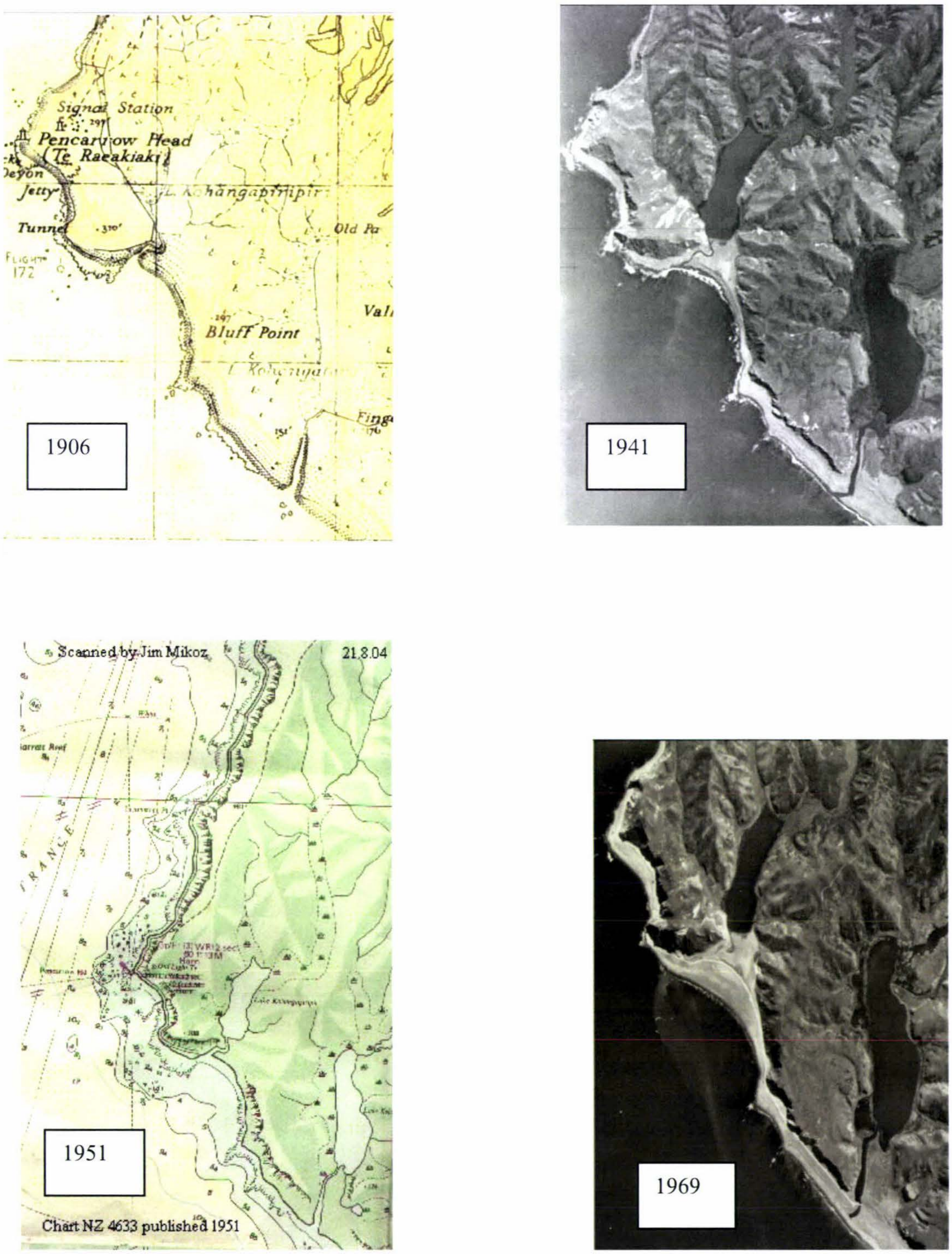

Fig 1. Historical pictures of Lake Kohangatera and Lake Kohanagapiripiri showing the outlets receding and becoming closed off to the sea. Note the road in the 1969 photo dissecting both outlets.

become closed off from the sea. Although the historical pictures (Fig 1) indicate that the lakes outlets were receding naturally, the building of a coastal road in the early 1960s with round concrete culverts used to bridge the lake outlets, along with sand quarrying operations in the area, are thought to have interfered with the normal erosion cycle of the beach barriers and may well have contributed to the lakes becoming blocked off from the sea (Gibbs 2002). Certainly in the present day the road and culverts impede the flow of water from the lake, limiting breaching events and arguably posing a velocity barrier to fish migration when breachings do occur. Fish migrating in from the sea must swim through water channelled through the culverts at artificially high velocities.

This study focuses on describing the fish fauna of Lake Kohangatera and its catchment, including the distribution patterns of species and the impacts of a large scale breaching event that occurred in February 2004 on the fish assemblage

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2

The impact of breaching to sea on the fish fauna of a shallow coastal lake and its catchment

INTRODUCTION

The make up of New Zealand freshwater fish communities has been found to be strongly influenced by the fact that a large proportion of its fish fauna are diadromous (McDowall1998, Joy *et al* 2000, Joy & Death 2001). Consequently elevation, distance to the sea and the presence or absence of migratory barriers have a large influence on fish distribution (Joy & Death 2004, Jowett & Richardson 2003, David *et al* 2002). Hence composition of lake faunas depend on their size, location and the type of outlet to the sea (Rowe & Graynoth 2002). Rowe & Graynoth (2002) gave a broad classification of lakes according to their altitude (reflecting distance inland) and size. They identified five main types of fish community according to the most dominant fish species present: salmonid, eel (small), eel (large), galaxiid and coarse fish.

The composition of shallow coastal lakes is normally quite different from deeper inland lakes. Trout are often absent or scarce and native fish such as eels generally predominate, however composition is very much dependant on access to the sea. Where access is completely unimpeded a wide range of migratory species such as common bullies, inanga and smelt are found. Where access is blocked however, these less strong swimmers are excluded and often only eel and landlocked populations of bullies are present (Rowe 2002). Other coastal lakes lie between these two extremes sometimes becoming closed off to the sea due to the build up of beach barriers, build up of sediment, drought/reduced water levels etc. so their fish composition may depend on the duration, frequency and regularity of breachings. Lake Kohangatera is an example of the latter.

Lake Kohangatera, is a shallow coastal lake situated 11 km south east of Wellington at Pencarrow, in close proximity to its "twin", Lake Kohangapiripiri (Fig.1). Lake Kohangapiripiri has an open water area of about 13ha and drains an area of about 280 ha of intact bush, farmland and wetlands via Cameron Creek. Lake Kohangatera is much larger having an open water area of about 17ha draining around 1700ha via Gollans Stream which passes through undisturbed beech forest, farmland and wetlands (Gibbs 2002). Both lakes are separated from the sea by a beach barrier, however Lake Kohangapiripiri rarely breaches to sea often remaining closed for years whilst Lake Kohangatera occasionally breaches its 420m wide beach barrier during flood events (Gibbs 2002). Unfortunately no records had been kept of breachings prior to 2004.

The fish community of Lake Kohangatera fits into the category of "eel (small)" (Rowe & Graynoth 2002) where the dominant fish species are eels, inanga, smelt, common bullies and giant kokopu. The NIWA New Zealand Freshwater Fish Database (NZFFD) lists the native longfin eel (*Anguilla dieffenbachii*), shortfin eel (*Anguilla australis*), giant kokopu, inanga (*Galaxias maculatus*), banded kokopu (*Galaxias fasciatus*), lamprey (*Geotria australis*), common bully (*Gobiomorpus cotidianus*), redfin bully (*Gobiomorphus huttoni*) and the exotic brown trout (*Salmo trutta*) as present within Lake Kohangateras catchment. All of the native species are diadromous (although giant kokopu, banded kokopu and common bully are capable of forming landlocked populations (McDowall 1990)) so breaching events are vital in maintaining fish diversity. In February 2004 a severe flood event occurred in the lower North Island of New Zealand and Lake Kohangatera breached for a prolonged period of time. Thus the purpose of this study was to firstly determine the present day fish fauna of Lake Kohangatera and secondly to investigate if the prolonged breaching event had any impact on the fish assemblage of the catchment.

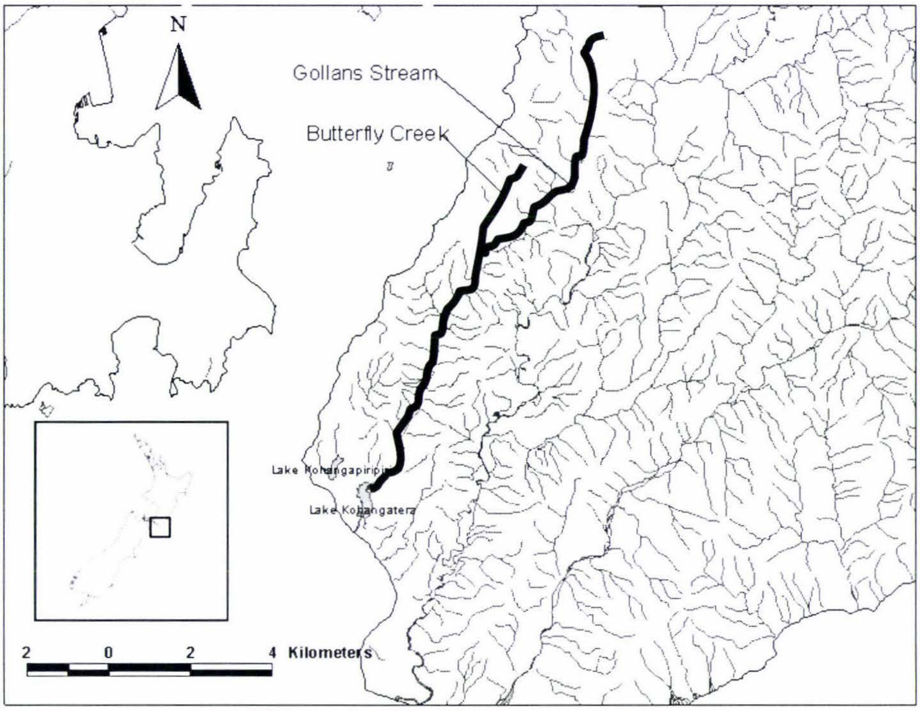

Fig. 1 A map of Pencarrow showing the location of Lake Kohangatera and its catchment, Butterfly Creek and Gollans Stream.

METHODS

Lake Kohangatera fish surveys

A quantitative fish monitoring program was undertaken to describe the present day fish assemblage of Lake Kohangatera for comparison with historical data and to monitor changes over time which could be linked to the major breaching event of 2004 or any subsequent breachings (breaching events now being recorded by Greater Wellington Regional Council). G-minnow traps with 20mm entrance apertures and 5mm square mesh (McDowall 1990) were used for trapping between June 2004 and June 2005. Traps were baited with cat biscuits, set up around the margins of Lake Kohangatera and left out overnight or, where time was limited, for a period of not less than three hours. From the 13^{th} to 17^{th} of February 2006 G-minnow traps and fine-meshed fyke nets (with mouth openings of 48x62cm and 1.5m in length), again baited with cat biscuits, were set at nine sites on three transects across Lake Kohangatera. Fyke nets are long bags held open with hoops into which fish can pass easily into an inner chamber where they are trapped (McDowall 1990). One fyke net and two g-minnows were set at each site. These were left out overnight, emptied each morning and reset. All fish caught were identified to species level, measured and counted.

Thirty-five smelt, caught in the lake fish survey, were euthenased in a solution of 500mg/L of tricaine methane sulfonate (MS 222) and were later x-rayed at the Institute of Veterinary Animal and Biomedical Sciences, Massey University, Palmerston North to obtain vertebral counts. To assess the migratory status of the fish the results were compared to vertebral counts made in other studies of diadromous, lacusterine and brackish lake populations of smelt.

A single trap "Southland Sock" whitebait net (with a mouth opening of 1.3x1.02m and a length of 3.5m was set in the breached channel of Lake Kohangatera on five occasions between the 18th July 2004 and 22nd October 2004. The net was set one hour before high tide and emptied a minimum of one hour after high tide. Galaxiid juveniles were transported back to Massey University, Palmerston North, where they were kept in an aquarium until they had grown sufficiently to identify to species level.

Salinity Profile

To obtain a salinity profile of Lake Kohangatera, a transect was taken at high tide on the 13th February 2006 running inland from the southern to the northern end of the lake. At the time the lake was not breached to the sea. The electrical conductivity of water is strongly dependant on its salinity. Thus conductivity was used as an indicator of salinity and measures were taken every ten metres using an Orion model 122 conductivity meter. The conductivity was measured at the water surface then the probe was slowly lowered to the lake bed while observing the readings. Any significant changes in conductivity within the water column were noted and a final conductivity reading was taken on the lake bed.

Stream Fish Surveys

As with the lake fish surveys, the stream fish surveys were undertaken to describe the present day fish fauna, monitor any changes over time and to compare with historical data in order to determine any changes which could be attributed to the prolonged breaching of Lake Kohangatera in 2004 or any subsequent breachings. Sampling was conducted approximately three monthly from June 2004 to September 2006. Stream fish surveys were carried out by single-pass electro-fishing using a Kainga EFM300 backpack electric fishing machine (NIWA Instrument Systems, N.Z.). The same 500 to 1000m stretches of both Gollans Stream and its tributary, Butterfly Creek, were sampled during each survey. They were surveyed in a continuous manner from the point where they meet for 500 to 1000 meters except where the depth of water or obstructions prevented electro-fishing. Five to ten metre stretches were fished at a time using dip nets and a stop net at the downstream end to catch fish. Again all fish caught were measured and identified to species level. On three occasions nightspotting surveys were conducted (Chapter 2).

The results of both the lake and stream fish surveys were compared with historical records from the Wellington Acclimitisation Society, NIWA New Zealand Freshwater Fish Database, and the Department of Conservation Database for Lake Kohangatera, and its catchment.

RESULTS

A total of 669 fish from 6 species, all of them native, were recorded in the 2004/2006 fish surveys of Lake Kohangatera: common bully, smelt, longfin eel, shortfin eel, lamprey, and inanga (Table1). Common bully was the most abundant fish making up 79% of the total catch, followed by inanga and smelt which each made up 8%. Longfin and shortfin eel made up 2% of catch and lamprey accounted for just 1% of total catch. Eel densities are likely to be underestimated as fyke nets, most suitable for their capture, were not used on every sampling occasion.

Comparative size (length) distribution histograms are presented for smelt and inanga caught in G-minnows/Southland Sock in the 2004/2005 survey (Fig 2) and for common bully, longfin eel and shortfin eel from the fishing surveys carried out in February 2006 (Fig 3). The majority of inanga caught (96%) were whitebait (juveniles) while the majority of smelt were in the 61-80mm range or adult size. Common bullies caught consisted mainly of adults (78%) 35mm and over. Only 27% of shortfin eels caught were fish less than 500mm in contrast to the longfin eels of which 69% of fish caught were smaller than 500mm. The lamprey consisted of 8 juveniles trapped as they were migrating out to sea in the outlet in July 2004, consequently there was insufficient data for lamprey to present meaningful distributions. A trend was evident in the distribution of the most frequently caught fish, the common bully. Whilst found throughout the lake, the largest catches were made on the western margins with densities particularly high in the southwestern corner (Fig 4).

Table 1: Total numbers and length ranges of the fish species sampled in Lake Kohangatera June 2004-February 2006.

Species		*N*	Length (mm)
Common bully	*Gobiomorpus cotidianus*	528	10-80
Inanga	*Galaxias maculatus*	52	40-115
Smelt	*Retropinna retropinna*	51	55-120
Longfin eel	*Anguilla dieffenbachii*	16	100-1400
Shortfin eel	*Anguilla australis*	14	120-800
Lamprey	*Geotria australis*	8	19-10

Vertebral numbers in the Lake Kohangatera smelt population ranged from 50 to 63 with a mean number of 57.2. Comparisons with data from other studies (Table 2) show this distribution fits closely with Lake Wairarapa (range 53-62 vertebrae, mean: 56.5) and

Lake Ellesmere (range 53-61 vertebrae, mean: 55.8) (McDowall 1972). Like Lake Kohangatera, these are both shallow lowland lakes with brackish water. They are prone to being cut off from the sea in some wind conditions. In contrast the diadromous smelt population of the Waikato Estuary had a higher mean vertebral number of 60.6 and a much reduced range of 59 to 62. The landlocked smelt populations of Lake Taupo and Lake Rotorua share a much lower mean vertebral count of 52.6 and again a much reduced range of 50-55 and 50-54 respectively.

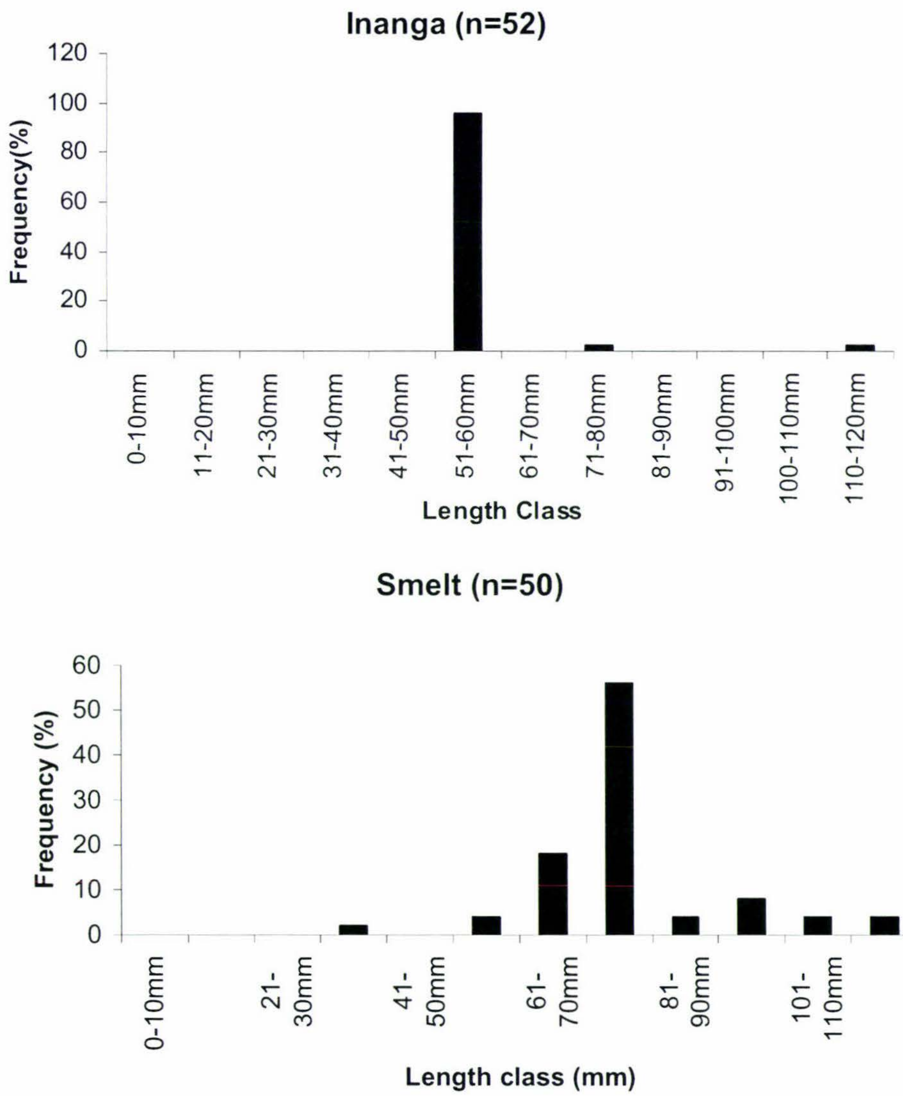

Fig. 2 Comparative length frequency distributions of inanga and smelt caught in Lake Kohangatera during 2004/2005 fish surveys

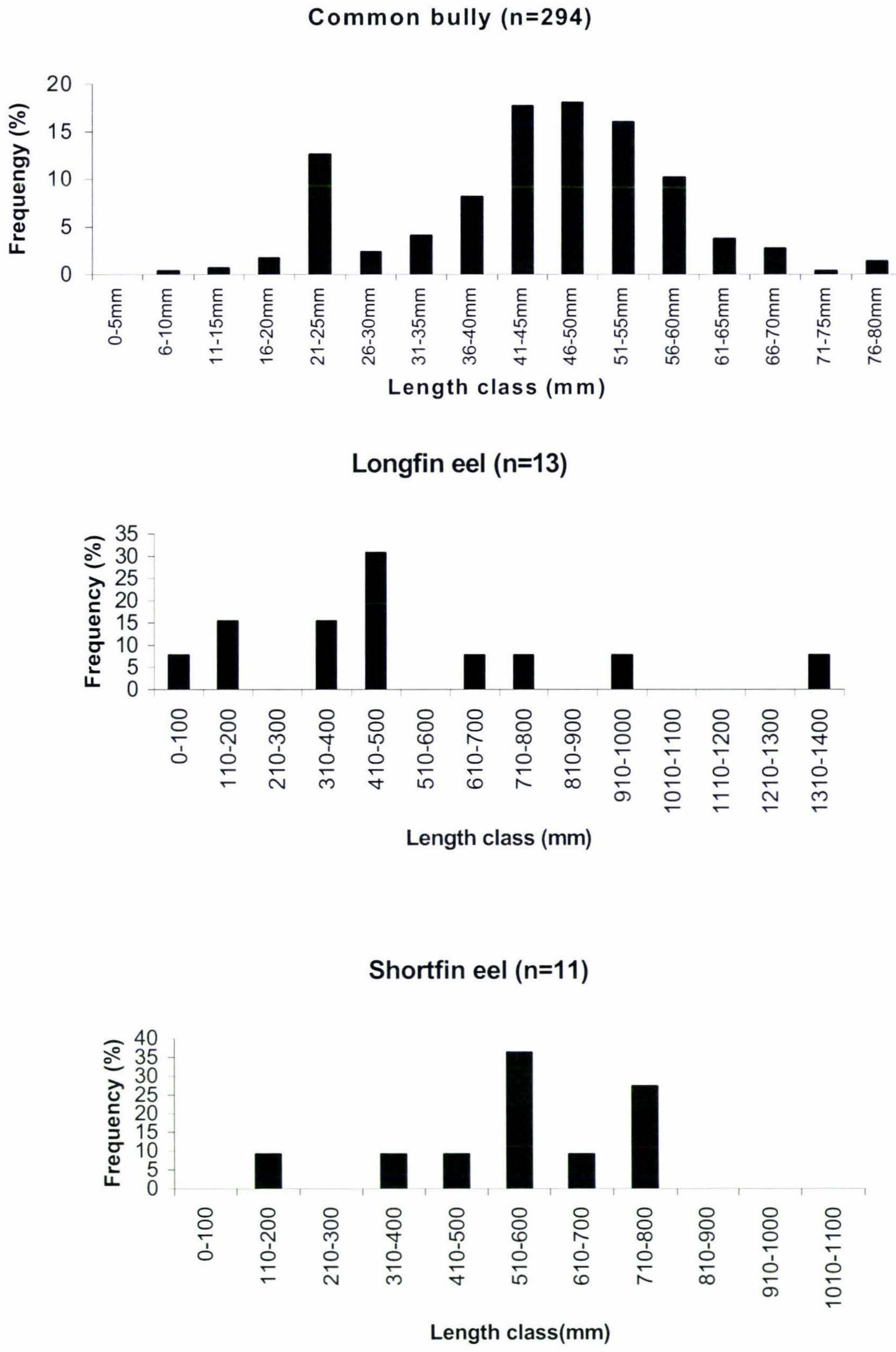

Fig. 3 Comparative length frequency distributions of common bully, longfin eel, and shortfin eel in Lake Kohangatera, February, 2006.

Table 2: Comparison of vertebral numbers in Lake Kohangatera common smelt with other lacusterine smelt popuations.

Locality	Number of vertebrae														
	50	51	52	53	54	55	56	57	58	59	60	61	62	63	Mean	Sample origin
River estuary																
Waikato River										3	18	17	5		60.6	McDowall 1979
Upland lakes																
Lake Taupo	2	1	5	8	3	1									52.6	McDowall 1979
Lake Rotorua	1	4	6	4	1										52.6	McDowall 1979
Lowland lakes																
Lake Wairarapa				1	5	13	12	5	1		2	6	1		56.5	McDowall 1972
Lake Ellesmere				1	3	22	17	12	1			1			55.8	McDowall 1972
Lake Kohangatera	**1**		**1**	**2**	**5**	**4**	**3**	**4**	**5**	**1**		**2**	**3**	**4**	57.2	

Whitebait identification

A total of 48 juvenile galaxiids were captured between mid July and late October 2004 and kept at Massey University, Palmerston North until they reached maturity and could readily be identified to species level by morphological characteristics. All of these fish were identified as inanga.

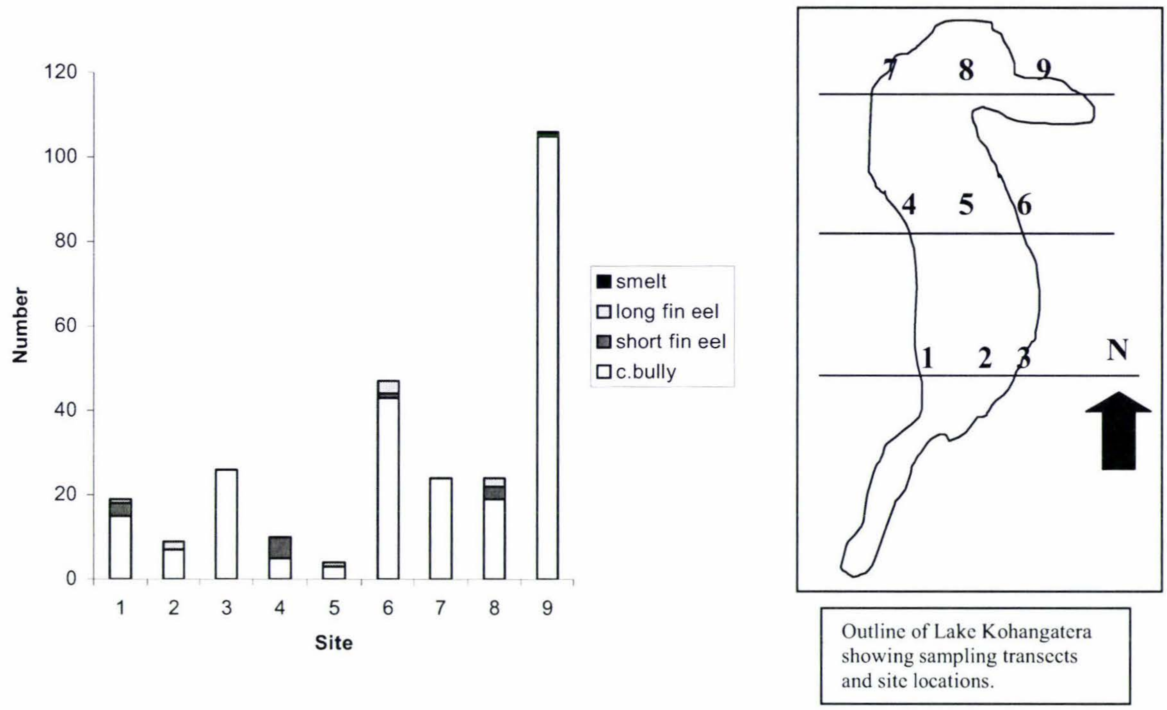

Fig.4 Total catch per site from three transects (refer inset) across Lake Kohangatera 13^{th} to 17^{th} February 2006.

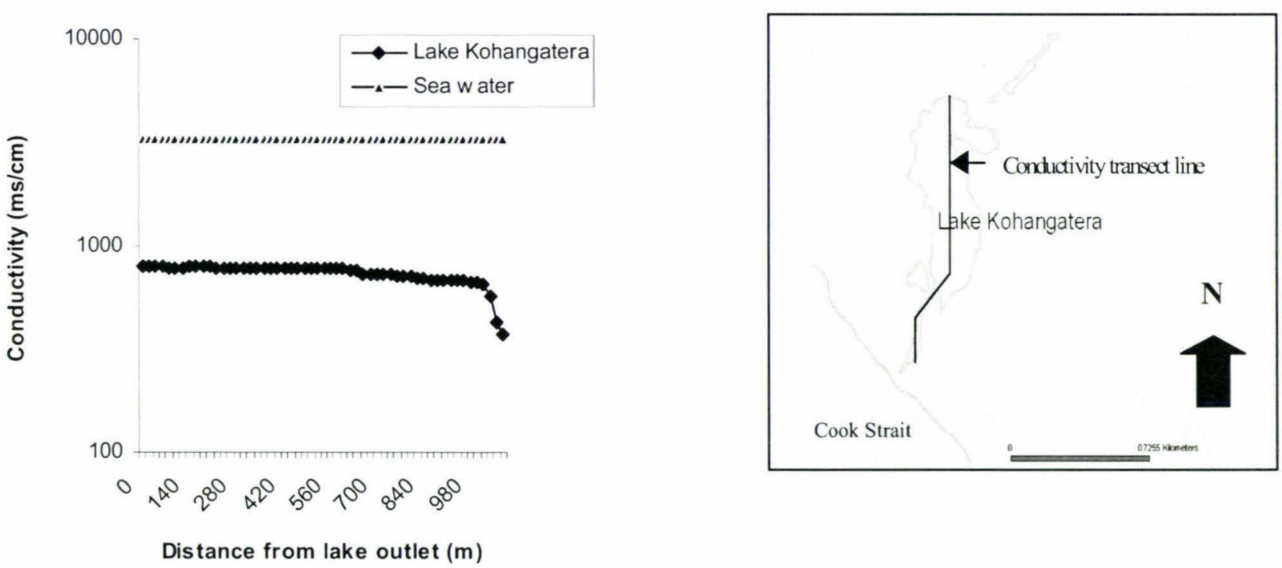

Fig.5 Conductivity profile (as an indicator of salinity) taken every 20metres on a transect running from south to north across the centre of Lake Kohangatera 13/2/06.

Salinity profile

Conductivity measurements indicated that salinity steadily declined from the seaward or southern end of Lake Kohangatera to the inland or northern end, gradually dropping from 788 ms/cm to 368 ms/cm (Fig 5). Within the last 60 metres there was a rapid drop off from 654 ms/cm to 368 ms/cm. Conductivity readings were constant within the water column at each twenty metre location along the transect.

Stream Fish Survey

A total of five fish species were detected in the Gollans Stream and Butterfly Creek (although a further species, koaro *Galaxias brevipinnis* was found in Gollans Stream in subsequent fish surveys for Chapters 2 & 3) four native species; giant kokopu (*Galaxias argentus*), banded kokopu (*Galaxias fasciatus*), longfinned eels (*Anguilla dieffenbachii*) and redfin bullies (*Gobiomorphus huttoni*) and one introduced species; the brown trout *(Salmo trutta).* All five species were present in Gollans Stream however just three species were found in Butterfly Creek (Table 3). The Gollans stream community was dominated by longfinned eels (46% of total catch), giant kokopu (*Galaxias argentus*) (21%) and banded kokopu (20%). Its tributary, Butterfly Creek had a fish community dominated almost exclusively by banded kokopu, which made up 88% of fish recorded (Chapter 2). Two giant kokopu and 6 longfinned eels were the only other fish caught in the stream throughout the duration of the two-year study. The number of fish caught during each fish survey varied widely. The highest numbers of fish caught per stream on any one occasion was 16 over a 500m stretch and the lowest just one longfin eel in Gollans stream in June 2005.

Comparative size (length) distribution histograms are presented for longfinned eel, banded kokopu and giant kokopu for the year June 2004/2005 and June 2005/2006 (Fig 6). In both years of the study the majority of eels caught were young fish less than 500mm in length. The banded kokopu population was dominated by mature fish in the 151-200mm class in the first year of the study however results showed an influx of younger fish below 150mm with a reduction in the number of older fish in the second year. Giant kokopu showed a similar trend, with a pronounced recruitment of young fish and a marked reduction of fish over 250mm within the catchment in 2005/2006. There was insufficient data for brown trout and redfin bullies to present meaningful distributions however the eleven brown trout caught over two years ranged between 35mm and 450mm in length and the two redfin bullies measured 45mm and 75mm.

Table 3: Total number of fish caught in Butterfly Creek and Gollans Stream by Electric Fishing Machine/ nightspotting during 2004 - 2006 fish surveys

Common Name	Scientific Name	Butterfly Creek	Gollans Stream	Total	Size (mm)
Banded kokopu	*Galaxias fasciatus*	56	19	75	30-280
Longfin eel	*Anguilla dieffenbachii*	6	44	50	60-1000
Giant kokopu	*Galaxias argentus*	2	20	22	110-390
Brown trout	*Salmo trutta*	0	10	11	35-450
Redfin bully	*Gobiomorphus huttoni*	0	2	2	45-75

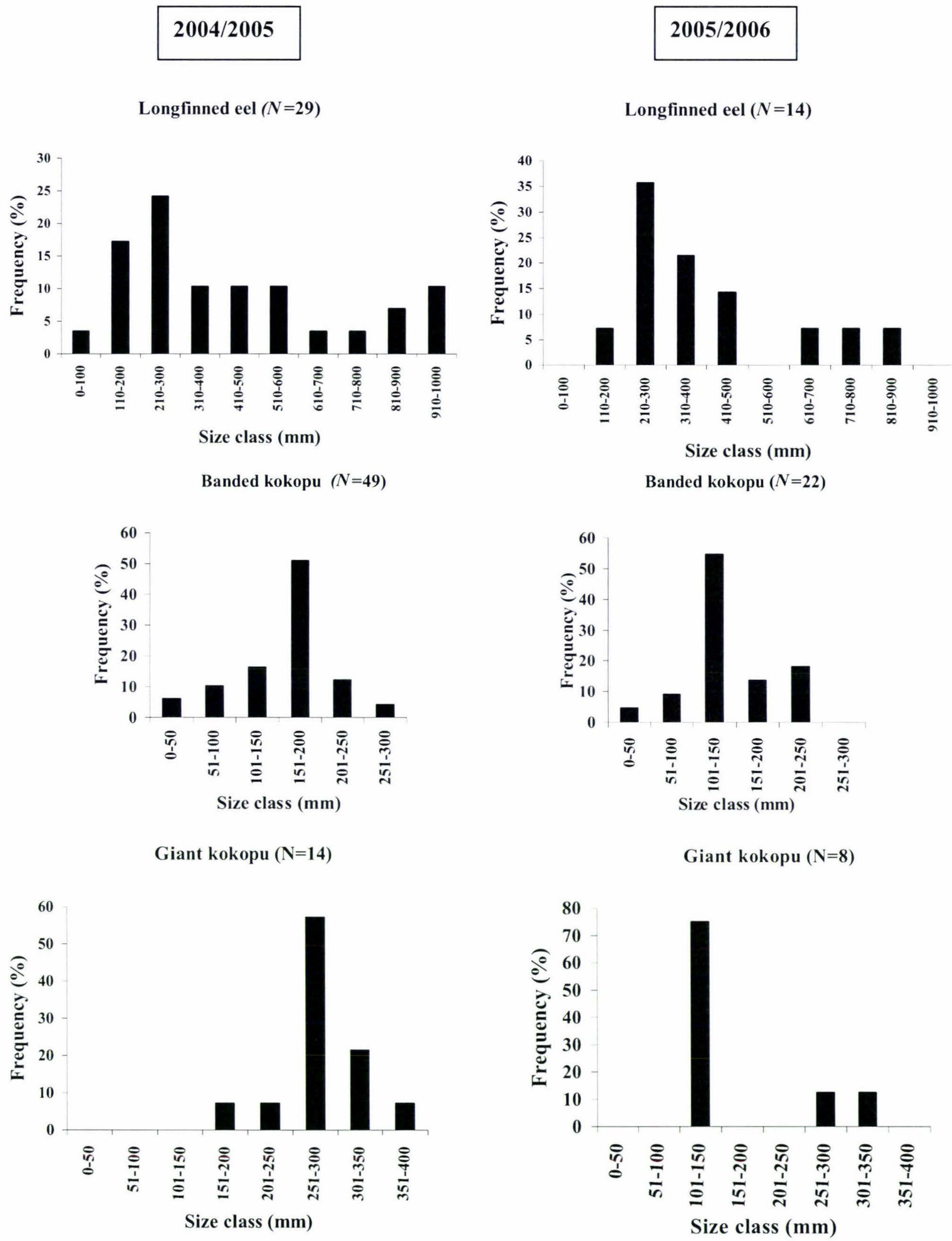

Fig. 6 Comparative length frequency distributions of longfinned eel, banded kokopu and giant kokopu in Gollans Valley catchment in 2004/2005 and 2005/2006.

Comparison of fish survey results to historical records

Comparison of the results of this study with historical records of fish in the Lake Kohangatera catchment (Table 4) show that fish assemblages have varied relatively little over the past 20 years. Longfin eel, shortfin eel, common bully, brown trout banded kokopu and giant kokopu have been consistently recorded in the catchment since 1987. Lamprey, inanga and redfin bully are also usually present in records (including this study) however in some surveys these fish are absent. Giant bullies (*Gobiomorphus gobioides*) were listed in the catchment by the Wellington Acclimitisation Society in 1987 and the Department of Conservation in 1999, but were not identified during this survey. It is possible that these fish were misidentified, as they are easily confused with the common bully. One species previously not recorded in the catchment, the common smelt (*Retropinna retropinna*) was detected during this study.

Table 4: Records of freshwater fish species found in the Lake Kohangatera catchment from 1987 to 2006

	Year Source	1987 (NZFFD)	1987 Wgtn. Accl Soc	1999 DOC Database	2002 (NZFFD)	2006 (This Study)
Common Name	Scientific Name					
banded kokopu	*Galaxias fasciatus*	*	*	*	*	*
brown trout	*Salmo trutta*		*	*	*	*
common bully	*Gobiomorphus cotidianus*	*	*	*	*	*
giant bully	*Gobiomorphus gobiodes*		*	*		
giant kokopu	*Galaxias argenteus*	*	*	*	*	*
inanga	*Galaxias maculatus*	*	*	*		*
lamprey	*Geotria australis*			*		*
longfin eel	*Anguilla dieffenbachii*	*	*	*	*	*
redfin bully	*Gobiomorphus huttoni*	*	*	*		*
shortfin eel	*Anguilla australis*		*	*	*	*
smelt	*Retropinna retropinna*					*
koaro+	*Galaxias brevipinnis*					*

* - indicates fish species presence, + refer chapter 3

DISCUSSION

Changes in fish fauna following February 2004 breaching

Since the extensive and prolonged breaching of Lake Kohangatera in February 2004 and the subsequent increased frequency of breaching events a number of changes were detected in the fish fauna of the catchment. These include the addition of a previously unrecorded species the common smelt, to Lake Kohangatera, the reappearance of redfin bullies to the catchment and an influx of young longfin eel, giant kokopu and banded kokopu in Gollans Stream and Butterfly Creek. Lamprey were also once again recorded but these were juveniles migrating out to sea so and would have been in the catchment prior to the breaching event.

Lake Kohangatera has only intermittent breachings to sea which is reflected in the historical records of the fish fauna (Table 4). The persistent fish species in the community are those that are extremely good climbers (eels) or those that are capable of forming land locked populations, omitting the sea going stage of their life cycle (e.g. banded kokopu, giant kokopu, common bully). Fish such as redfin bully and lamprey that are obligatory migrators periodically disappear from the records. Their presence is dependent on breachings coinciding with migration times i.e. spring for inanga and November onwards for young redfin bullies returning from the sea (McDowall 1990). In contrast, in streams where access to sea is the sea is unimpeded such as Kaiwharawhara Stream in the

Wellington area, the NZFFD shows redfin bully recorded in every fishing survey from1982 to 2004. In late 2003 the lake breached for a period in October and again in early December prior to the prolonged breaching that occurred during the February 2004 floods and both redfin bullies and inanga reappeared in the fish fauna of the catchment.

During the February breaching extensive scouring of the beach barrier occurred, exposing areas of bedrock. Consequently the barrier has become less robust and anecdotal evidence suggests the frequency of breachings has increased (Gibbs, Spearpoint pers com). Certainly this has been reflected in the fish community with the appearance of a previously unrecorded species, the common smelt, and improved recruitment levels of giant kokopu, banded kokopu and longfin eel in the 2005/2006 surveys of the upper catchment. Smelt migrate into freshwater to spawn during spring and summer (McDowall 1990) which coincides with the prolonged breaching during February 2004 and would have allowed ample opportunity for smelt to colonise Lake Kohangatera if not already there from previous breaching events since the catchment was last surveyed. The increase in recruitment levels of giant kokopu, banded kokopu and longfin eel could well, at least partially, be the result of young fish migrating into the catchment from the sea however the only way of substantiating this was to kill fish for otolith examination. Because of the low density of fish within the upper catchment and the high cost of the procedure this was avoided. It is unclear why recruitment of shortfin eel was did not improve.

Vertebral counts of the smelt community revealed that some of the population is migratory and some non-migratory. McDowall 1972, 1979 & Northcote & Ward 1985 (Table 2) found that resident smelt from closed lakes such as the Lake Taupo have low vertebral numbers and those from open lakes or river systems such as the Waikato River had high vertebral counts. Non-migratory smelt have an average of around 50-53 vertebrae, brackish lake populations an average of 55 or 56 and sea-going populations 60-62 (McDowall 1990). This variation in vertebral numbers is a result of the environmental conditions during egg and larval development. Eggs developing in saline water will produce adult smelt with more vertebrae than those developing in brackish water (McDowall 1990). Smelt from some lowland lakes such as Lake Wairarapa have both lake resident and migratory smelt inferred from two populations, one with high vertebral counts and one with lower vertebral counts. Lake Kohangatera smelt exhibit this same bimodal distribution suggesting that only some of the population remains migratory (Table 2). Galaxiid fish also exhibit this relationship with diadromous populations having more vertebrae than their land-locked conspecifics (McDowall 2003) however no galaxids were x-rayed for vertebral counts during this study.

Electrical conductivity is strongly dependant on salinity and the conductivity profile of Lake Kohangatera suggested that at the time of sampling there was a gradual decline in salinity with distance from the sea with a sudden drop off at the northern end. The constant readings with in the water column are evidence that there was no salt wedge present. At the time however the lake was closed to the sea. Clearly the salt profile of the lake could be expected to change markedly when breaching occurs. This in turn could be expected to influence the fish population such as vertebral development in larval smelt and galaxids and the distribution of fish within the lake, depending on their tolerance of salt water.

During this study the only species caught in the lake in sufficient numbers to study its distribution in relation to salinity was the common bully. This species was abundant on the most southern transect were conductivity/salinity was lowest (Fig. 4) however most of these fish were caught on the north eastern corner of the transect (site 9). Highest densities were in fact along the eastern side of the lake increasing markedly with distance from the outlet/decreasing salinity. As found in a study by Glova and Sagar (2000) densities were also highest inshore than off-shore and also associated with an inflowing tributary (the northeastern corner is where the Gollans Stream wetlands enter the lake) and marginal habitat.

Smelt and inanga number were almost certainly underestimated in the fish surveys in February 2004 .Very few smelt and no inanga were caught despite significant numbers being observed on two occasions when night spotting. This survey was carried out in a short time frame in contrast to the the G-minnow trapping which was done periodically between June 2004 and June 2005 and could account for the lack of success in catching these species. Both species tend to swim in schools reducing the chances of catching them. In contrast common bullies and eels are bottom dwellers and are free swimming and tend to be widely distributed through out lakes (McDowall 1990, Glova & Sagar

2000, Rowe 2002). More extensive trapping of the lake would likely have improved catch results.

Although the impacts of the breaching were evident, particularly with smelt appearing in Lake Kohangatera, recruitment of young fish in the upper catchment was slow. It did not become evident until two years after the breaching event in the case of giant kokopu, banded kokopu and longfin eels and was not detected in the shortfin eel population. Additionally only two redfin bullies were caught. This would be due the timing of the main breaching event which occurred in February. Although prolonged it did not coincide with the migration times of any of these species which migrate into freshwater in spring. Subsequent more frequent breachings do however appear to be improving recruitment of these species. Continued regular monitoring of the fish assemblage of the catchment in conjunction with the timing and frequency of lake breachings would help clarify the complex interactions between breaching and the fish community of a shallow coastal lake.

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3

Divergent fish assemblages in two Gollans Valley streams

INTRODUCTION

Fish assemblages are influenced by a number of complex interacting physical, geographical and biological factors (Jowett & Richardson 1996). The influence of structuring forces will vary, with biotic factors such as predation and competition being important forces in some streams and abiotic factors such as cover and depth in others (David et al 2002). In New Zealand, diadromy and the effects of elevation and migratory barriers have been found to have strong influences on fish distribution and abundance (Joy & Death 2000).

East Harbour Regional Park, administered by the Wellington Regional Council, is situated in the hills between Eastbourne and Wainuiomata. It comprises beech/rata forest with semi-swamp forest in the valleys including kahikatea, pukatea and nikau palms. Gollans Stream and its tributary Butterfly Creek originate within the park, Gollans Stream continuing down through an area of farmland and extensive wetlands to Lake Kohangatera, a coastal lake.

Lake Kohangatera is separated from the sea by a beach barrier that only occasionally breaches, consequently there is limited opportunity for the recruitment of diadromous fish into the catchment however both Gollans Stream and Butterfly Creek are reported to a have a significant endemic freshwater fish fauna (Gibbs 2002). These include banded kokopu (*Galaxias fasciatus*), giant kokopu (*Galaxias argentus*), longfin eels (*Anguilla dieffenbachii*) and redfin bullies (*Gobiomorphus huttoni*) and one introduced species; the brown trout *(Salmo trutta*) (New Zealand Freshwater Fish Database (NZFFD). Koaro *Galaxias brevipinnis* were also discovered to be present during this study. Both streams would appear to offer ideal habitat for these species (Fig 1&2); there is a high percentage of instream cover in the form of undercut banks and vegetation, and many pools and overhead cover. In my preliminary fish surveys, however, there appeared to be two distinctly different fish assemblages in Gollans Stream and Butterfly Creek and both streams had low fish density.

The first objective of this of study was to describe the fish communities of Gollans Stream and Butterfly Creek and determine if they differ. As stated, fish assemblages are influenced by diadromy, elevation, migratory barriers, biotic factors (such as predation and competition) and abiotic factors (such as width and depth). However the influences of diadromy, elevation and migratory barriers are the same for both streams (being in the same location and catchment) and with low fish densities, predation and competition are unlikely to be having any major influence. On the other hand abiotic factors such as cover and depth may be quite different in the two streams. The second objective therefore was to measure a variety of habitat variables in both streams and determine if they could account for any differences in the fish assemblages of Gollans Stream and Butterfly Creek

Fig. 1 Gollans Stream

Fig. 2 Butterfly Creek

their total length measured. They were then returned to the same reach they were captured from.

Spotlighting

In June 2004, May 2005 and December 2006 fish surveys were carried out for 200m on the same stretches of stream using the spotlighting technique. On both occasions two 75-watt Lightforce SL140 Lance spotlights were used and the streams surveyed by two observers walking slowly upstream on separate sides and scanning the water. As with electrofishing it was done in a continuous manner except where obstructions made it impractical. Fish detected were captured where possible, using a dip net, identified to species level and total length measured. Where the fish was unable to be caught a visual estimate of size was made. In addition an upstream site in both Gollans Stream (UG) and Butterfly Creek (UB)(Fig. 3) were spotlighted using the same technique over a 200m stretch in order to compare upstream and downstream fish assemblages.

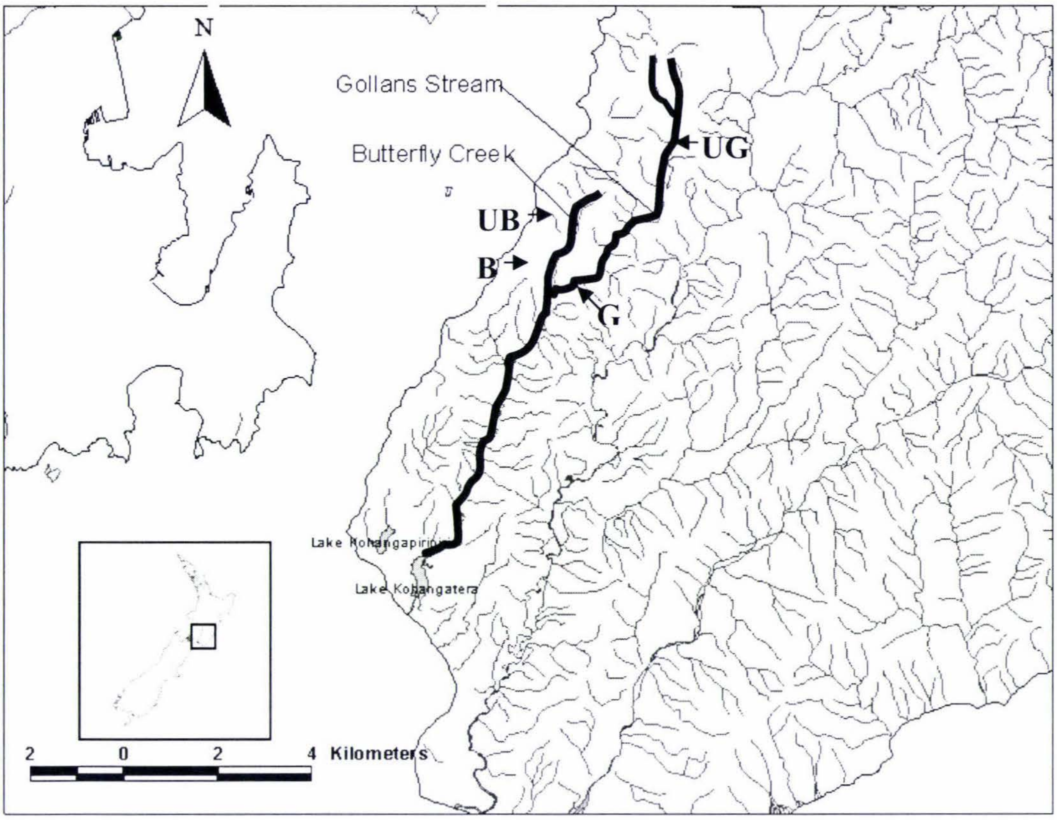


Fig. 3 A map of Pencarrow showing the location of Gollans Stream and Butterfly Creek sites: **B**=Butterfly; **UB**= Upper Butterfly; **G**=Gollans; **UG**=Upper Gollans.

Habitat Variables

Habitat variables were measured at the four fish survey sites: four 50m reaches along 'Gollans Stream' and 'Upper Gollans Stream' and four 50m reaches along 'Butterfly Creek' and 'Upper Butterfly Creek' (Table 1). Conductivity was measured using Eutech ECScan pocket meter and pH with a Eutech pH Testr 2. Sinuosity was calculated as the ratio of actual stream length to straight-line stream length. Channel shading, filamentous algae cover, undercut banks and the amount of periphyton and macrophytes were estimated visually and expressed as a percentage. Packing of cobbles was expressed as tight, moderate or loose from observation and pool/riffle/run make up of each stretch was again expressed as a percentage from visual observation. In addition 5 transects were taken (one every 10m along each 50m stretch) and wetted width, depth, depth of undercuts, the size of 5 cobbles and sediment type were recorded. Mean width was calculated from 5 measurements and mean depth of undercut, from 10 measurements at each site. The Wolman Walk method (Wolman 1954), using 50 cobble sizes (10 from each of the 5 transects) was used to assess average cobble size of the streambed. Assessment of sediment was calculated by taking the mean of 5 visual assessments classified as percentage of the following categories; fine organic, fine inorganic, leaves and sticks/logs at each site. Temperature loggers were placed in both streams however one was washed away during a storm leaving only data for Gollans Stream. For this reason temperature was omitted from analysis.

Table 1. Habitat and environmental characteristics of the four study sites in Gollans Valley

Study Sites [1]	Site B1	Site B2	Site B3	Site B4	UB1	UB2	UB3	UB4	G1	G2	G3	G4	UG1	UG2	UG3	UG4
pH	7.7	7.6	7.5	7.6	8.6	8.6	8.6	8.6	7.7	7.6	7.6	7.5	7.9	8	8	8.1
Conductivity (mS/cm)	479	480	480	477	343	343	343	343	295	297	297	295	178	178	178	178
Shading(%)	75	75	25	75	75	75	75	75	75	75	25	25	75	75	75	75
Filamentous Algae [2]	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Bryophytes [2]	1	2	2	2	2	2	2	2	2	1	2	1	2	2	1	1
Pac Cobble [3]	1	1	1	1	2	2	2	2	1	2	2	2	2	2	2	2
Sinuosity [4]	1.35	2.17	1.09	2.38	1.35	1.19	1.32	2.08	1.06	1.22	1.92	2.27	1.47	1.11	3.13	1.28
Stream stretch make up																
Pool (%)	10	50	60	30	50	45	50	50	0	10	15	70	50	50	40	20
Riffle (%)	30	10	20	10	10	5	10	5	50	45	50	15	10	10	30	40
Run (%)	60	40	20	60	40	40	40	45	50	45	35	15	40	40	30	40
Mean wetted width (m)	2.02	2.19	2.34	1.78	1.53	1.67	1.40	1.21	4.1	3.78	4.8	5.18	1.8	1.658	2	1.68
range	(1.5-2.7)	(1.65-3)	(1.75-2.8)	(1.1-2.1)	(0.59-2.45)	(1.2-2.4)	(0.79-2.1)	(0.591.75)	(3.7-4.7)	(3.2-4.6)	(3.3-11.7)	(1.8-7.3)	(1.1-2.6)	(0.34-2.25)	(1.75-2.45)	(1.35-2.1)
Undercut banks (%))	25	25	25	25	25	25	25	25	25	75	25	25	75.0	75.0	75.0	75.0
Mean undercut depth (cm)	7.4	4.05	10.1	11.9	12	5.2	3.5	4.3	10.2	7.8	9.9	15.2	10.5	7	1.7	4.5
range	(0-63)	(0-30)	0-34)	(0-27)	(0-32)	(0-24)	(0-15)	(0-29)	(0-27)	(0-50)	(0-30)	(0-35)	(0-35)	(0-23)	(0-5)	(0-16)
Mean stream depth (cm)	24.16	23.04	27.36	20.2	19.16	7.52	6.14	6.22	20.6	25.84	25.52	37.92	16	8.26	6	8
range	(1-50)	(3-57)	(6-63)	(1-52)	(0.5-59)	(0.5-34)	(0.5-14)	(0.5-14)	(5-48)	(1-89)	(1-68)	(1-68)	(1-51)	(1-26)	(0.5-31)	(0.5-17)
Median substrate size index [5]	2.459	3.0175	0.879	1.476	5.678	6.704	5.2575	6.837	3.3185	4.0665	3.827	5.3975	6.2075	5.2655	3.852	6.8125
Sediment type																
Fine organic detritus (%)	10	19.4	7.5	3.6	5.6	6.8	4.2	7.4	1.2	2.4	2.6	4.3	10	15	11.8	6.8
range	(5-25)	(2-35)	(2.5-12.5)	(2-5)	(1-10)	(4-15)	(3-5)	(2-15)	(1-5)	(0-5)	(0-5)	(2-7.5)	(0-20)	(5-40)	(5-30)	(2-15)
Fine inorganic detritus (%)	23	11.5	23	8.4	2.8	3.4	7.2	5.6	3.6	3	7.4	9.9	7.2	15.4	14.4	12.4
range	(15-35)	(5-20)	(10-40)	(2-15)	(1-7)	(2-5)	(4-10)	(3-10)	(2-5)	(2-5)	(2-15)	(3-20)	(3-15)	(7-20)	(5-25)	(7-20)
Leaves (%)	6.1	9.4	5.4	2.2	3.7	7.2	9.6	11.0	1	1.2	2.6	2.2	4.4	9.8	8.4	5.4
range	(3-10)	(2-15)	(2-10)	(1-2)	(1-10)	(3-10)	(1-15)	(5-20)	(0-5)	(0-5)	(0-10)	(1-5)	(2-15)	(2-20)	(2-20)	(1-10)
Sticks/logs (%)	7.7	18.4	10	4.2	5	5	5.4	9.8	2.2	5	6.4	7	4.6	7.2	7.6	4.8
range	(1-15)	(2-35)	(7.5-15)	(3-5)	(2-10)	(3-7)	(2-10)	(2-15)	(1-15)	(0-15)	(2-15)	(3-12.5)	(2-10)	(2-10)	(3-15)	(1-7)

1 B= Butterfly Creek; UG= Upper Butterfly Creek; G=Gollans Stream; UG= Upper Gollans Stream sites

2 Visually assessed (0 =absent; 3 =abundant)

3 Subjectively assessed at site after moving substrate (1=loosely packed; 4= tightly packed)

4 Actual length of stream over 50m/50m in a straight line

5 50 stones were collected using the Wolman walk method and the index calculated (Wolman 1954)

Statistical analysis

Differences in fish habitat between the streams were visualized using Non-metric Multidimensional Scaling (NMS) using the covariance matrix (PC Ord version 5) (McCune and Mefford (200*). In addition median values were compared using Tukey's non-parametric multiple range tests (SAS 2000) to identify any significant variation in fish assemblages and habitat variables between the streams, with the significance level set at 5%.

RESULTS

Fish composition

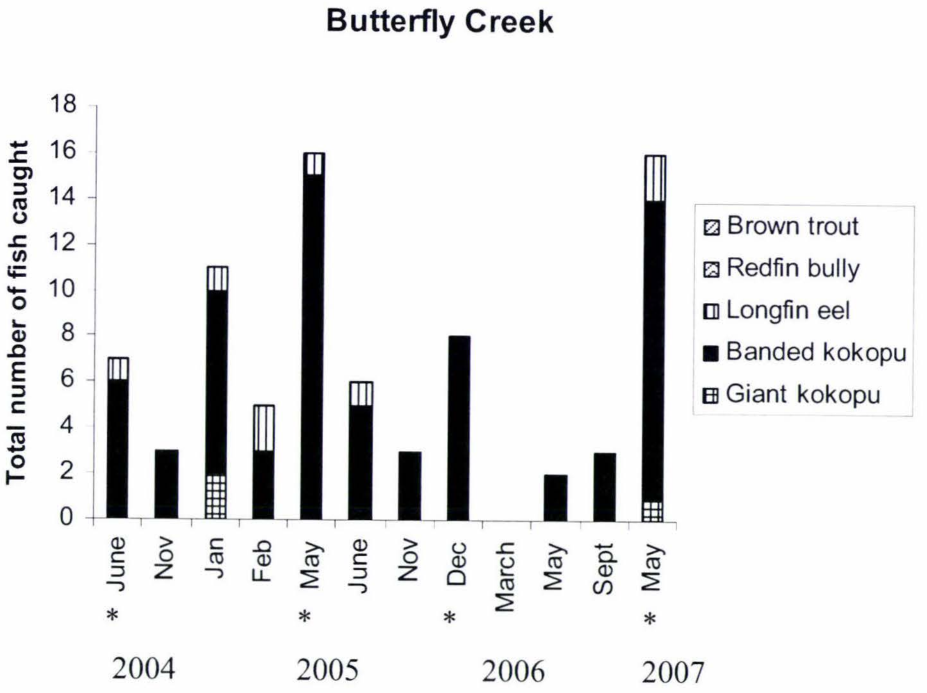
A total of five fish species were detected in the lower catchment, four native species; giant kokopu, banded kokopu, longfin eel and redfin bully and one introduced species; the brown trout. All five species were present in Gollans Stream however just three species were found in Butterfly Creek (Table 2). The Gollans stream community was dominated by longfin eels (46% of total catch), giant kokopu (21%) and banded kokopu (20%). Its tributary, Butterfly Creek had a fish community dominated by banded kokopu, which made up 88% of fish recorded. Two giant kokopu and 6 longfin eels were the only other fish caught at site 'B' in Butterfly Creek throughout the duration of the three-year study (Fig 2). The upper Butterfly Creek site "UB' continued to be dominated by banded kokopu (81% of catch) whilst the upper Gollans Stream site 'UG' still exhibited greater diversity with the addition of koaro to the fish assemblage and the disappearance of both brown trout and redfin bully (Table 2). Tukey tests confirmed a significant difference

($P<0.05$) between fish density for all species apart from the redfin bully in the two streams (Fig 5).

Table 2: Percentage catch of fish caught in Butterfly Creek and Gollans Stream by Electric Fishing Machine/ nightspotting during 2004 - 2007 fish surveys; B= Butterfly Creek, UB= Upper Butterfly Creek,G=Gollans Stream, UG=Upper Gollans Stream

Common Name	Scientific Name	B N=48	UB N=16	G N=65	UG N=35
Giant kokopu	*Galaxias argentus*	3	6	21	9
Banded kokopu	*Galaxias fasciatus*	88	81	20	23
Koaro	*Galaxias previpinnis*	0	0	0	23
Longfin eel	*Anguilla dieffenbachii*	9	13	46	46
Redfin bully	*Gobiomorphus huttoni*	0	0	2	0
Brown trout	*Salmo trutta*	0	0	11	0

The number of fish caught during each fish survey in the lower catchment (sites B & G) varied widely and was generally very low (Fig 4). The highest numbers of fish caught per stream on any one occasion in the lower sites ('B' was 'G') was 16 over a 200m stretch in Gollans Stream in June 2004 and 16 in Butterfly Creek in May 2005. The lowest was just one fish, a longfin eel, caught in Gollans Stream in June 2005 (Butterfly Creek was not fished during the March 2006 survey because of a problem with the electric fishing machine). From November 2005 to September 2006 banded kokopu were the only species caught in Butterfly Creek. Fish densities appeared to be higher in the upper Gollans Stream and Butterfly Stream sites. These were only surveyed on the one occasion in May 2007 but in Gollans Stream 35 fish were detected over a 200m stretch and in Butterfly Creek 16 fish were detected.



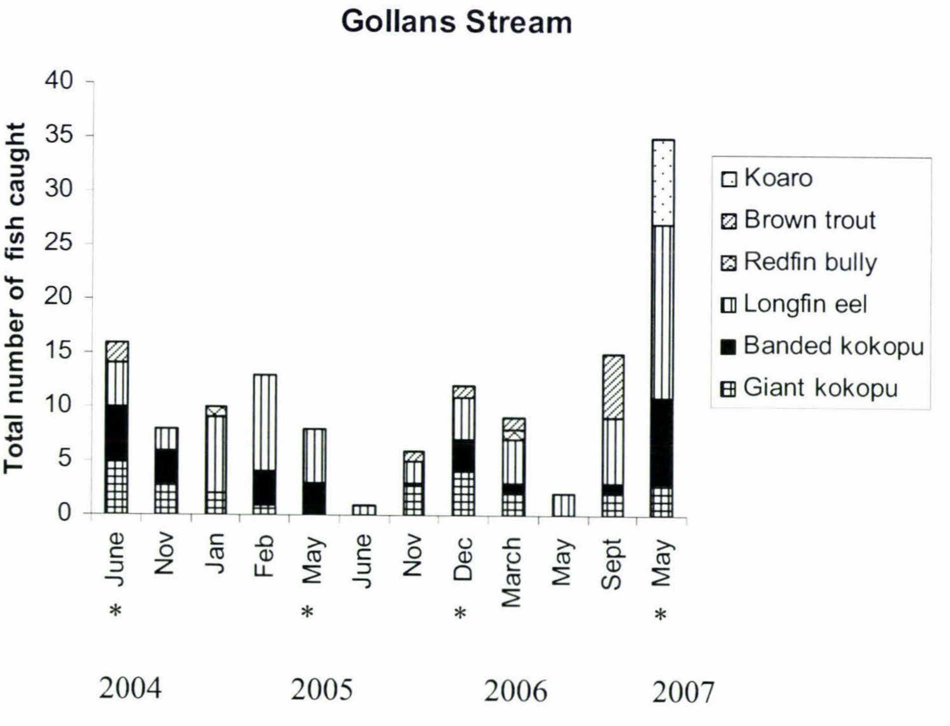


Fig.4 The total number of fish caught in Butterfly Creek and Gollans Stream by electro-fishing/spotlighting between June 2004 and May 2007.
* Spotlighting data

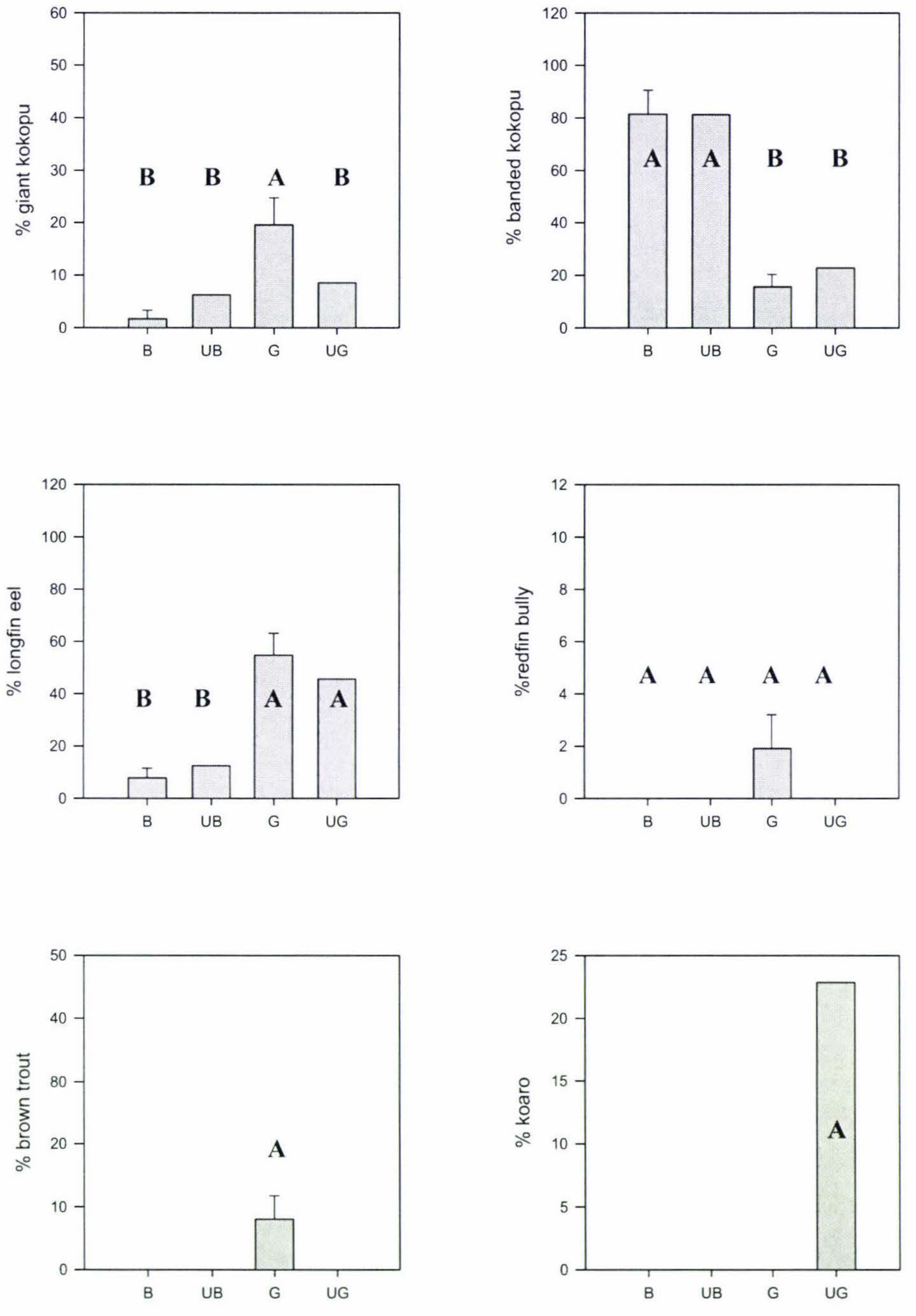


Fig 5 Bar graphs showing the differences in fish assemblage between Gollans Stream and Butterfly Creek. Different groupings indicate a significant difference between medians compared using Tukey's multiple range tests (SAS 2000). Error bars indicate standard error.

Habitat Comparison

The NMS ordination of habitat variables showed a clear separation of the four stream sites (Fig. 6). The most significant variable in separating Butterfly Creek from Gollans Stream was conductivity. Butterfly Creek had high conductivity (B=479mS/cm, UB= 343mS/cm), almost double that of Gollans Stream (G=296mS/cm, UG=178mS/cm).

Despite significantly different fish assemblages in the two streams the Tukey Groupings (Fig 7) clearly demonstrate the similarity of habitats shared by the upstream Gollans Stream site and both upstream and downstream sites of Butterfly Creek. These sites are grouped together for wetted width, amount of shading, pool, fine organic detritus and leaves. Further Upper Gollans shares a grouping with Upper Butterfly for depth, cobble size and packing of cobbles. All four sites shared a grouping for depth of undercut, detritus in the form of sticks and logs, sinuosity and percentage run. Lower Gollans was separated from all three other sites by greater wetted width, depth and slightly lower average pH and percentage shading. The upstream sites of both streams were separated from the lower sites by greater average cobble size and tighter packing of substrate. Conductivity separated all sites although both Butterfly Creek sites had the highest readings.

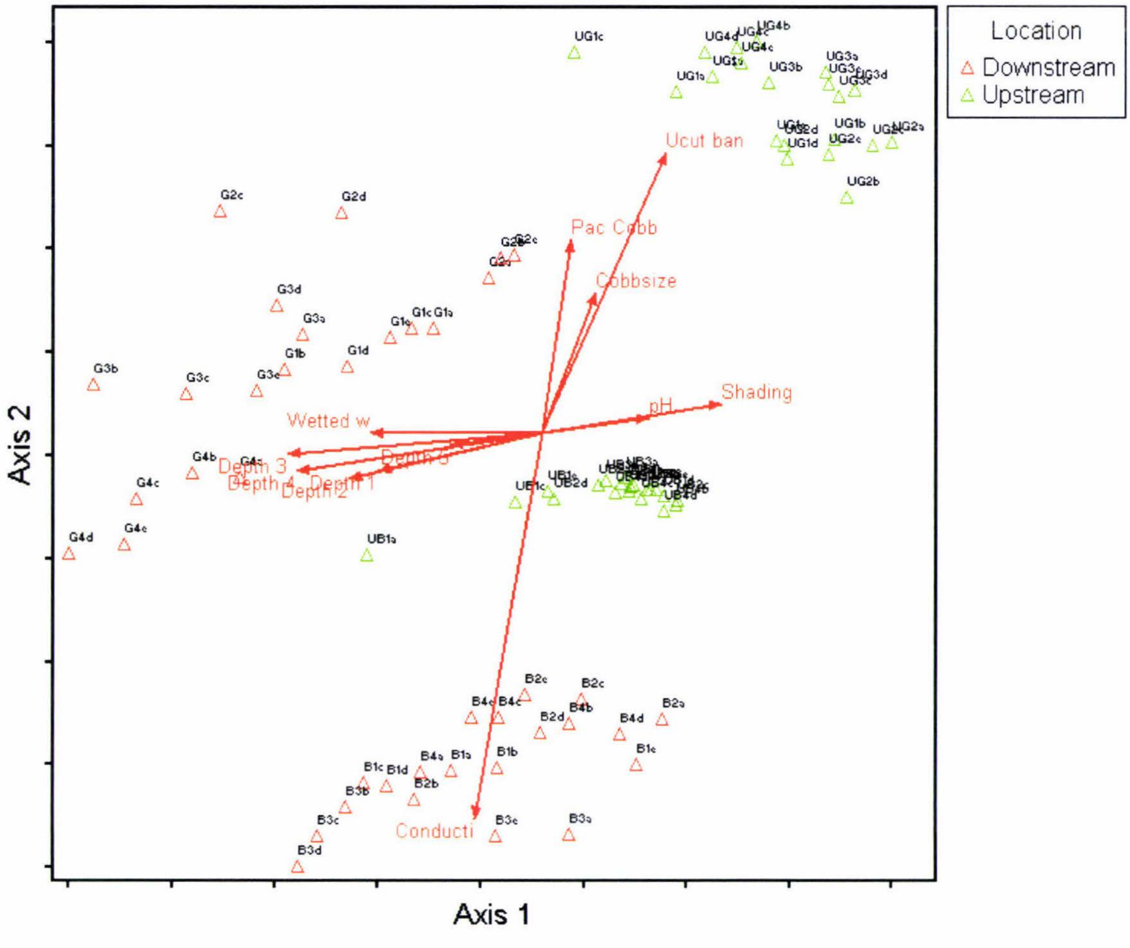


Fig. 6 Graph of NMS (using the distance measure correlation PC Ord version 5 (McCune and Mefford (200*)) depicting the relative significance of measured habitat variables in separating Butterfly Creek and Gollans Stream sites.

Butterfly Creek (Sites B1 – B4, five replicates a,b,c,d,e); Upper Butterfly Creek (Sites UB1 – UB4, five replicates a,b,c,d,e); Gollans Stream (Sites G1 – G4, four replicates a,b,c,d,e); Upper Gollans Stream (Sites UG1 – UG4, four replicates a,b,c,d,e).
Habitat Variables: Ucut ban = Depth of bank undercut, Pac Cobb= tightness of cobble packing, Cobbsize= size of cobbles, Shading= percentage of stream shaded, Wetted w= wetted width, Depth1,2,3,4,5= depth of stream taken at 5 points across a transect, Conducti = conductivity.

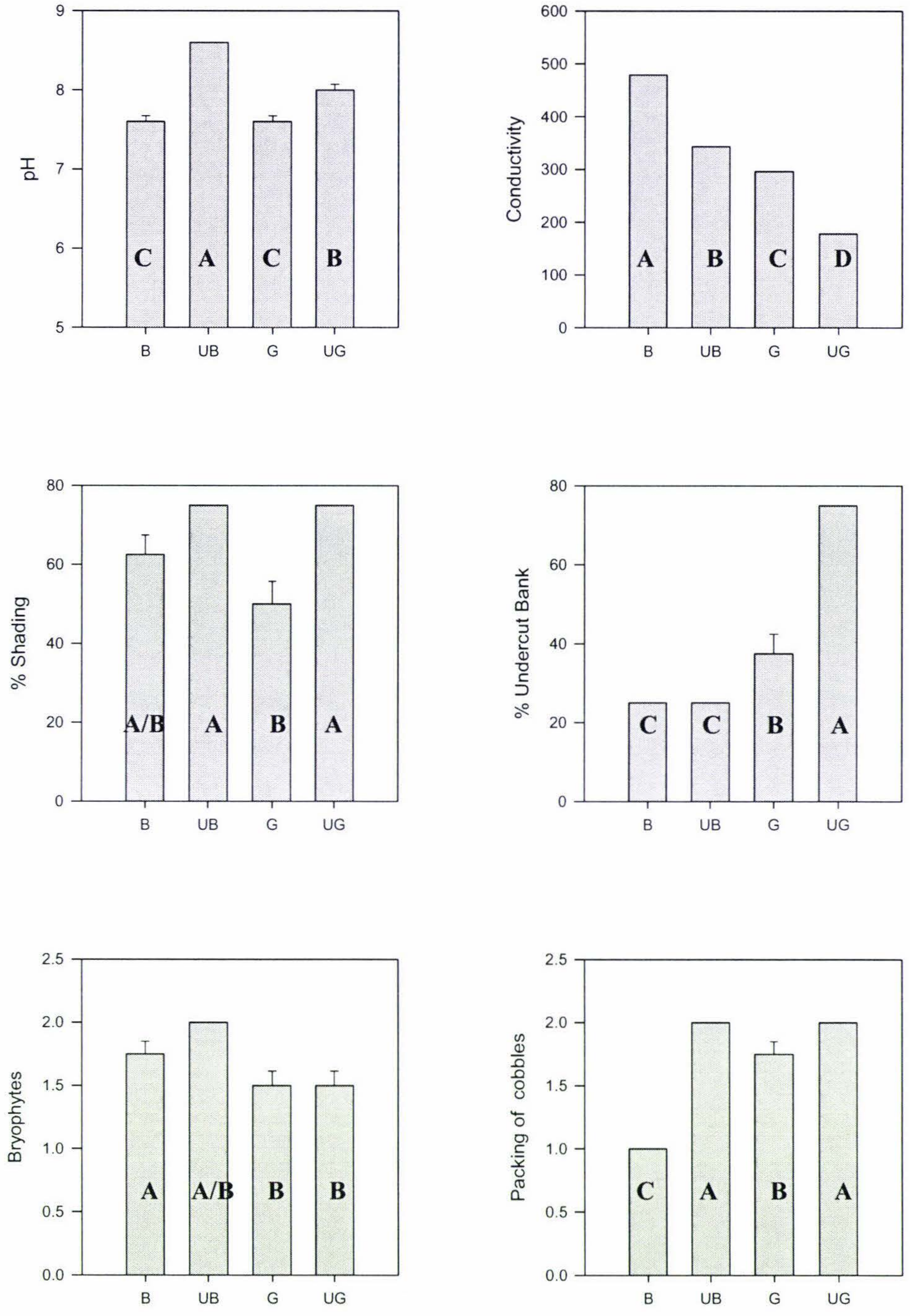


Fig 7 Bar graphs showing the differences in environmental variables between Gollans Stream and Butterfly Creek . Different groupings indicate a significant difference between medians compared using Tukey's multiple range tests (SAS 2000). Error bars indicate standard error.

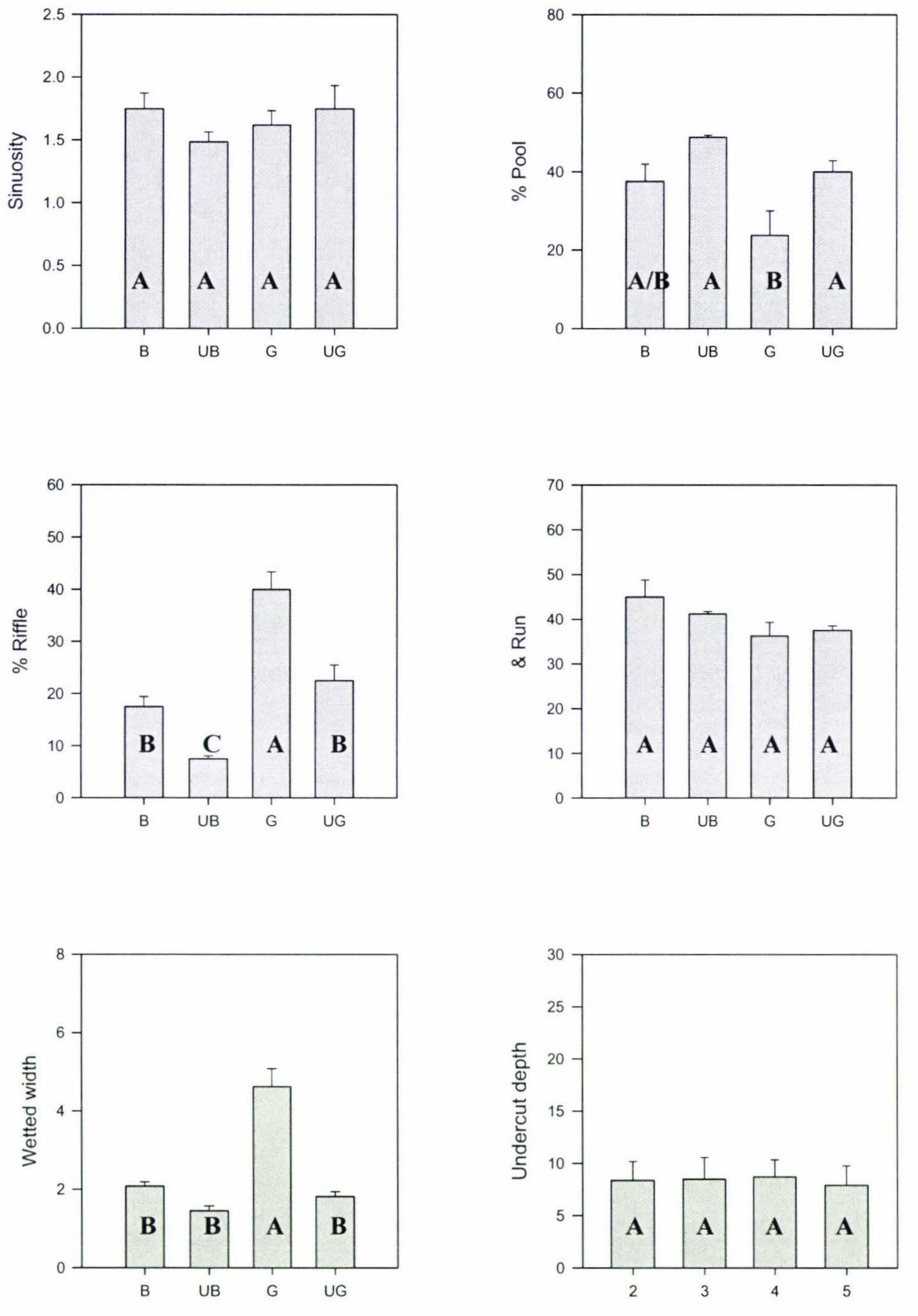


Fig 7(continued)

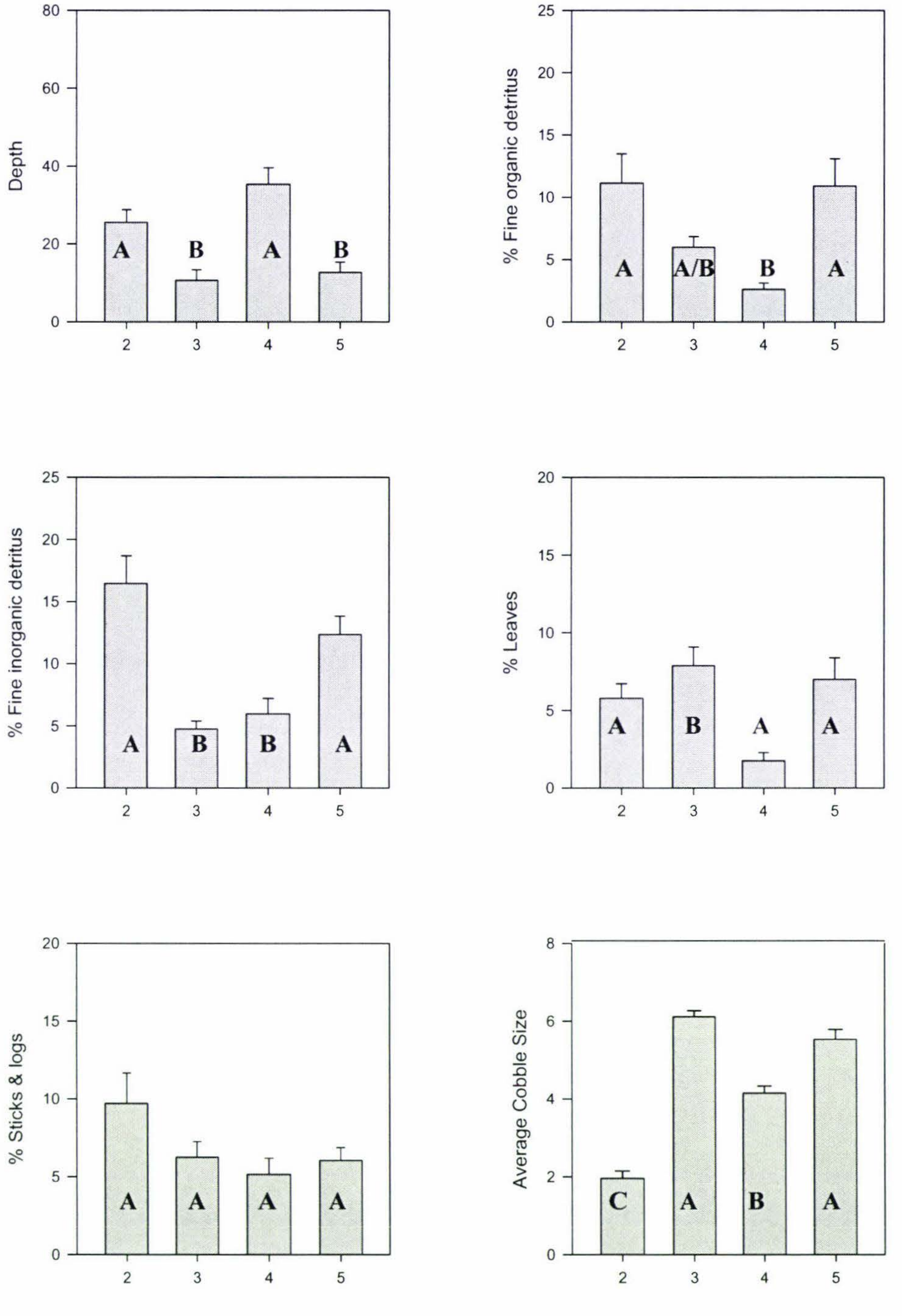


Fig 7 (Continued)

DISCUSSION

Electro-fishing was chosen as the main fishing method. While not effective in water deeper than 0.5m (Jellyman 2006), has been found to be the most effective fishing method for the greatest size range and number of species and provides estimates of abundance (Jowett and Richardson 2003). Gollans Stream and Butterfly Creek are first and second order streams are small with only a few deep pools and therefore suitable for electro-fishing. Problems did occur with detecting fish that were taking cover beneath undercut banks. While eels tended to be stunned and float out from cover, suspected giant and banded kokopu did not exhibit such a strong reaction to the electric current. Bonnett (2000) found that catch efficiency for giant kokopu using an electric fishing machine was low. For this reason spotlighting was also utilised.

Spotlighting was found to be useful in detecting both giant kokopu and banded kokopu firstly because of their nocturnal nature (David et al 2003) and secondly because the large amount of undercut bank available in both streams made electro-fishing for these species difficult. During the day both species tended to be hiding in undercuts or under debris and although often detected would swim deep under cover where they were inaccessible to the electro-fishing machine or would be stunned and trapped beneath the cover they were utilising. However at night they tended to be out in the pools and were readily detected with the spotlight. While spotlighting has been found to be less efficient in detecting juvenile fish (40-70mm) as they are less conspicuous (David et al 2002) and tends to underestimate species abundance in riffles, it was a useful tool to augment the electro-fishing results and more effective than electro-fishing in detecting giant and banded kokopu. Jellyman (2006) found fyke netting to be the most effective method of capturing giant kokopu in deeper water, however the Gollans Valley is only accessible by foot over steep terrain and after initial trials it was discarded as impractical because of the difficulty of transporting large heavy nets to and from the site.

The wide variation in fish counts between sampling events during this study may be partially explained by fish movement in and out of the sampling area. It was evident during the study that the larger more conspicuous giant kokopu periodically relocated to new home reaches. Several studies have found that giant kokopu remain within defined stream reaches during base flow conditions (David & Stoffels 2003; David & Closs 2003; David & Closs 2002). However they have been shown to move extensively during flood events (David & Closs 2002) with some exhibiting homing instincts and returning to their former territories while others relocate permanently. Banded kokopu also show strong pool fidelity (West et al 2005; Rowe & Smith 2003) but the adults are poor swimmers and are easily dislodged during high flows where adequate cover is unavailable (Rowe & Smith 2003; Main 1988). Weather patterns during the three-year study were particularly unsettled and marked by numerous flooding events and may explain this movement.

The fish fauna of Butterfly Creek and Gollans Stream were found to be distinctly different even where available habitat was almost identical. Banded kokopu dominate the fauna of Butterfly Creek with just two other species present; giant kokopu in very low numbers and longfin eel. While banded kokopu are found throughout the length of Gollans Stream, here they are part of a more diverse and evenly distributed fish assemblage of giant kokopu, banded kokopu, redfin bully, brown trout, koaro and longfin eel. Other studies have found banded kokopu presence positively related to small streams with plenty of cover (in the form of woody debris and undercut banks), pool habitat and a closed forest canopy (Rowe et al 1992; Jowett et al 1996; Rowe & Smith 2003, Baker & Smith 2007). The NZFFD of fish assemblages throughout New Zealand show that banded kokopu are found in small streams. Smaller streams provide more stable habitat with protection against flood events, essential for the banded kokopu, which relies on a strategy of low egg production over many years (Rowe & Smith 2003). While both streams have plenty of cover, pools and undercut banks Butterfly Creek is significantly smaller than Gollans Stream in the vicinity of their confluence and hence may be more attractive to banded kokopu in this area. However, the upper reaches of Gollans Stream, where it could also be classified as a small stream, would be expected to be equally attractive to banded kokopu and have a similar fish assemblage dominated by this species. However in the upper reaches of Gollans Stream, where habitat was almost identical (including wetted width) to both Butterfly Creek sites, the divergent fish assemblage persisted. Distance from the sea and gradient are environmental variables also strongly correlated to fish distribution (Hayes et al 1989; Jowett & Richardson 1995; Jowett et al 1996; Chadderton & Allibone 2000; Joy& Death 2004) but as both Butterfly Creek and Gollans Stream are coastal, of low gradient and only penetrate inland approximately 10kms and 14km respectively their effect would be negligable.

It is unclear why the Butterfly Creek fish fauna is dominated by banded kokopu. Previous studies may offer some explanation. Baker & Montgomery (2000) demonstrated that the whitebait of banded kokopu have a species-specific attraction to adult banded kokopu pheromones during migration, and that this is possibly a basis for river selection. Although Gollans Stream does have banded kokopu they are at much lower densities and hence may not be have such a strong attraction to the juveniles of the species migrating up from the lake/sea. (Interestingly, Montgomery's study found that high levels of banded kokopu pheromones had a negative effect on banded kokopu migration. Although Butterfly Creek had higher densities of banded kokopu then Gollans Stream they could not be regarded as high enough for this to occur). Studies have found banded kokopu presence to be negatively related to the presence of longfinned eel (Hanchet 1990, Rowe & Smith 2003) which dominate the Gollans Stream fish fauna. Again longfinned eels are present in Butterfly Creek but at much lower densities and, consequently would pose less detraction.

Equally puzzling however is the question of why longfin eel, giant kokopu and trout are absent or in low numbers in Butterfly Creek. All are generalist feeders (McDowall 2000; McDowall 1989; Bonnett & Lambert 2002) and both trout and eel have a widespread distribution throughout New Zealand in a wide range of habitats including small streams (McDowall 2000; McDowall 1989). Banded kokopu habitat is commonly associated with giant kokopu habitat (Jowett et al.1998; Bonnett et al 2002). Giant kokopu are often found in small streams and prefer slow moving water with abundant cover (McDowall 1990: Bonnett et al 2002). In a study on the habitat requirements of giant kokopu Bonnett

& Sykes (2002) identified five important habitat features: in-stream cover, deep water, low water velocity, proximity to the sea and overhead shade/riperian cover. Butterfly Creek fulfills all these requirements only differing from Gollans Stream significantly in the form of cover available (Gollans Stream having significantly more cover in the form of undercuts). Baker & Smith (2007) found the features that discriminate banded kokopu and giant kokopu habitat are elevation, habitat size and riparian cover, banded kokopu tending to be found at higher elevations, in smaller pools with a higher percentage of riparian cover. Again these findings fail to explain the divergent assemblage in these two Gallans Valley streams. Koaro was another species present in the upstream site of Gollans Stream but absent from the upstream site in Butterfly Stream with almost identical habitat

The most significant habitat difference between the two streams was conductivity, which averaged 411 mS/cm in Butterfly Creek compared to 237 mS/cm in Gollans Stream. The higher conductivity of Butterfly Creek is unexpected considering the streams close proximity to one another in valleys of identical geology. It is possible that strong southerly winds that funnel up the valleys periodically from the Cook Straight with salt laden air have a greater effect on Butterfly Creek because it is contained within a much shorter valley than Gollans Stream. Also Butterfly Creek is more coastal, running parallel to the Wellington Harbor coastline again making it more exposed to salt laden air than Gollans Stream. Banded kokopu may be more resistant than other fish species to high conductivity levels allowing them to dominate the Butterfly Creek fish fauna. Other fish species may be repelled by the high conductivity. Both questions require further investigation.

In conclusion the divergent fish assemblages of Butterfly Creek and Gollans Stream reflect the variety of different biotic and abiotic habitat variables that influence fish assemblages and the difficulties of identifying the structuring forces behind them. Whilst studies that indicate habitat preferences of different species such as the banded kokopu and the giant kokopu are useful in identifying preferred habitat on the geographical scale, diversity within a small catchment such as Gollans Valley can vary according to different factors acting on a much smaller scale.

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4

Distribution patterns of fish in the streams of Gollans Valley.

INTRODUCTION

A high level of diadromy in the native fish fauna of New Zealand has implications on the longitudinal distribution of fish. Diadromy has played a vital role historically and in the present day in the dispersal and recolonisation of catchments following perturbation events such as volcanism, drought and flood (McDowall 1996). More than half of the 35 recognised species are diadromous (McDowall 1998). As a result diversity and abundance generally decrease with distance from the sea (McDowall 1993, Joy & Death 2000). Lowland streams and estuaries, as the interface of fish migration, tend to exhibit the greatest concentration and diversity of native fish. Here, fish with low ability or drive to penetrate inland, as well as good climbers which are capable of penetrating further will be found. Inland and at higher altitudes communities tend to have low diversity and are composed of non-migratory species and diadromous species with climbing ability (Jowett & Richardson 2003).

The colonisation of New Zealand has had a severe impact on its freshwater ecosystems. Extensive deforestation of lowland areas has occurred. It is estimated that only 15% of pre-human lowland forest remains intact. This along with drainage of wetlands, damming of rivers for hydro-electric power, reshaping of river channels and the introduction of exotic fish has meant most New Zealand lowland streams and rivers are now highly modified (Chadderton & Allibone 2000). Barriers to fish migration such as dams, river diversions and wetland drainage, competition with introduced species and the huge loss of loss of habitat caused by deforestation, drainage and pollution have left New Zealand's native fish highly restricted and fragmented in their distributions.

Catchment land use has been found to strongly influence fish communities. Shortjaw kokopu (*Galaxias postvectis*) and koaro (*Galaxias brevipinnis*) have been found strongly associated with native forest (Minns 1990, Jowett *et al* 1996, McDowall 1997) and banded kokopu with native and exotic forest (Hanchett 1990, Swales & West 1991, Hicks & McCaughan 1997, Rowe *et al* 1999). In contrast pasture catchments tend to contain high densities of eels (Hicks & McCaughan 1997, Rowe *et al* 1999) and inanga (*Galaxias maculatus*) (Rowe *et al* 1999, Jowett & Richardson 2003). For example the Oroua River and Rangitikei River, which are modified for most of their length, have high numbers of eels, low numbers of galaxid species and no redfin bullies (*Gobiomorphus huttoni*) (Joy 1998, Lewis & Hamer 2004).

Essential to our understanding of native fish communities is the finding of fish distribution patterns prior to anthropological influences. Historical records of New Zealands fish fauna are sparse, with over half today's recognised species not being described until after 1935 (McDowall 2000). Any lowland areas that remain unmodified provide a valuable insight into natural distribution patterns and the mechanisms behind them. In a study of an unmodified stream on Stewart Island Chadderton & Allibone (2000) found that the galaxiid species giant kokopu (*Galaxias argenteus*), banded kokopu (*Galaxias fasciatus*) and koaro had an extensive distribution using a wide variety of habitat, suggesting that native fish have been excluded from habitat in other areas of New Zealand by the loss of riparian vegetation and the introduction of exotic fish, particularly salmonids. Jowett et al (1998) studyed unmodified streams in Kahurangi National Park, and established that "in the smaller streams "galaxiid communities were encountered more frequently than in similar sizes steams in other parts of New Zealand".

Despite its proximity to Wellington, the capital city of New Zealand, the Gollans Valley catchment, as described in Chapter 1, remains largely unmodified, providing an invaluable opportunity to study native fish distribution *in situ.* Because of rare intermittent breechings of Lake Kohangatera to the sea there have been limited opportunities for the migration of fish within the catchment however some of the species in the catchment are known to be capable of forming self-sustaining landlocked populations. These include koaro, giant kokopu, banded kokopu, common bully (*Gobiomorphus cotidianus*) and brown trout (*Salmo trutta*). The remaining species are not known to form landlocked self-sustaining populations and include longfin eel (*Anguilla diffenbachii*), shortfin eel (*Anguilla australis*) lamprey, redfin bully (*Gobiomorphus huttoni*) and inanga (*Galaxias maculatus*). Inanga do form self-sustaining landlocked populations in Australia and South America but to date there are no confirmed records of such populations within New Zealand.

Whole catchment distribution studies are very uncommon, thus, this study gives a rare insight into fish distribution over an entire catchment. The aim of this chapter was to describe in detail the distribution of each of the species longitudinally through the catchment from the lake to the headwaters. The only gap in this analysis was a privately owned section of approximately 4km in length, in the lower part of Gollans Stream, where access was not allowed. Historical records were utilised as an indication of what species would be present in this area.

Study Area

The study was carried out on the two streams draining the Gollans Valley; Gollans Stream and its tributary, Butterfly Creek as described in Chapter 2. Gollans stream originates on the slopes of Mount Lowry (373m) 14kms from the sea and its tributary, Butterfly Creek, originating near Mt Hawtrey (343m) 10kms from the sea (Fig 1). The upper reaches of Gollans Stream (approximately half its length) runs through unmodified native forest to a point just below its confluence with Butterfly Stream where it runs through an area of farmland with low intensity grazing and then wetlands before entering Lake Kohangatera. Butterfly Creek has intact native riparian vegetation throughout its length.

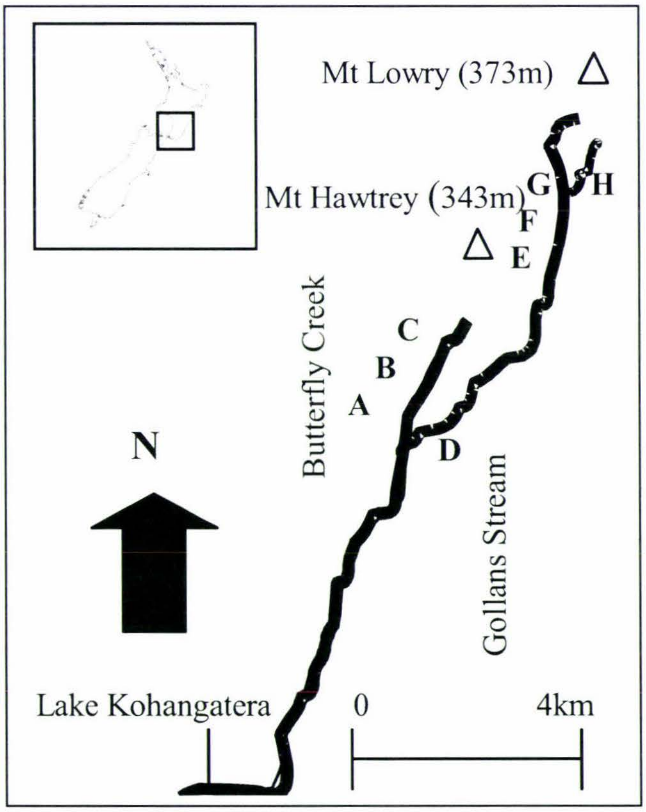

Fig. 1 Gollans Stream and Butterfly Creek showing the location of spotlighting sites (A-G).

Historical Records

Because permission could not be obtained to sample the lower reaches of Gollans Stream, which run through private land, this study was restricted to the upper two thirds of the catchment. However a report produced in 1987 by the Wellington Acclimitisation Society (Smith 1987), when there was a proposal to utilise the wetlands of Gollans Valley for tertiary treatment of sewage effluent, was used to give an indication of fish assemblages in this area. This study covered ten sites (Fig 2), and involved the use of a generator powered pulsed DC electric fishing machine (EFM) or a portable backpack EFM. All sites were assessed using a single pass. Fish numbers were classified according to relative abundance (i.e. present, common or abundant).

Spotlighting

Spotlighting was selected as the most suitable method of sampling the upper reaches in light of the high numbers of banded and giant kokopu in the streams and the comparative efficiency of spotlighting versus electro-fishing in detecting these species (refer Chapter 2). Eight sites were surveyed in total, three along the length of Butterfly Stream and five along the length of Gollans Stream from the point where the two streams meet. All sampling was conducted using 75-watt Lightforce SL140 Lance spotlights with two observers walking slowly upstream scanning the water ahead of them for fish. The streams were surveyed for 200 metres in a continuous manner at each site. Fish surveys were conducted once at each site at base flow conditions in April and May 2007 apart from sites 'A' and 'D' where results were taken from the fish survey done from June 2004 to September 2006 (where sites were sampled on several occasions approximately three monthly) for Chapters 1 & 2. All fish detected were captured where possible using a dip net, identified to species level and total length for each fish was measured.

RESULTS

Fish Species Composition

Including the historical records of the report produced in 1987 by the Wellington Acclimitisation Society (Smith 1987) for the lower catchment of Gollans Stream and the NZFFD, a total of nine species of fish have been recorded in Gollans Valley (Tables 1 & 2). Eight of these are native: longfin eel, shortfin eel, common bully, redfin bully, inanga, banded kokopu, giant kokopu and koaro. One exotic species; brown trout was recorded (giant bully were also recorded in the Acclimatisation Society report but have been excluded from the results of this survey as they were not found in the catchment throughout the three year duration of my field work in the area and not that far inland in any other study and could have easily been confused with common bully).

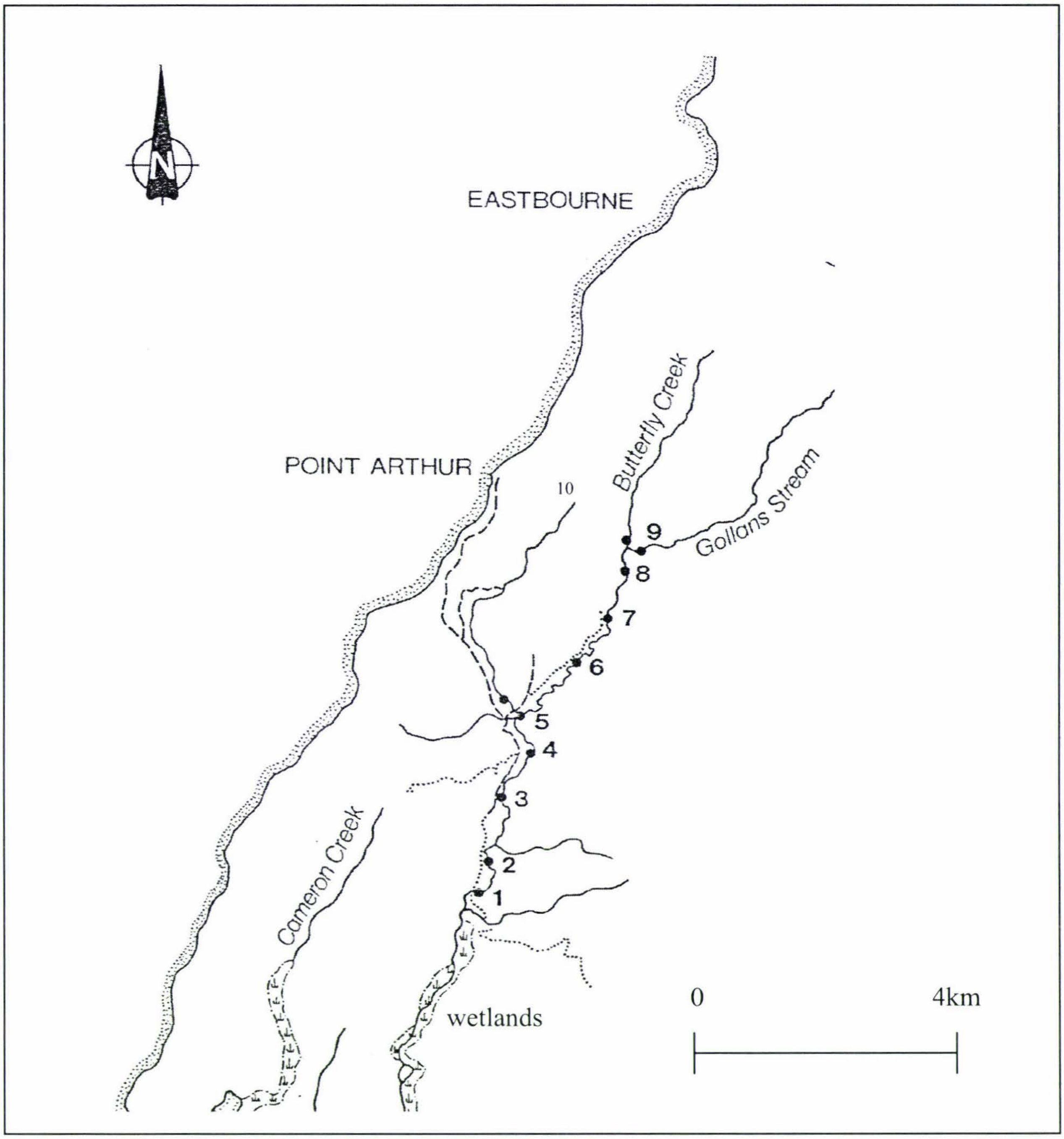

Fig 2 Sites (1-10) sampled by Acclimitisation Society reprinted from Smith 1987

Table 1: Historical record of fish in lower reaches of Gollans Stream: Wellington Acclimitisation Society (Smith 1987) P=Present, C=Common

	Site									
Common name	1	2	3	4	5	6	7	8	9	10
Inanga	P		P	C						
Common bully	P	P	P	P	P	P	P	C		
Longfin eel	P	C	C	C	C	C	C	C	C	C
Shortfin eel	P	P	P	P						
Redfin bully		P			C	C	C	P		
Giant bully			P		P		P		P	C
Banded kokopu							P			
Giant kokopu									P	
Brown trout									P	

Table 2: Total number of fish caught in Butterfly Creek and Gollans Streams in A 2007 spotlighting surveys.
* results taken from 2004-2006 fish surveys (refer Chapter 2)

	Site									Size Range
Common Name	A*	B	C	D*	E	F	G	H	Total	(mm)
Banded kokopu	56	13	7	19	1	8	0	1	105	30-280
Longfin eel	6	2	15	44	10	16	6	3	102	60-1000
Giant kokopu	2	1	1	20	1	3	0	0	28	110-390
Brown trout	0	0	0	10	0	0	0	0	10	35-450
Redfin bully	0	0	0	2	0	0	0	0	2	45-75
Koaro	0	0	0	0	14	8	10	0	32	60-170

Longitudinal distribution of fish

The longitudinal distribution and abundance of fish species within Gollans Valley showed a distinctive pattern according to species (Fig 3). The fish fauna of Butterfly

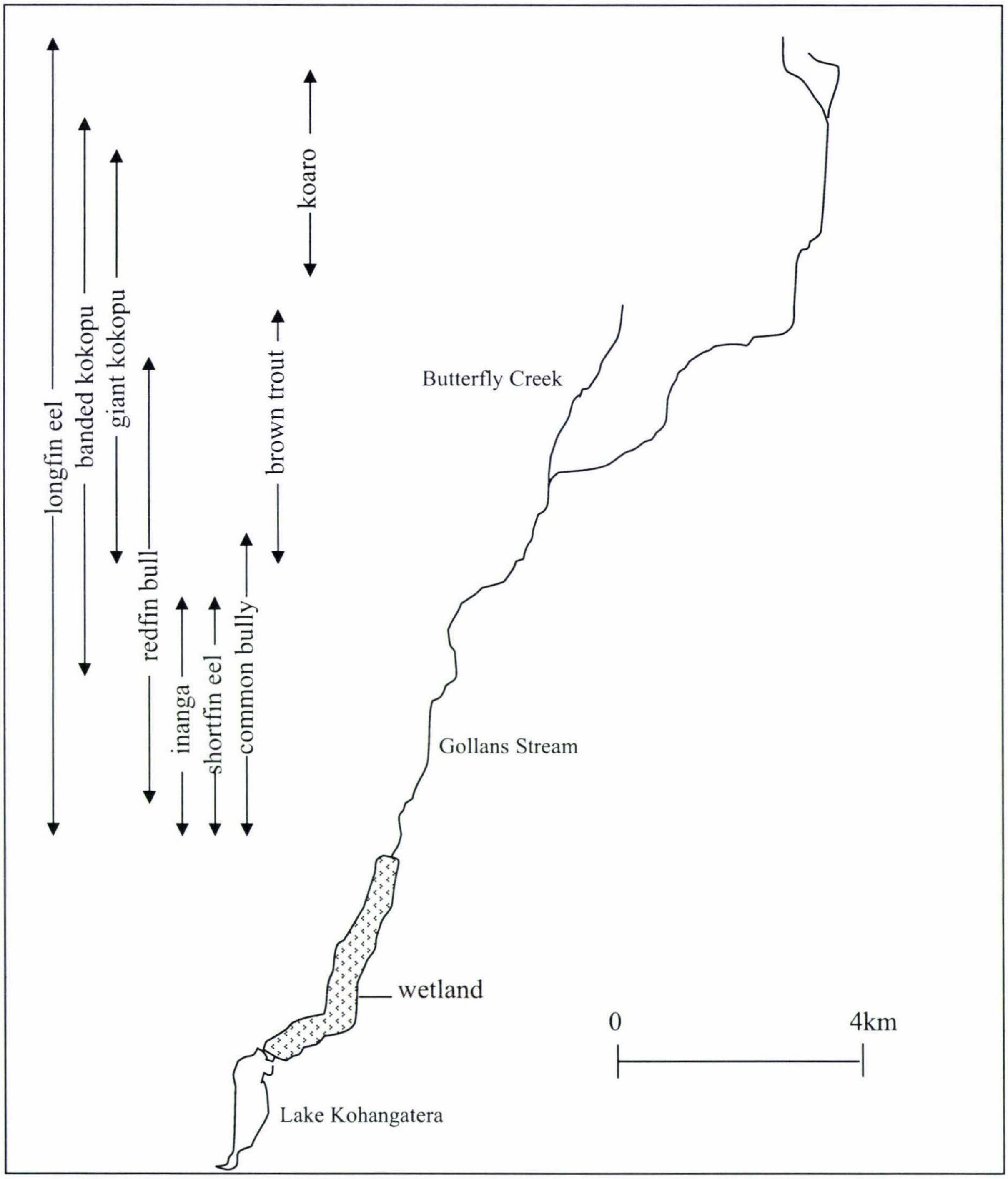

Fig 3 Longitudinal distribution of fish species in the streams of the upper half of Gollans Valley.

Creek was dominated by banded kokopu with just two other species recorded; longfin eels and very low numbers of giant kokopu. These three species were present at all sites surveyed along its length. In contrast, the number of species present in Gollans Stream declined with distance from the sea, the lower reaches had 8 species recorded: redfin bully, common bully, longfin eel, shortfin eel, inanga, giant kokopu, banded kokopu and brown trout, the mid reaches 5 species (Site D); giant kokopu, banded kokopu, longfin eel, redfin bully and brown trout and the upper reaches just 2 species; longfin eel and koaro (Site F). Thus inanga, shortfin eel, common bully, and redfin bully were confined to the lower end of Gollans Stream, giant kokopu, banded kokopu and longfin eel had an overlapping distribution throughout its length and koaro (previously unrecorded within the catchment) were only present in its headwaters. Brown trout were only present in the middle reaches.

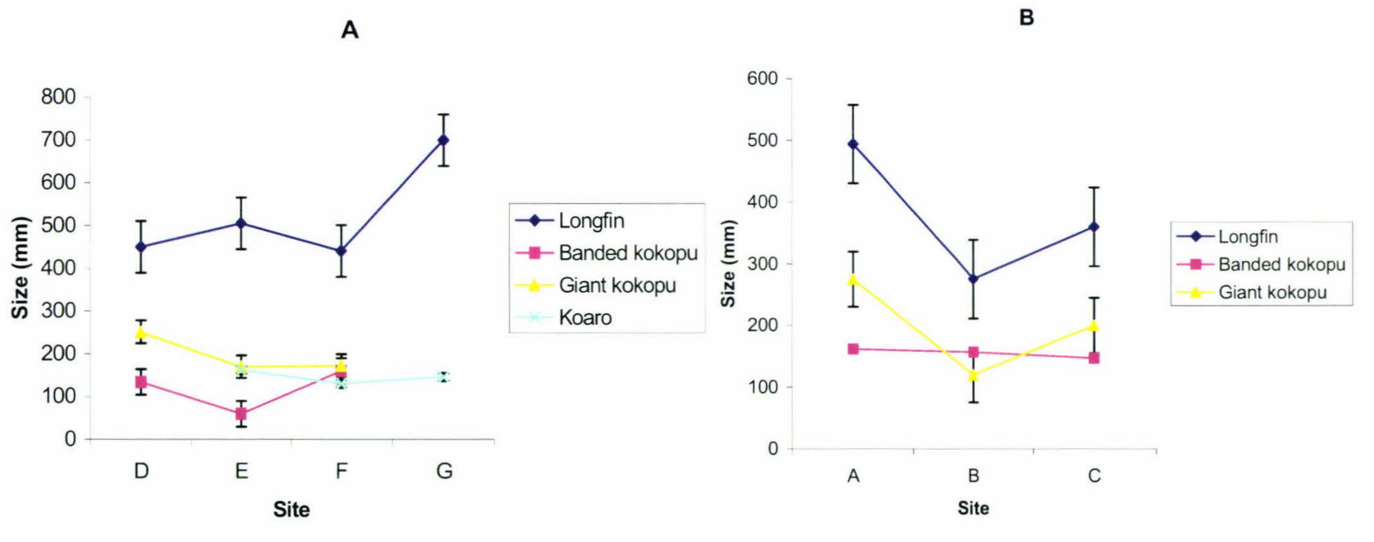

Fig 4 Mean size of longfin eel, giant kokopu, banded kokopu and koaro at sites in (A) Gollans Stream and (B) Butterfly Creek with standard error bars.

Fish Abundance

The abundance of fish was similar in both streams with 92fish/km in Butterfly Creek and 97fish/km in Gollans Stream. Banded kokopu were most abundant at site 'A' in the lower reaches of Butterfly Creek, giant kokopu at site 'D' in the middle reaches of Gollans Stream, and koaro at site 'E' in the upper reaches of Gollans Stream.

Fish Size

In Gollans Stream the mean size of longfin eels increased markedly at upstream sites, banded kokopu size increased slightly and koaro sizes remained uniform. The size of giant kokopu decreased at upstream sites. In Butterfly Creek however the mean size of longfin eel and giant kokopu both decreased in size with banded kokopu sizes remaining relatively constant (Fig 4).

DISCUSSION

A total of nine species of fish were recorded in Gollans Valley. Eight of these were native species: longfin eel, shortfin eel, common bully, redfin bully, inanga, banded kokopu, giant kokopu and koaro. One exotic species; brown trout was recorded. The most common species were longfin eel, banded kokopu and giant kokopu. The presence of giant kokopu, longfin eel, lamprey and banded kokopu is of conservation significance; the giant kokopu being listed as vulnerable on the IUCN Red List of Threatened Species (2006) and rated 5 (in gradual decline) by the Department of Conservation as is the longfin eel, lamprey listed as '6' (sparse) and banded kokopu having "declined substantially in range and abundance as a result of habitat degradation" (McDowall 2000). Also of significance is the finding of koaro in the upper reaches of Gollans Stream, the first time these fish have been identified within the catchment. This highlights the importance of sampling the whole catchment when determining the fish fauna. The limited distribution of koaro in the Gollans Valley is in contrast to other studies where koaro were distributed throughout the catchment (Chadderton et al 2000, Joy & Death 2004).

The distribution of fish in the Gollans Valley clearly demonstrates how fish diversity tends to decrease with distance from the sea (Mc Dowall 1993) and how New Zealand fish species can exhibit very defined distributions within a stream/catchment. Eight species were found in the lower catchment and just two or three in the headwaters. Some species were very low in abundance e.g. redfin bully or were restricted to a particular stretch e.g. koaro, while others are widespread throughout the catchment e.g. longfin eel as described by Glova *et al* (1998).

This study demonstrates how in order to accurately record fish diversity in a stream/catchment extensive longitudinal sampling is required (David et al 2002). In addition it is often necessary to use a variety of sampling techniques, some being more effective than others depending on the species. The electric fishing machine has been used extensively in the sampling of freshwater streams however they are ineffective for sampling in water greater than one metre in depth (David *et al* 2002), the preffered habitat of species such as banded kokopu and giant kokopu. Spotlighting has been found to ba an effective alternative for these species (McCullough 1998, McDowall 2000, David et al 2002) as well as fyke nets. Sampling methods need to be carefully chosen to ensure that species diversity is not underestimated due to sampling bias.

Other whole catchment studies where streams remain unmodified, in Kahurangi National Park and Stewart Island, have had similar results to this study with eels and galaxids being the most common species (Jowett *et al* 1998, Chadderton & Allibone 2000) along with redfin bully. In contrast catchments such as Owhiro Stream on the East Coast of the South Island the Oroua River and Rangitikei River catchments, which are modified for most of their length, have low numbers of galaxid species and no redfin bullies (Joy 1998, David *et al* 2002, Lewis & Hamer 2004).

Fish with less climbing ability and drive to penetrate inland, inanga, common bully and redfin bully were only recorded in the lower catchment, as were shortfin eels which prefer lowland lakes rivers and wetlands (McDowall 2000). The low numbers of inanga and redfin bully may be attributable to restricted access for these obligate migrators imposed by the beach barrier at Lake Kohangatera into which the catchment feeds.

The banded kokopu distribution was very distinct; while being widespread throughout most of the catchment they showed a pronounced domination of the Butterfly Creek fauna. David *et al* (2002) found a similar pattern in the lower Taieri and Waipori River catchments, on the east coast of the South Island, where Picnic Gully was dominated by banded kokopu. Here however the distribution was more easily understood as it was the only stream in the study with an intact riparian margin. Banded kokopu are rarely found in streams without a forest canopy (McDowell 1990, Jowett & Richardson 2003, Baker & Smith 2007). In Gollans Valley however the entire upper catchment has an intact riparian margin and even where habitat variables were almost identical between the two steams the domination of banded kokopu persisted in Butterfly Creek (refer Chapter 2). The Acclimitisation Society Report on the Gollans Valley (Smith 1987) shows that this domination of Butterfly Creek by banded kokopu was evident twenty years ago (refer site 10 Table 1).

Giant kokopu were most prevalent in the middle reaches of Gollans Valley. Like banded kokopu they strongly select sites with pools with plenty of cover in the form of undercut banks or in stream debris (Jowett et al 1998, Chadderton & Allibone 2000, Bonnett & Sykes 2002, Baker & Smith 2007). The mid and upper reaches of the Gollans Valley provide this habitat type but the higher densities of giant kokopu in the mid reaches where pool dimensions tended to be larger demonstrated this species preference for larger pools (Baker & Smith 2007). Giant kokopu found in the mid reaches also tended to be of larger average size. Their absence from the lower reaches in historical records was probably as a result of a lack of cover in this area which runs through farmland and lacks riparian cover (Smith 1987).

Koaro favour small swift forested boulder-cobble streams (McDowall 2000). They are proficient climbers and are often found at high elevations. Neither Gollans Stream nor Butterfly Creek reach high elevations but the koaro were found in the swifter headwaters of Gollans Stream at the top of the catchment where cobble size was largest and also at their highest densities at a site 'E' where banded kokopu and giant kokopu were largely absent. In this stretch, the stream bed was composed largely of bedrock with little undercut or instream debris, which both banded and giant kokopu favour. These results are consistent with the findings of Main (1988) and Chadderton & Allibone (2000) who found that in the absence of giant kokopu and banded kokopu, koaro inhabit more diverse habitat. Koaro were not located in Butterfly Creek despite habitat in the headwaters being virtually indistinguishable from the Gollans Stream headwaters. Perhaps the high density of banded kokopu is a detraction however this seems unlikely as longfin eel banded kokopu and giant kokopu all influence the distribution of koaro (Main 1998, Chadderton & Allibone 2000) and are all present in Gollans Stream.

Longfin eels, generalist feeders that utilise a broad range of habitat types (Glova et al 1998, McDowall 2000) were the dominant species throughout the majority of the catchment. It was noted that right up in the headwaters of both streams above sites 'C' and 'G' where the streams were less than a metre in width, longfin eel still persisted. In Gollans Stream the eels at site 'G' had the largest average size of all sites surveyed. In Butterfly Creek however, longfin eels only dominated in the headwaters. Perhaps the high conductivity of Butterfly Creek acts as a deterrent and their range is restricted to the upper reaches where conductivity is lowest (refer Chapter 2).

Brown trout were present in small numbers in the mid and lower reaches of Gollans Stream. This is of concern considering the conservational significance of the native fish fauna of Gollans Valley. Brown trout have been found to cause the fragmentation of galaxiids by competition and predation (Townsend & Crowl 1991, Crowl et al 1992, Closs & Lake 1996, McDowall 2007). Trout were present in 1987 (Smith 1987) and have remained at low numbers. However, the increased regularity of breaching events (refer Chapter 1) may allow for more recruitment of not only native fish from the sea, but also trout and this may pose a threat to galaxiid species.

In conclusion this study reveals the distribution of native fish in a largely unmodified environment and gives a conservative insight into the sort of fish distributions that may have occurred prior to the large-scale deforestation of New Zealand by Polynesian and European settlers. It demonstrates how species diversity naturally decreases with distance from the sea. With a lack of competition and predation from exotic species and where the riparian margin is intact, banded kokopu and giant kokopu are widespread throughout the catchment. In pre-human times the abundance and diversity within the catchment was almost certainly even greater, taking into account that whitebait were historically much more abundant (McDowall 1990), aiding recruitment. These findings have significance in the protection and restoration of native fish habitat highlighting the importance of the preserving or restoring of riparian margins and controlling of pest fish species to increase what has become very restricted habitat availability for these species since the colonisation of New Zealand.

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Synthesis

Synthesis

The fish fauna of the relatively undisturbed catchment of Lake Kohangatera, in the East Harbour Regional Park, Wellington, contains a high diversity of species by New Zealand standards with no less than ten native species; inanga, banded kokopu, giant kokopu, koaro, smelt, longfin eel, shortfin eel, lamprey, common bully and redfin bully and one exotic species; the brown trout being present With three of these species, giant kokopu, longfineel and lamprey being listed on the Department of Conservation Threatened Species List the catchment should be considered of national conservational significance.

The longitudinal distribution and abundance of fish species within Gollans Valley showed a distinctive pattern according to species. The fish fauna of Butterfly Creek is dominated by banded kokopu with just two other species recorded; longfin eels and very low numbers of giant kokopu. In Gollans Stream however, inanga, shortfin eel, common bully, and redfin bully were confined to the lower end of Gollans Stream, giant kokopu, banded kokopu and longfin eel had an overlapping distribution throughout its length and koaro (previously unrecorded within the catchment) were only present in its headwaters. Brown trout were only present in the middle reaches.

Notwithstanding the lake being closed off to the sea with only occasional breachings and despite the majority of the fish fauna being diadromous, the catchment retains relatively high diversity. This highlights the adaptive significance of many of these species being capable of forming landlocked populations. Historical records show that those species such as the redfin bully that are obligatory migrators occasionally disappear from the catchment. Following the major breaching event of February 2004 the redfin bully returned to the catchment after an absence of several years and recruitment of longfin eel, banded kokopu and giant kokopu was improved. Breaching events play a vital role in retaining the diversity of the catchment improving recruitment and enhancing genetic diversity.