Fine scale spatial behaviour of indigenous riverine fish in a small New Zealand stream

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Abstract

The substrate and flow characteristics of a 100m reach of a small, North Island, New Zealand stream were mapped and drawn to a 0.25m^2 grid scale. One hundred and thirty four individual fish, representing five native and one introduced species were PIT tagged and then monitored with a portable transceiver over 41 occasions during day and night in autumn to winter of 2008, then on 3 occasions in January 2009. Redfin bullies (*Gobiomorphus huttoni*), shortjaw kokopu (*Galaxias postvectis*) and koaro (*Galaxias brevipinnis*) were most commonly represented and redetected in the 100m reach (75%, 73%, and 83% detection rates respectively). Redfin bullies with a lower condition factor than conspecifics were less likely to be redetected and gravid fish were considered more at risk of infection or death associated with PIT tagging. Shortjaw kokopu were less likely to be redetected but more likely to retain tags in the longer term than both redfin bullies and koaro. No difference was found in tag detection rates at a range of flow levels, nor between day and night surveying, although a small decline in detection rates occurred as water temperature decreased.

Four hundred and twelve locations of untagged fish were collected during 14 night samples and added to the dataset of 557 locations of PIT tagged fish. A total of 1112 (82% of the reach) 0.25m^2 grid squares were inventoried for microhabitat characteristics using 16 physical variables which, together with fish locations, enabled the microhabitat characteristics of the grid squares where fish were found to be compared with those where fish were not found. Redfin bullies and shortjaw kokopu showed strong associations with large substrates and large interstitial refuge spaces and both species showed marked diel differences in microhabitat utilisation. Koaro were more dependent on velocity and surface turbulence and used similar microhabitat types regardless of diel period. No size-based or seasonal differences were found regarding microhabitat use. Potential segregation was observed between shortjaw kokopu and koaro but no other biotic influences on habitat utilisation were apparent.

Three floods occurred during the 2008 sampling period which facilitated the collection of fish behavioural data in relation to high flows. A total of 31 individuals were detected during flood conditions and these were found either within 0.5 metres of the base flow stream bed edge or inside the base flow stream bed in areas with large boulder substrates. A subset of the population was found returning to the same locations during multiple floods. Individual fish detected during high flows were significantly less familiar (see pages 68-69 for a detailed description of the term “familiar” in this context) in comparison to the subset of individuals that were commonly resident in the study reach during base flow conditions, showing that tagged fish made larger scale movements during flood conditions. While small changes in community composition occurred that were able to be attributed to flood-induced microhabitat changes, overall a remarkable level of persistence was observed in the tagged community, with over half of all individuals remaining in or returning to the same 100m section of stream following each flood.

Explanation of text

This thesis is a combination of four individual papers. This format has resulted in some repetition in introductions and methods sections between chapters, however a number of chapter and page references have been included to aid the reader. Chapters two, three and four are currently in preparation to be submitted to scientific journals for publication. The appendix contains a reviewed manuscript that was submitted to the New Zealand Journal of Marine and Freshwater Research in December 2008. Reviewers comments were received in late March 2009, specified changes were made and the manuscript was resubmitted on 25th May 2009.

The experimental manipulations and fish sampling methods have been sanctioned by the Massey University Animal Ethics Committee (protocol No. 07/30 and 07/106)

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Above all I would like to acknowledge my primary supervisor Dr Mike Joy, who envisioned and coordinated this research. During the very first undergraduate lecture you gave me four years ago, my educational path took a sharp turn to the left and the road since then has been far from uninteresting. Thank you for teaching me to question, thereby exponentially increasing the value I have been able to extract from my tertiary education. You are an inspiration, as well as a very good friend.

I am especially grateful to the fabulous Anderson Family, the landowners and faithful caretakers of Te Ara Hiwi and the Mangaore stream that flows through it. Pat and Marlene, I enjoyed your company immensely.

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Thanks to the Whanganui River Enhancement Trust, the family of the late Julie Alley, the Department of Conservation and Greater Wellington Regional Council for expressing faith in the merit of this research through assistance with funding and equipment.

Lastly, the fish. It feels wrong to thank you as I never offered you a choice about participating in this research. PIT tag implantation is neither risk nor pain free, you all endured short term suffering and at least one of you died. I strongly hope that the benefits of this research will justify this many times over.

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Chapter 1.

GENERAL INTRODUCTION

The New Zealand indigenous freshwater fish fauna has little in common with those of Europe and North America, from where the majority of freshwater research originates. The fauna is distinct due to a high degree of endemism, a high incidence of amphidromy and a relatively sparse species list (26 extant species belonging to 7 families). In addition, New Zealand indigenous fish are highly cryptic–most are small (<150mm), benthic and nocturnal (McDowall 1990). These characteristics mean they have largely gone unnoticed by the general public as well as biologists in comparison to charismatic terrestrial species such as the famous New Zealand endemic avifauna. Nevertheless, public awareness of indigenous freshwater species has increased in recent years, but so too has the threat status of those species. Historical records (Brunner 1848; Mair 1902; Fletcher 1919; Armstrong 1935), together with current restricted species' distributions (Joy, in press) tell us that freshwater fish existed in far higher densities and were much more widely distributed than in current times. Today, approximately two thirds of New Zealand native freshwater fish species are on the national threatened species list. To address these declines, national freshwater policy must be backed by solid science. Unfortunately, the cryptic habits of the fauna make it difficult to study with a high degree of spatial resolution and relatively little is known regarding native species' behaviour in the wild.

When studying aspects of behaviour, it is important to cause as little disturbance as possible and thus minimise chances of affecting the behaviour under scrutiny. To date, freshwater fish behavioural research in New Zealand has predominantly used electrofishing as a survey tool (Jowett and Richardson 1995; Rowe and Smith 2003; Crow 2007). Electrofishing is a highly invasive sampling method that can cause immediate injury or death of shocked fish (Reynolds 1996; Holliman and Reynolds 2002) and can reduce subsequent fitness and growth rates (Dwyer et al. 2001). This method is also subject to spatial error, as fish that are shocked are often no longer in their original position by the time they come into view of researchers (Crow 2007).

Alternatives to electrofishing, such as snorkelling surveys (Henry and Grossman 2008; Martinez-Capel et al. 2009) and night spotlighting (Chadderton and Allibone 2000; Whitehead et al. 2002) are non-invasive and offer higher spatial resolution but snorkelling is limited to swimmable streams and spotlighting is limited to night time use in shallow clear water with low surface turbulence. These methods also rely on fish being visible and thus have limited applicability to New Zealand native freshwater fish in general as most spend the majority of their time concealed to terrestrial eyes, within substrate matrices, submerged debris or hidden by surface turbulence in riffle zones (McDowall 1990).

A viable solution to this problem is to use a method that enables fish to be located without having to be visible and this can be achieved through radio or acoustic tagging. Acoustic and radio tags are commonly used around the world to study fish and have successfully provided valuable fine scale spatial information for 2 New Zealand native anguillid species (Jellyman and Sykes 2003) and the largest member of the family galaxiidae, the giant kokopu *Galaxias argenteus* (Gmelin, 1789) (David and Closs 2001). Unfortunately, while radio and acoustic tag technology may adapt sufficiently in future, these tags are currently still too large to be safely implanted in most New Zealand native species.

Advances in Passive Integrated Transponder (PIT) technology however, have enabled very small fish (<70mm FL) to be tagged with growth and survival rates unaffected (Baras et al. 2000; Bruyndoncx et al. 2002; Ruetz et al. 2006; Cucherousset et al. 2007). PIT tags carry no battery so rely on electronic pulses from an antenna placed within a specified range (100 – 750mm, depending on tag size) to transmit their individual identification code, so provide high resolution information. PIT tags can be read through substrate and the development of portable monitoring systems has facilitated the collection of fine scale spatial data (Roussel et al. 2000; Zydlewski et al. 2001; Hill et al. 2006) in small streams with benthic fauna overseas but to date this method has not been used in New Zealand.

To address this shortcoming we first set out to locate a suitable study site and encountered further evidence of recent native fish decline. Seven 2nd and 3rd order streams in the Manawatu and Wellington regions in the North Island known to contain high densities of native fish 10 years ago (NZ Freshwater Fish Database: Richardson 1989) were backpack electrofished over late 2007 and early 2008 before a site was found that still contained densities we considered high enough to facilitate a fine-scale tagging and monitoring study. The Mangaore stream is a third order, western tributary of the Manawatu River (Fig. 1), with 92% of its headwaters still covered in indigenous forest and scrub (Wild et al. 2004) and contains 9 native fish species (Table 1) with three occurring in relatively high densities – *Gobiomorphus huttoni* (Ogilby, 1894) (redfin bully), *Galaxias postvectis* Clarke, 1899 (shortjaw kokopu) and *Galaxias brevipinnis* Günther, 1866 (koaro). Chapter 2 of this thesis describes and assesses the use of portable PIT technology on a subset of the Mangaore stream native fish community, with focus on: 1) detection rates between species and in a range of environmental conditions and 2) tag retention and survival in relation to species and body size. Fish were tagged with 12mm, 0.06g PIT tags (Biomark Inc.) in a 100 metre reach of this small, semi-pristine stream and repeatedly monitored during day and night. This methodology produced high redetection rates with high spatial resolution of fish locations and thus provided valuable opportunities to investigate multiple facets of natural behaviour such as interactions with the physical environment.

The physical environment in which New Zealand's native freshwater fish fauna evolved has undergone great change. The arrival of European colonists to New Zealand was followed by the clearfelling and burning of three quarters of existing original indigenous forest cover (Fleet 1986; Leathwick et al. 2003) and the draining of ninety percent of original wetlands (Campbell 2004). The past thirty years has seen further change through the widespread conversion of previously extensive pastoral and forestry land to intensive dairy farming, a practise which causes increased nutrient runoff, intensified sedimentation and increased water abstraction for irrigation (Harding et al, 1999; Bowden et al. 2004; Young et al. 2005). Perhaps not surprisingly, native freshwater fish populations have also shown significant declines during the past thirty years (Joy, in press).

In the face of such rapid degradation, the determination of fundamental habitat requirements of native freshwater fish not only increases in urgency but becomes progressively more difficult to achieve as sites with no or low anthropogenic impact grow rarer. Previously in New Zealand, methodologies developed overseas have been used to determine habitat requirements of freshwater fish. For example, the Instream Incremental Flow Methodology (IFIM: Bovee 1982) is currently used widely throughout the country as a means of determining minimum flow standards. However, IFIM was developed in North American streams, using diurnal pelagic species and is thus highly unsuitable for application to New Zealand freshwater environments. In addition, IFIM habitat suitability curves were produced for New Zealand species (Jowett and Richardson 1995) using electrofishing data collected during the day only and offer no information regarding night time habitat use of these predominantly nocturnal species.

To address this gap in knowledge and obtain habitat requirement data through appropriate methods the study reach containing the PIT tagged community described in chapter 1 was comprehensively mapped and drawn to a $0.25m^2$ grid square scale, with each individual grid square inventoried according to 16 microhabitat variables. Chapter 3 of this thesis describes the associations that fish showed with microhabitat variables and the differences found between species. Particular hypotheses investigated included: 1) do fish show positive and/or negative correlations with physical habitat variables at both a $0.25m^2$grid scale and a pool-run-riffle scale, and if so, what physical habitat variables are particularly sought or avoided?; 2) are there measurable differences in microhabitat use between species and between size classes?; and 3) do fish utilize microhabitat differently during the day compared to during the night? This chapter highlights the strong dependence of fish on the presence of large substrate interstices and describes significant differences between day and night time habitat requirements.

Another area of freshwater research that has gone largely unstudied and is of particular relevance in New Zealand is the behaviour of freshwater fish during flood events. New Zealand streams and rivers are comparatively short and steep and characterised by high levels of disturbance (Winterbourn et al. 1984). Floods are common and many species actively use high discharge events to spawn in temporarily inundated riparian margins (McDowall 1990; Allibone and Caskey 2000; Charteris et al. 2003). The ongoing persistence of native fish communities through multiple flooding events shows that harm is successfully avoided but the behaviours expressed to achieve this remain mostly speculative due to the logistical difficulty of surveying during flood conditions.

One way to overcome some of this difficulty is to use a PIT monitoring system. As a result of having an ongoing intensive monitoring regime of a tagged stream community in place, comprehensive data was able to be collected regarding behaviour associated with three significant flood events that occurred during the sampling period and these behaviours are described in chapter 3 of this thesis. In particular: 1) Did tag detection and fish movement vary with flow level? And 2) Did tagged fish seek shelter during flood events and if so what kind of shelter was sought?

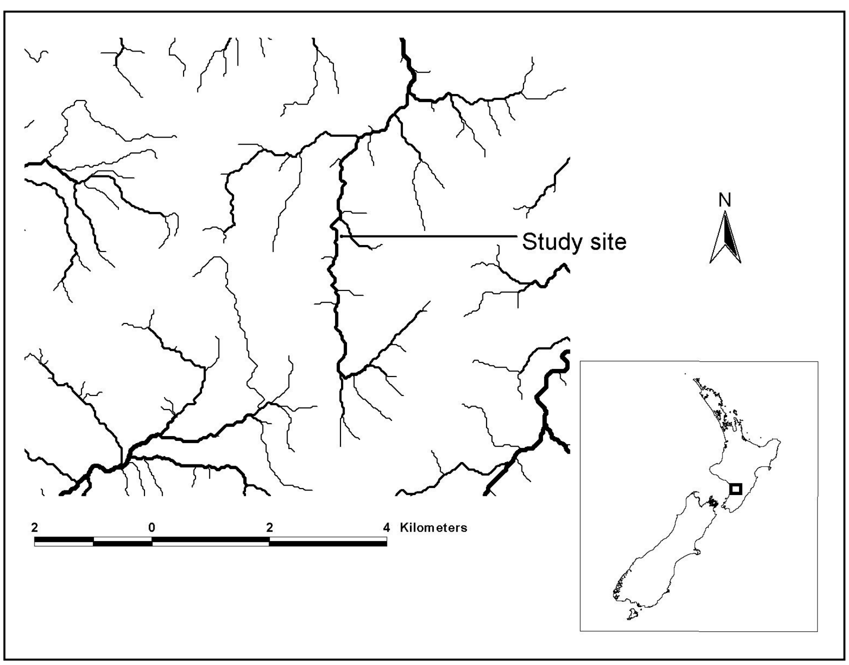

Figure 1. Map showing the location of the Manawatu catchment (inset) and the study site on the Mangaore stream.

Table 1. Freshwater fish species present in the Mangaore stream, Horowhenua, New Zealand. * indicates a threatened species.

Scientific name	*Common name*	*Biogeographic status*
Anguilla australis Richardson, 1848	Shortfin eel	Native
Anguilla dieffenbachii Gray, 1842	Longfin eel	Endemic*
Cheimarrichthys fosteri Haast, 1874	Torrentfish	Endemic
Galaxias argenteus (Gmelin, 1789)	Giant kokopu	Endemic*
Galaxias brevipinnis Günther, 1866	Koaro	Native
Galaxias fasciatus Gray, 1842	Banded kokopu	Endemic
Galaxias postvectis Clarke, 1899	Shortjaw kokopu	Endemic*
Gobiomorphus basalis (Gray, 1842)	Cran's bully	Endemic
Gobiomorphus huttoni (Ogilby, 1894)	Redfin bully	Endemic
Oncorhynchus mykiss (Richardson, 1836)	Rainbow trout	Introduced
Salmo trutta Linnaeus, 1758	Brown trout	Introduced

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Chapter 2.

Description and evaluation of the use of passive integrated transponder (PIT) technology for monitoring a New Zealand native freshwater fish community.

ABSTRACT

The substrate and flow characteristics of a 100m reach of a small, North Island, New Zealand stream were mapped and drawn to a $0.25m^2$ grid scale. One hundred and thirty four individual fish, representing five native and one introduced species were PIT tagged and then monitored with a portable transceiver over 41 occasions during day and night in 2008. Redfin bullies (*Gobiomorphus huttoni*), shortjaw kokopu (*Galaxias postvectis*) and koaro (*Galaxias brevipinnis*) were most commonly represented and redetected in the 100m reach (75%, 73%, and 83% detection rates respectively). Nine longfin eels (*Anguilla dieffenbachii*) were tagged but only 2 were redetected and torrentfish (*Cheimarrichthys fosteri*) and the exotic brown trout (*Salmo trutta*) were represented by only 2 tagged individuals each. Redfin bullies with a lower condition factor than conspecifics were less likely to be detected following PIT tag implantation and gravid fish were considered more at risk of infection or death associated with PIT tagging. Shortjaw kokopu were less likely to be redetected but more likely to retain tags in the longer term than both redfin bullies and koaro. No difference was found in tag detection rates at a range of flow levels, nor between day and night surveying, although a small decline in detection rates occurred as water temperature decreased

Keywords freshwater fish; PIT tags; habitat mapping; behaviour

INTRODUCTION

Collecting fine scale data on fish behaviour in small streams can be challenging in comparison to many other disciplines in wildlife biology. Previous such studies have commonly used electrofishing as a sampling tool (Watkins et al. 1997, Lonzarich et al. 2000, Rowe and Smith 2003, Santos et al. 2004). Electrofishing however has a number of shortcomings, being both a highly invasive sampling method (Reynolds 1996) and also subject to spatial error, as fish that are shocked are often no longer in their original position by the time they come into view of researchers (Crow 2007). Riverine native fish in New Zealand are especially difficult to survey as they are mostly nocturnal and benthic (McDowall 1990) and spend much of their time within benthic substrate matrices (see Chapter 3). Night spotlighting has increased in popularity among New Zealand freshwater fish behavioural researchers (e.g. Chadderton & Allibone 2000, Whitehead et al. 2002) although this method is restricted to shallow areas of clear water with low surface turbulence. As a consequence of this limited surveying capacity, relatively little is known regarding fine scale behaviour of New Zealand native freshwater fish species that live close to or within the stream benthos.

Advances in Passive Integrated Transponder (PIT) technology have enabled progressively smaller fish to be tagged, facilitating comprehensive studies on aspects of individual fish movement (Armstrong et al. 1999, Zydlewski et al. 2001, Cookingham and Ruetz 2008) and habitat use (Greenberg and Giller 2000, Elso and Greenberg 2001, Teixeira and Cortes 2005). PIT tags rely on electronic pulses from an antenna placed within a specified range to transmit their individual identification code. This means that PIT tagged fish being studied in a field situation must either be physically recaptured or otherwise come within approximately 100mm – 750mm (depending on tag size) of an antenna to generate data.

Attempts at addressing this shortcoming have been made by using flat bed antennae that cover the width of a stream and detect fish as they pass over (Armstrong et al. 1996), which is a relatively easy way of collecting large amounts of data but observations are limited to immigration/emigration movements and offer little information regarding habitat use or finer scale spatial behaviour. Teixeira & Cortes (2007) attempted to address this problem by strategically installing a number of separate transceiver units and instream antennae placed in selected habitat types. This provided habitat use data but only for tagged fish which were active or which swam into range of an antenna.

The most appropriate method of locating benthic tagged fish in wadeable streams is to use a portable PIT detection system (Roussel et al. 2000, Zydlewski et al. 2001, Hill et al. 2006, Cucherousset et al. 2007) whereby a reader and antenna are modified to allow them to be carried by a researcher i.e. the equipment is mobile rather than reliant on mobility or activity levels of tagged fish. This method is more labour intensive but is considerably less expensive than using fixed instream antennae. Such a system also enables greater spatial resolution of data at fine scales, thus improving interpretive potential of behaviours and activity levels expressed by tagged subjects.

This paper outlines an example of the use of PIT technology on a New Zealand native fish community and describes and assesses the use of a portable PIT monitoring regime that is the first of its kind in New Zealand. Particular focus was given to: 1) efficiency of tagging and monitoring methodology; 2) detection rates between species and with a range of environmental conditions; and 3) tag retention and survival in relation to species and body size.

METHODS

Site description

The Mangaore stream is a third order, western tributary of the Manawatu River (Fig. 1), with 92% of its headwaters still covered in indigenous forest and scrub (Wild et al. 2004). Nine native fish species are present (see page 12), three in relatively high densities – *Gobiomorphus huttoni* Ogilby (redfin bully), *Galaxias postvectis* Clarke (shortjaw kokopu) and *Galaxias brevipinnis* Günther (koaro) (common names are used hereafter). The substrate and flow characteristics of a 100m reach of the stream was mapped and drawn to scale (Fig. 2).

PIT tagging

Fish in the study reach were caught and tagged during two periods: 01-03 January 2008 and 21-24 March 2008. Fish were collected using a combination of multiple pass electrofishing and repeated spotlighting.

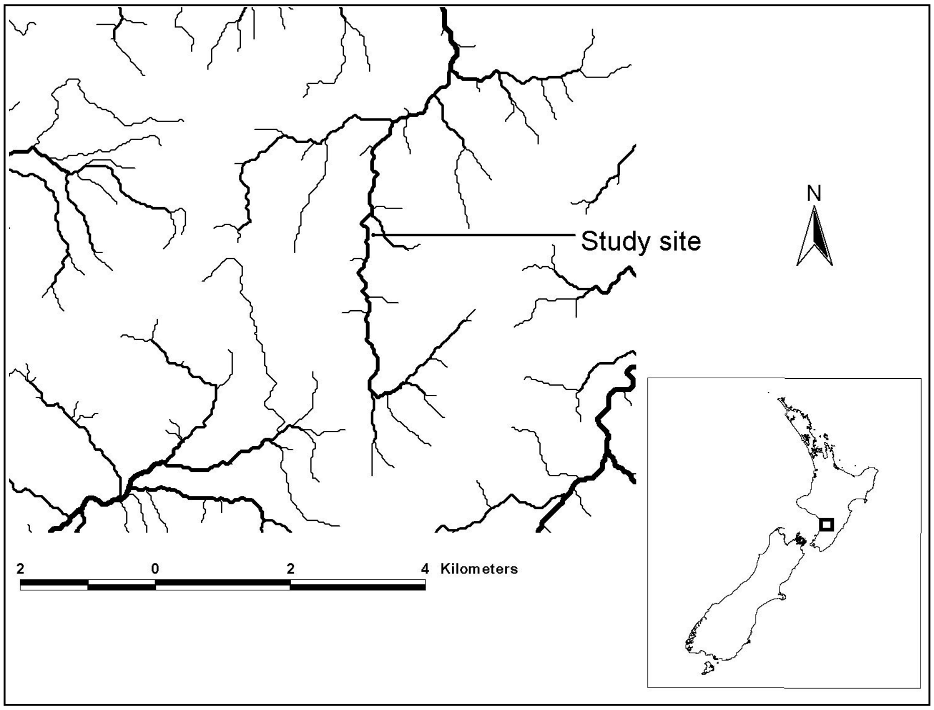

Figure 1. Map showing the location of the Manawatu catchment (inset) and the study site on the Mangaore stream.

All fish were anaesthetised using 2-phenoxyethanol (0.2ml l^{-1}), weighed and measured (to the nearest 0.1g and 1mm respectively) and implanted with a 12.5mm, 0.06g PIT tag (Biomark Inc.). The tag was placed to the right of the ventral midline and directly under the pectoral fin for bullies, galaxiids, torrentfish and trout and to the anterior right of the dorsal fin for eels (Fig. 3). All tagging was assisted with a hand-held 12-gauge implanter and all equipment was washed with an iodine solution (Betadine™) prior to implantation. Once implanted, fish were allowed to recover in in-stream cages before being released back into the approximate region of the study reach where they were caught.

PIT monitoring

The PIT tag antenna was fixed onto the end of a wooden pole and the PIT tag reader was attached to a harness so the screen could be read (Fig. 4). Monitoring of the study reach was conducted by a single researcher systematically moving upstream and slowly scanning the entire bed. Upon detection of a tag, the antenna was re-positioned a number of times until the position of the tag could be recorded to the nearest 100mm or closer.

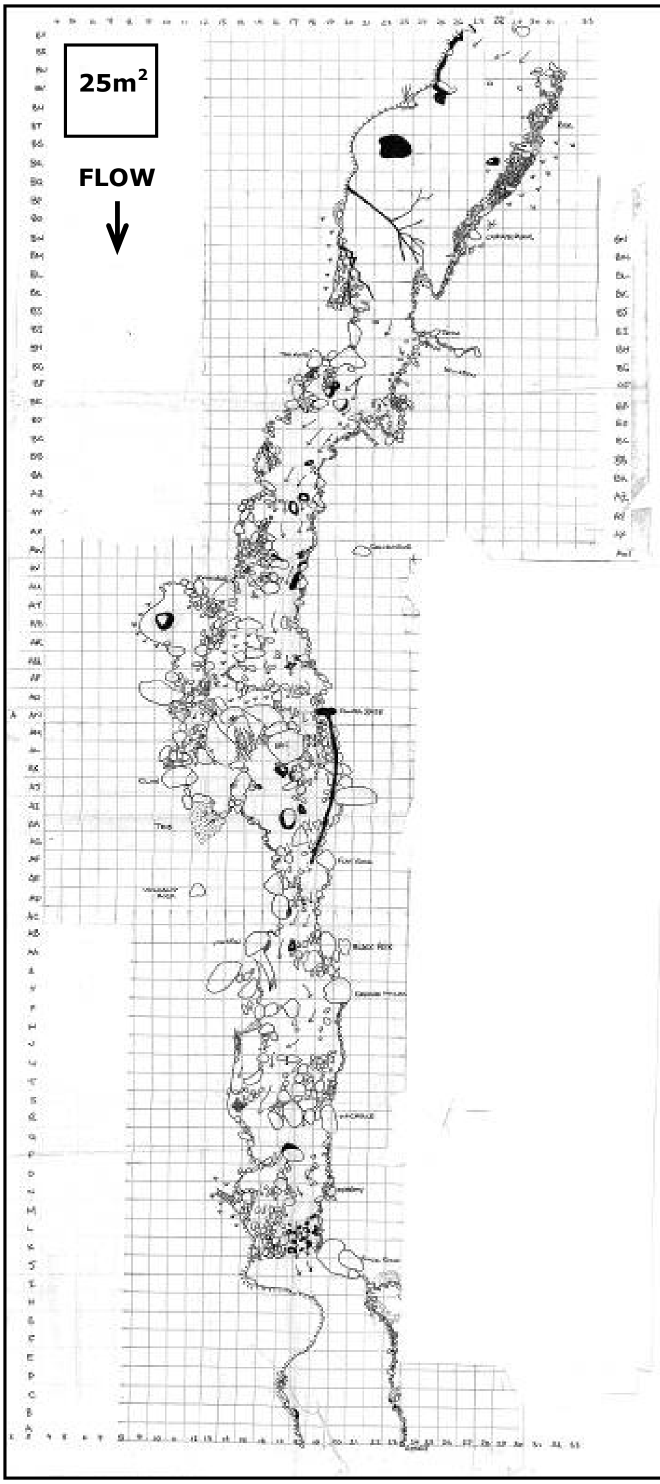

Figure 2. Map of the 100m study reach drawn to scale. A copy of the map (field copies were ~3.5 times larger than the image depicted) was carried for each sampling session in order to record the locations of tagged fish.

A copy of the stream map was carried on each sampling occasion and the location of each tag entered in the corresponding coordinate on the map. Sampling was conducted slowly and precisely, with care taken to cause as little physical disturbance as possible and maximise the number of tag detections per sample.

Figure 3. PIT tag implant sites for (right) longfin eel and (left) for all other species.

Figure 4. Modifications made to equipment to render it portable. Care was taken while sampling to cause as little physical disturbance as possible.

If a tag was repeatedly detected in the same location on more than five consecutive occasions then the tag was physically searched for by disturbing the substrate until either the tag stopped emitting (the fish swam away) or sufficient disturbance had occurred for the still-emitting tag to be classified as lost. As active (not lost) tags frequently remained stationary for a number of consecutive samples, for the three surveys conducted in 2009, physical searching was carried out for every tag that was detected more than once in the same location to confirm their status. Day surveys were carried out any time between 9am and 3pm and night surveys were carried out between 7pm and midnight, commencing at least one hour after sunset. The section was sampled on 26 occasions during the day and on 15 occasions at night (assisted by spotlight) over March to July 2008 and then on 3 occasions in February 2009 - twice during the day and once at night.

Rainfall, stream depth and water temperature were monitored during the 2008 survey period using a rain gauge, instream depth gauging stations and instream temperature loggers.

Statistical analysis

Species' differences with regard to "detectability" were examined graphically and tested using the Kruskall Wallis test (proc Npar1way in SAS 9.1: SAS Institute Inc. 2002). Spearman's Rank correlation analysis (Proc Corr in SAS 9.1) was used to determine if relationships existed between the number of tags detected per sample and local environmental conditions: water temperature and stage depth and the number of tags detected during the day was compared to the number of tags detected at night by Mann-Whitney testing (Proc Npar1way in SAS 0.1). The variety of potential tag fates and differences between species and tagging months was examined and a classification tree (De'ath and Fabricius 2000), implemented in WEKA 3.4 (Hall et al. 2009) was used to recommend size thresholds for future tagging projects. The classification tree was used to discriminate between fish that were redetected and fish that "disappeared" following tagging using individual characteristics of tagged individuals (tag date, length, weight and gender) as classifiers. Cohen's Kappa (Cohen 1960) and area under the receiver-operator curve (AUC) values were generated to evaluate the correct classification rate of the model using the resubstituted (10%) output from the tree.

The number of sampling occasions required to detect all individuals that were largely resident in the study section was determined graphically using the 2008 sampling data and extrapolated to the data collected from 2009 to produce estimates of how many active PIT tags remain in the study section one year after they were implanted.

RESULTS

A total of 134 fish, representing five native and one introduced species were tagged and monitored (Table 1), although 2 species: torrentfish and trout were each represented by only 2 individuals so were excluded from analysis. Detection rates (number of tags detected at least once) for redfin bully, shortjaw kokopu, koaro and longfin eel were 75%, 73%, 83% and 22% respectively, producing 700 datapoints for analysis. During the 2008 sampling period, sample 13 was the first instance in which no new tags were detected (i.e. all tags that were found had been found at least once during the previous twelve samples) (Fig. 5). A total of 24 tags (thirteen redfin bullies, 6 shortjaw kokopu and 5 koaro) were detected over 3 samples in February 2009. This number is markedly less than the 40 individual tags detected during the first 3 samples in 2008 and indicates that only approximately 60% of the original tagged population remained in the study reach after 1 year.

Table 1. Information regarding fish species that were PIT tagged and monitored on 41 occasions over March to July 2008 and 3 occasions in February 2009. Species codes are used hereafter in figures. *denotes exotic species.

Scientific name	*Common name (species code)*	*Size range (mm_{TL})*	*Number of tagged individuals*	*Number of tags detected at least once*	*Number of tags redetected at least 5 times*	**Total number of datapoints**
Gobiomorphus huttoni (Ogilby, 1894)	Redfin bully (RFB)	75-111	69	52	43	488
Galaxias postvectis Clarke, 1899	Shortjaw kokopu (SJK)	99-204	22	16	11	69
Galaxias brevipinnis Günther, 1866	Koaro (KOARO)	79-155	30	25	22	125
Anguilla dieffenbachii Gray, 1942	Longfin eel (LFE)	254-1100	9	3	2	18
Cheimarrichthys fosteri Haast, 1874	Torrentfish (TFISH)	118-146	2	1	1	8
Salmo trutta Linnaeus, 1758	Trout* (TROUT)	107-198	2	1	1	13
	Total		134	98	80	721

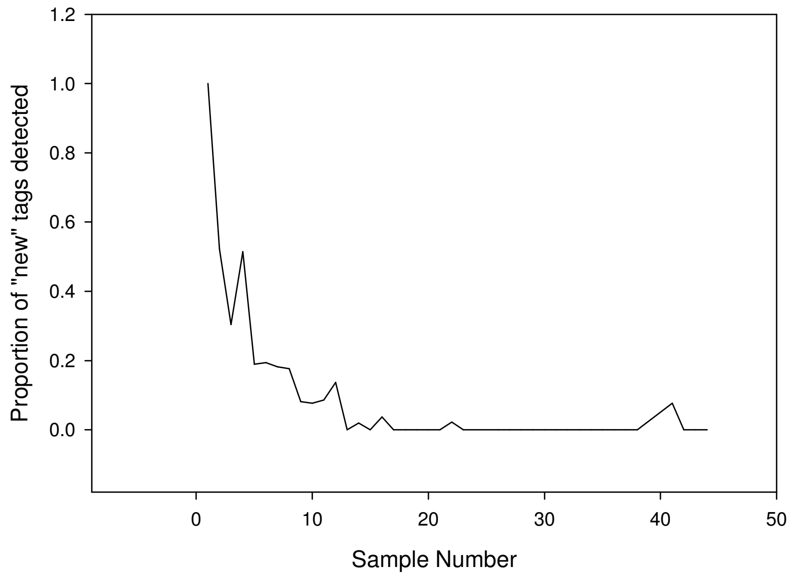

Figure 5. The proportion of new tags (detected for the first time) detected on each sample during 2008 (time between samples was not equal).

Koaro were most likely to be detected at least once and longfin eels were least likely (Fig. 6). Significant differences were found between species (longfin eels not included here as only 2 individuals were redetected) in the number of times each individual was redetected ($K_{2df} = 15.40$, $p = 0.0005$), with redfin bullies most likely to be redetected 5 times or more and shortjaw kokopu least likely (Fig. 7).

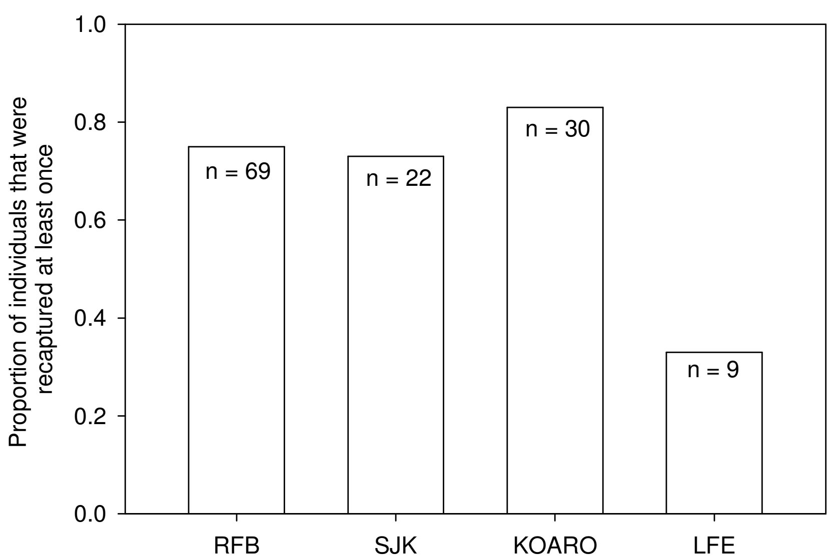

Figure 6. Differences in the proportion of each species that were detected at least once.

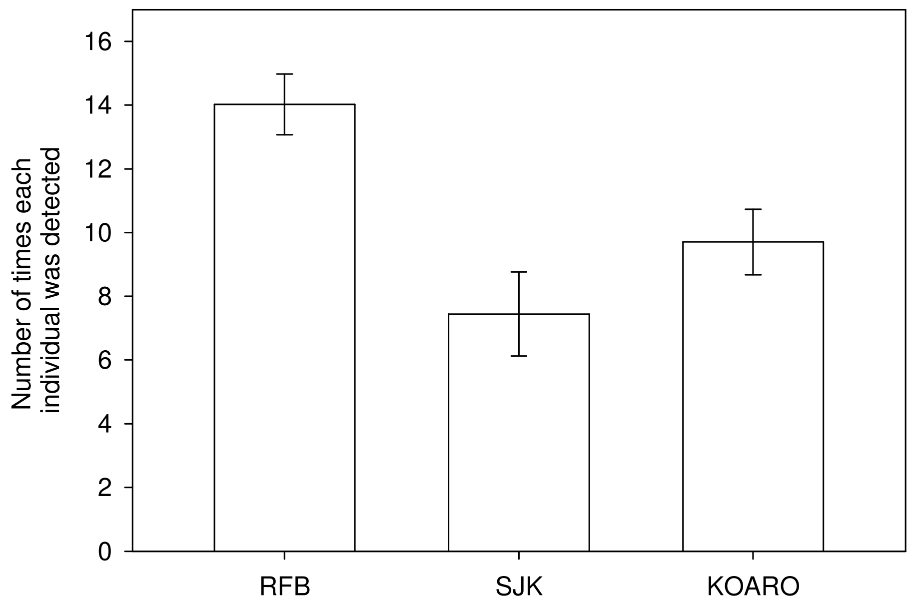

Figure 7. Differences regarding the mean number of times that each individual fish was redetected for each of the three most frequently encountered species. Error bars represent one standard error. Kruskall Wallis Test: $K_{2df} = 15.40$, $p = 0.0005$.

No significant difference was found in the number of tags detected by day versus the number of tags detected by night ($Z = 1.19$, $p = 0.23$). No relationship was evident between stage depth and per-sample detection rate but significantly fewer tags were detected as water temperature decreased ($r^2 = 0.07$, $p = 0.70$ and $r^2 = 0.40$, $p = 0.01$ respectively; Fig. 8).

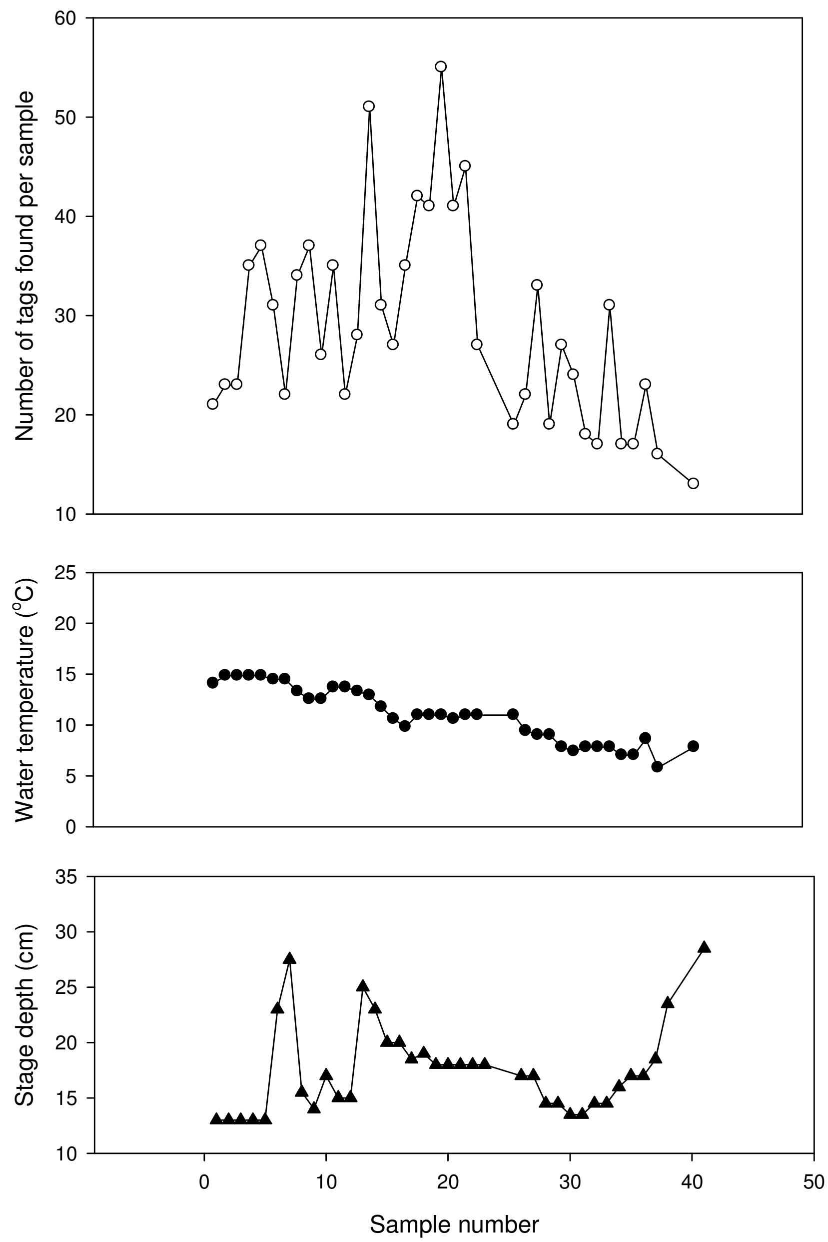

Figure 8. Graphs showing (top) the number of tags detected during each sampling occasion, (middle) water temperature at sample time and (bottom) stage depth over the sampling period.

Each tag could be allocated one of six potential fates (Table 2), grouped into "active", "disappeared" and "confirmed lost/dead". In total twelve tags were confirmed as lost (12% of redfin bullies, 5% of shortjaw kokopu and 10% of koaro). One fatality was confirmed. This was a large, gravid female koaro, estimated to have died around three days after PIT tagging.

Table 2. Numbers and (proportions) of each species allocated to one of 6 PIT tag fates.

Tag Fate	*RFB*	*SJK*	*KOARO*	*LFE*	*TOTAL*
Still active and in study section 1 year later	11 (0.16)	6 (0.27)	5 (0.17)	0	22 (0.17)
Detected at least once – not found in study section 1 year later	34 (0.49)	9 (0.41)	17 (0.57)	2 (0.22)	62 (0.48)
Disappeared	16 (0.23)	6 (0.27)	4 (0.13)	7 (0.78)	33 (0.25)
No active detection then confirmed lost (lost immediately)	2 (0.03)	1 (0.05)	0	0	3 (0.02)
Active detection or redetection then confirmed lost (not lost immediately)	6 (0.09)	0	3 (0.10)	0	9 (0.07)
Confirmed dead	0	0	1 (0.03)	0	1 (0.01)
Total	69 (1.00)	22 (1.00)	30 (1.00)	9 (1.00)	130 (1.00)

Thirty three tags (23% of redfin bullies, 27% of shortjaw kokopu, 13% of koaro and 78% of longfin eels) were classed as disappeared (i.e. they were never detected). Graphs of length versus weight (not generated for longfin eels due to small sample size and only 2 individuals being redetected) show no apparent pattern for shortjaw kokopu and koaro but redfin bullies that were never found again are predominantly located below the linear regression line – representing smaller and relatively underweight fish (Fig. 9). Closer examination of the redfin bullies that were never redetected show that the majority of comparatively underweight individuals were tagged in January (Fig. 10).

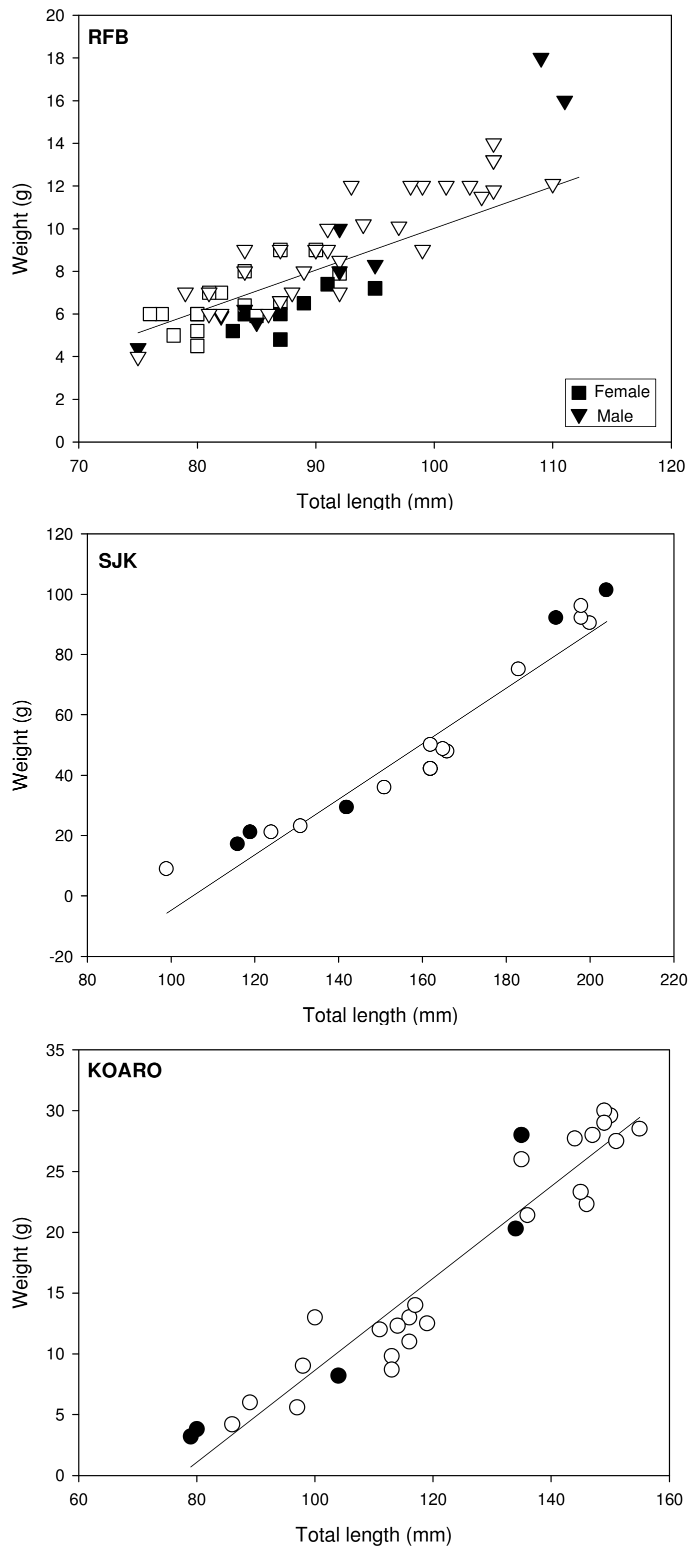

Figure 9. Length versus weight for (top) redfin bully, (middle) shortjaw kokopu and (bottom) koaro. Open symbols represent fish that were detected at least once and closed symbols represent fish that were never detected. Redfin bullies were the only species able to be reliably sexed.

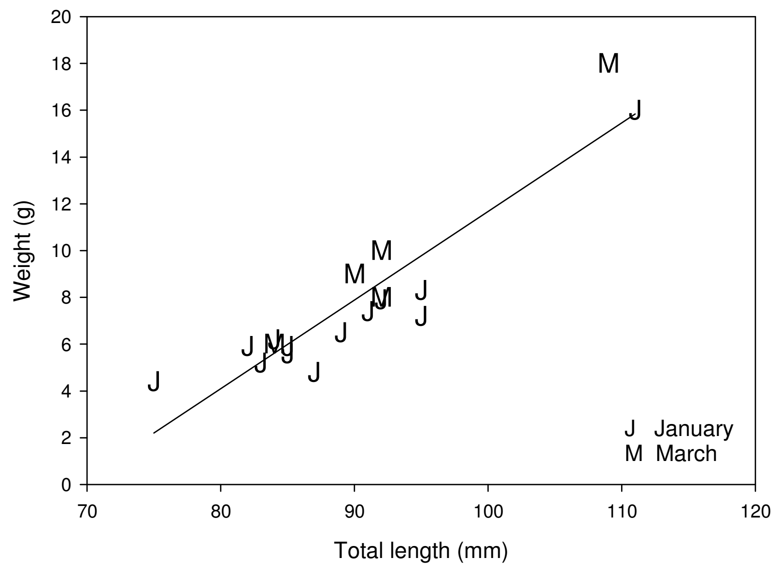

Figure 10. Length versus weight for redfin bullies that were never redetected. Points are coded to correspond with the month in which an individual was tagged – January or March 2008.

Size thresholds for successfully tagging redfin bullies were identified by the results of a classification tree that classified redfin bully tags correctly as either active or disappeared 87.5% of the time (Cohen's Kappa = 0.62; AUC = 0.78) based on weight and length (although the most important variable was whether fish were tagged before or after the significant flood event in January 2008. The model did not identify gender as a classifying variable. Classification tree results show that, for redfin bullies less than 8.3g in weight redetection is less likely when that fish is also more than 87mm in length (Fig. 11).

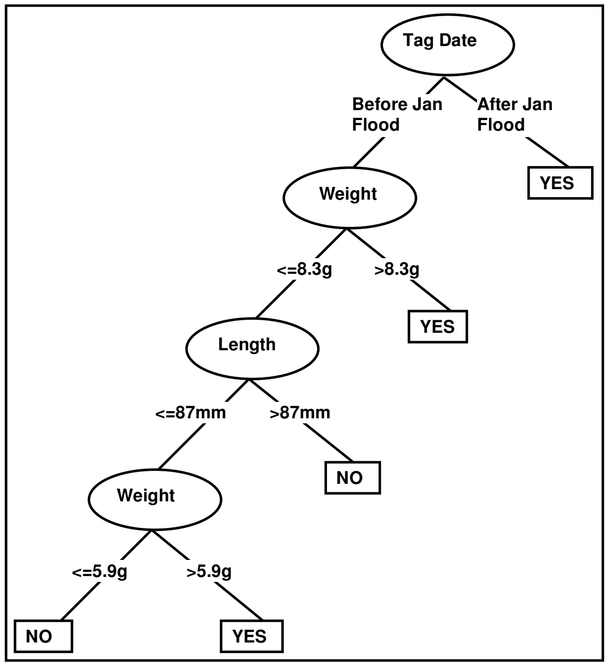

Figure 11. 10% resubstituted classification tree showing variables used by the model to classify redfin bullies as either detected at least once (YES) or never detected (NO).

DISCUSSION

This study was the first in New Zealand to use a portable PIT monitoring regime on native fish in the wild. Overall, 83% of tagged fish were detected at least once and 65% were redetected 5 times or more. Other studies using portable monitoring techniques have been able to report exact redetection rates on a per-sample basis as researchers have either had flat bed antennae installed at the top and bottom of a study section (Enders et al. 2007) or have physically blocked off an area using nets or cages (Roussel et al. 2000, Hill et al. 2006, Cucherousset et al. 2007, Cookingham and Ruetz 2008). In contrast, the open state and physical complexity of the study section combined with the 30cm read range of 12mm tags meant that during any given sample, fish could either be absent from the section or present in the section but out of range of the antenna

At the scale of 100m of stream, results indicate that koaro are most likely to be redetected at least once and longfin eels are least likely, perhaps reflecting in part a relatively higher degree of site fidelity in koaro due to a strong preference for riffle environments. Jellyman & Sykes (2003) found that longfin eels made extensive movements immediately after being implanted with radiotags compared to subsequent movements and the same phenomenon could have occurred here. Alternatively, longfin eels may have been more likely than other species to expel PIT tags as a result of subcutaneous tag placement instead of the peritoneal placement used for other species.

When multiple redetections of individuals were examined, the observed higher "detectability" of redfin bullies compared to shortjaw kokopu could be attributed to a higher degree of mobility in shortjaw kokopu (i.e. they were absent from the section during sampling occasions). This seems unlikely, given that previous work indicating that shortjaw kokopu typically occupy home ranges of 10-20 metres of stream (Allibone et al. 2003). It is possible that, compared to other species, shortjaw kokopu bury themselves further in the substrate while resting during the day (i.e. they were present in the section but were out of the range of the antenna.

Detection rates did not vary according to diel period or water depth, indicating that the sampling method used here is not biased by activity levels to a significant degree nor confined to either day time or night time application, and that (barring extreme discharge events) this method is equally effective at a variety of flow levels. Slightly lower numbers of tags were detected as water temperature decreased, possibly reflecting the propensity for some NZ freshwater fish to become less active and bury themselves deeper in the substrate during winter (McDowall 1990). However, this relationship could also be due to the passing of time and the lowered detection rates may also represent tag loss and emigration from the study section.

Researchers looking at the effects of 12mm PIT tag implantation on small bodied fish recommend minimum fish lengths of 50mm FL (Baras et al. 2000, Cucherousset et al. 2007), 55mm TL (Ruetz et al. 2006) 70mm TL (Bruyndoncx et al. 2002) or weights of 8g (Das Mahapatra et al. 2001) if growth and survival rates are to be unaffected. The precautionary principle was applied in this study and no fish <70mm TL were tagged. However, results from tagged redfin bullies indicate that the length to weight ratio is more important than body length or weight alone i.e. long, thin fish, in worse condition than conspecifics of a similar length are more likely to succumb to the effects of stress associated with tagging and to subsequent infection that may occur. Redfin bullies are known to spawn in winter through to spring (McDowall 1990) so the higher occurrence of underweight fish in January is likely due to factors other than recent spawning activity, such as lower food availability. It is important to note however, that the apparent non-survival of underweight fish observed could also be due to mortality related to the significant flood event that occurred in January 2008. Keeler et al. (2007) found that survival of PIT tagged slimy sculpin (*Cottus cognatus*) (also a small-bodied benthic fish) was negatively related to maximum stream discharge. During this study, not only were a higher proportion of underweight tagged individuals not redetected after the January flood, there were also less fish of this size caught overall during tagging undertaken in March.

The single confirmed fatality was a large koaro that was gravid at the time of tagging, therefore possibly already under a degree of physiological stress. Post mortem examination showed dark red colouring around the implant site (Fig. 10), probably indicating death from infection.

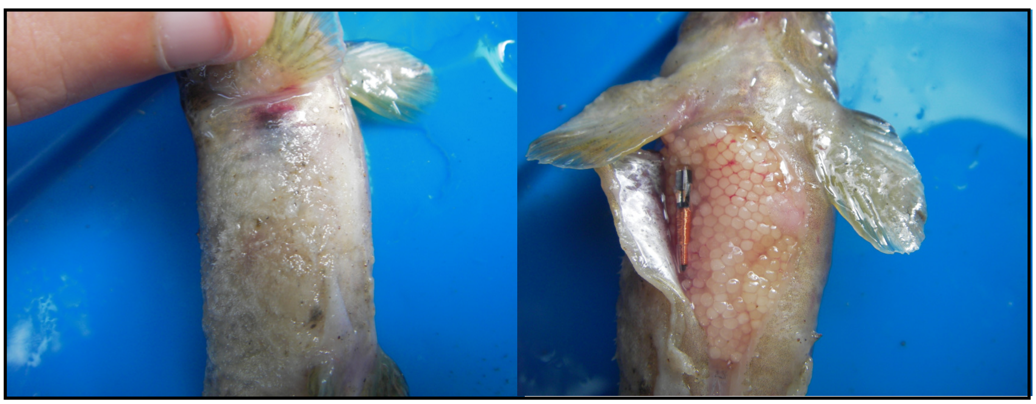

Figure 10. Photos showing the one confirmed tagging fatality. Subject is a mature, gravid female koaro. Dark red appearance of the implant site possibly indicates death from infection.

Shortjaw kokopu could potentially have a relatively higher likelihood of tag retention as only one individual (5% of tagged shortjaw kokopu) was confirmed to have lost a tag, whereas eight redfin bullies and three koaro (12% and 10% respectively) were confirmed to have lost tags. This seems to be supported by the results of 2009 sampling, where shortjaw kokopu were highly overrepresented - 27% of all tags found during February 2009 were shortjaw kokopu despite this species only constituting 18% of the original tagged population as well as being the species least likely to be encountered during 2008 sampling. These results indicate that shortjaw kokopu are more likely than both redfin bullies and koaro to retain PIT tags over a long term period (one year plus). Of the 22 fish that were found during 2009 sampling, 50% were redfin bullies, which contrasts with the higher encounter likelihood previously shown by this species (68% of all redetections in 2008 belonged to redfin bullies). This indicates that long term tag retention is potentially least likely for this species when compared to shortjaw kokopu and koaro.

In summary, we would not recommend 12mm PIT tags for *Anguilla* species if using a small scale, intensive portable monitoring regime such as that described. However, the methodology described has proved to be a highly effective means of gathering large amounts of behavioural data regarding *Galaxias* and adult *Gobiomorphus* species in small streams. In terms of maximising survival, minimum body lengths used here for shortjaw kokopu and koaro ($99mm_{TL}$ and $79mm_{TL}$ respectively) appear to be appropriate, however redfin bullies with a total length of 90mm or more should only be PIT tagged providing they weigh more than 8g and those less than 90mm in length should only be PIT tagged if they weigh more than 6g. Extra precaution should also be applied to gravid fish – especially when working with threatened species. If investigating short term discrete relationships (e.g. microhabitat use) a minimum of twelve monitoring sessions, divided approximately equally between day and night, single detection rates of around 80% and multiple (5+) could produce redetection rates of around 70% if working with similar species in similar streams. If investigating longer term trends (e.g. growth) adjustments should be made to the described methodolgy as progressively lower redetection rates can be expected as a result of tag loss and emigration. If resources permit it, fixed instream antennae at the top and the bottom of the study reach would give additional valuable information regarding immigration and emigration to and from the study reach.

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Chapter 3.

Microhabitat requirements of three New Zealand native freshwater fish species in a small stream community.

ABSTRACT

The substrate and flow characteristics of a 100m reach of small upland stream was drawn to scale and microhabitat inventoried with each $0.25m^2$ grid square assessed according to 16 physical variables. Sixty seven redfin bullies (*Gobiomorphus huttoni*), 21 shortjaw kokopu (*Galaxias postvectis*) and 30 koaro (*Galaxias brevipinnis*) were PIT tagged within the reach and monitored during day and night in 2008, allowing the physical characteristics of the grid squares where fish were found to be compared with those where fish were not found. Redfin bullies and shortjaw kokopu showed strong associations with large substrates and large interstitial refuge spaces and both species showed marked diel differences in microhabitat utilisation. Koaro tended to be associated with high velocity and surface turbulence and used similar microhabitat types regardless of diel period. No size-based or seasonal differences were found regarding microhabitat use for any species. Potential segregation was observed between shortjaw kokopu and koaro but no other biotic influences on habitat utilisation were apparent.

INTRODUCTION

Comprehensive and multi-scale understanding of the microhabitat requirements of freshwater fish is essential when identifying causes of decline in freshwater fish populations and when designing restoration schemes to combat such declines. While research at a catchment scale has defined the relationships between native freshwater fish distributions and land-use types in New Zealand (Rowe et al. 1999, Joy and Death

2003, 2004, Leathwick et al. 2005), finer scale studies investigating habitat requirements are sparse and many questions remain unanswered. Researchers who spend large amounts of time in the field quickly realise that there are strong links between fish and particular microhabitat variables but very little empirical data exists to confirm these ideas and most remain anecdotal.

Previously in New Zealand, methodologies developed overseas have been used to determine habitat requirements of freshwater fish. For example, the Instream Incremental Flow Methodology (IFIM – Jowett & Richardson 1995) is currently used widely throughout the country as a means of determining minimum flow standards. However, IFIM was developed in North American streams, using diurnal pelagic species and is thus likely unsuitable for application to the New Zealand native freshwater fauna which are primarily benthic and nocturnal (McDowall 1990).

When studying aspects of behaviour, it is important to cause as little disturbance as possible and thus minimise chances of affecting the behaviour under scrutiny. The use of electrofishing to categorise microhabitat requirements in New Zealand (Baker and Smith 2007, Crow 2007) is not ideal as it is a highly invasive sampling technique and prone to spatial inaccuracy – by the time an electroshocked fish becomes visible it is often far from the position it was originally occupying (Crow 2007). Studies from overseas (Henry and Grossman 2008, Martinez-Capel et al. 2009) have used snorkelling surveys to measure microhabitat use – a non-invasive method, but one that is limited to swimmable streams

Advances in Passive Integrated Transponder (PIT) technology have allowed progressively smaller fish to be tagged and have facilitated non-invasive field monitoring with the use of portable transceivers (see Roussel et al. 2000). Unlike conventional radio tags, PIT tags do not carry a battery but respond to power momentarily transmitted through an antenna placed within 100mm – 750mm (depending on tag size) of the tag to transmit an individual identity code, thus providing an ideal means of studying small-bodied fish behaviour at very fine scales. With a portable monitoring system, PIT tagged fish need not be recaptured, which enables behavioural data to be collected with minimal disturbance. Of particular relevance to New Zealand native fish, PIT tagged individuals can also be detected within the benthos, as tags can be read through substrate, which enables behavioural data to be collected with maximum accuracy. The efficacy of portable PIT technology has been evaluated by a number of researchers (Roussel et al. 2000, Hill et al. 2006, Cucherousset et al. 2007, Linnansaari and Cunjak 2007) and deemed highly suitable for application to studying microhabitat use in wadeable streams.

This study is the first in New Zealand to use non-invasive portable PIT monitoring to measure microhabitat use of native freshwater fish. We aimed to comprehensively define the microhabitat requirements of three charismatic native freshwater fish species living as components of a larger fish community in a small stream: *Gobiomorphus huttoni* (Ogilby, 1894) (redfin bully), *Galaxias postvectis* Clarke, 1899 (shortjaw kokopu) and *Galaxias brevipinnis* Günther, 1866 (koaro) (common names are used hereafter). As the species in question are living in sympatry in the same macroenvironment, fine scale differences between species and potential interactions between species were also able to be examined.

MATERIALS AND METHODS

Site description, reach mapping and habitat inventorying

The Mangaore stream is a third order, eastern tributary of the Manawatu River (Fig. 1), with 92% of its headwaters still covered in indigenous forest and scrub (Wild et al. 2004). Nine native fish species are present in the Mangaore stream (see page 12), three of those in relatively high densities – redfin bully, shortjaw kokopu and koaro. A 100m reach of the stream was selected based on a high level of physical heterogeneity and the substrate and flow characteristics of the reach were mapped and drawn to scale (Fig. 2).

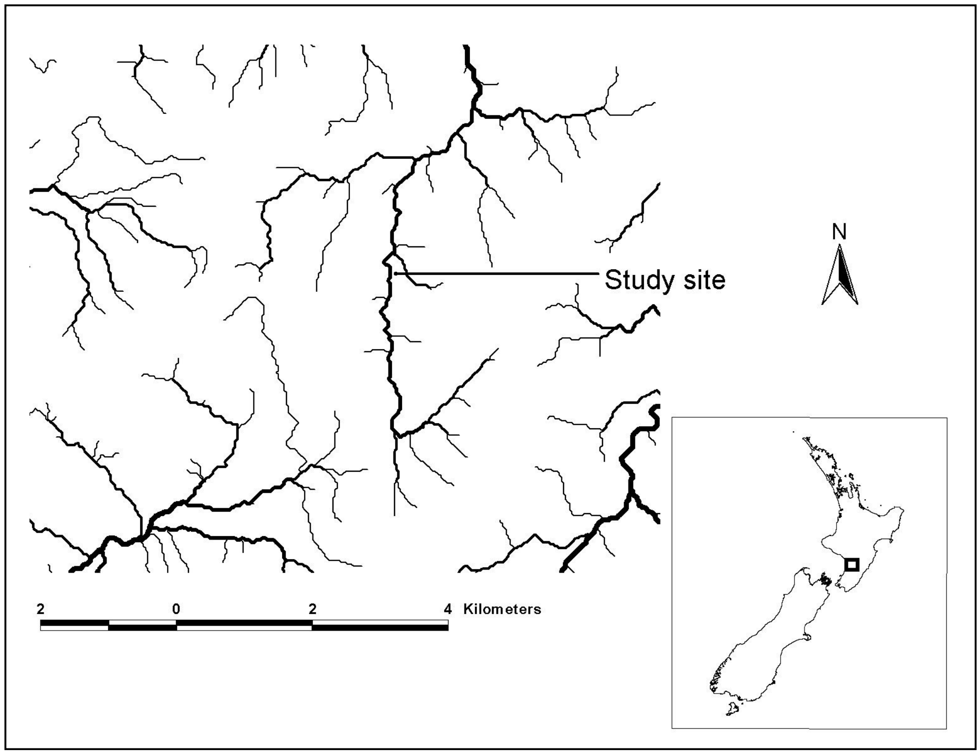

Figure 1. Map showing the location of the Manawatu catchment (inset) and the study site on the Mangaore stream.

Each 0.25m² coordinate square was assessed independently according to 16 physical habitat variables (Table 1). All microhabitat inventorying was conducted between a flood event that occurred in April and another in July, with coordinates to be inventoried selected on a random basis. Due to the potential for physical variables to change, inventorying was stopped after the July flood, by which time 82% (1112 individual coordinates) of the entire reach had been inventoried.

PIT tagging and monitoring

Fish in the study reach were collected using a combination of multiple pass electrofishing and repeated spotlighting and were caught and tagged during two periods: 01 - 03 January 2008 and 21 - 24 March 2008. All fish were anesthetised using 2-phenoxyethanol (0.2ml l^{-1}), weighed and measured (to the nearest 0.1g and $1mm_{TL}$ respectively) and implanted with a 12.5mm, 0.06g PIT tag (Biomark Inc.) to the right of the ventral midline, directly under the pectoral fin.

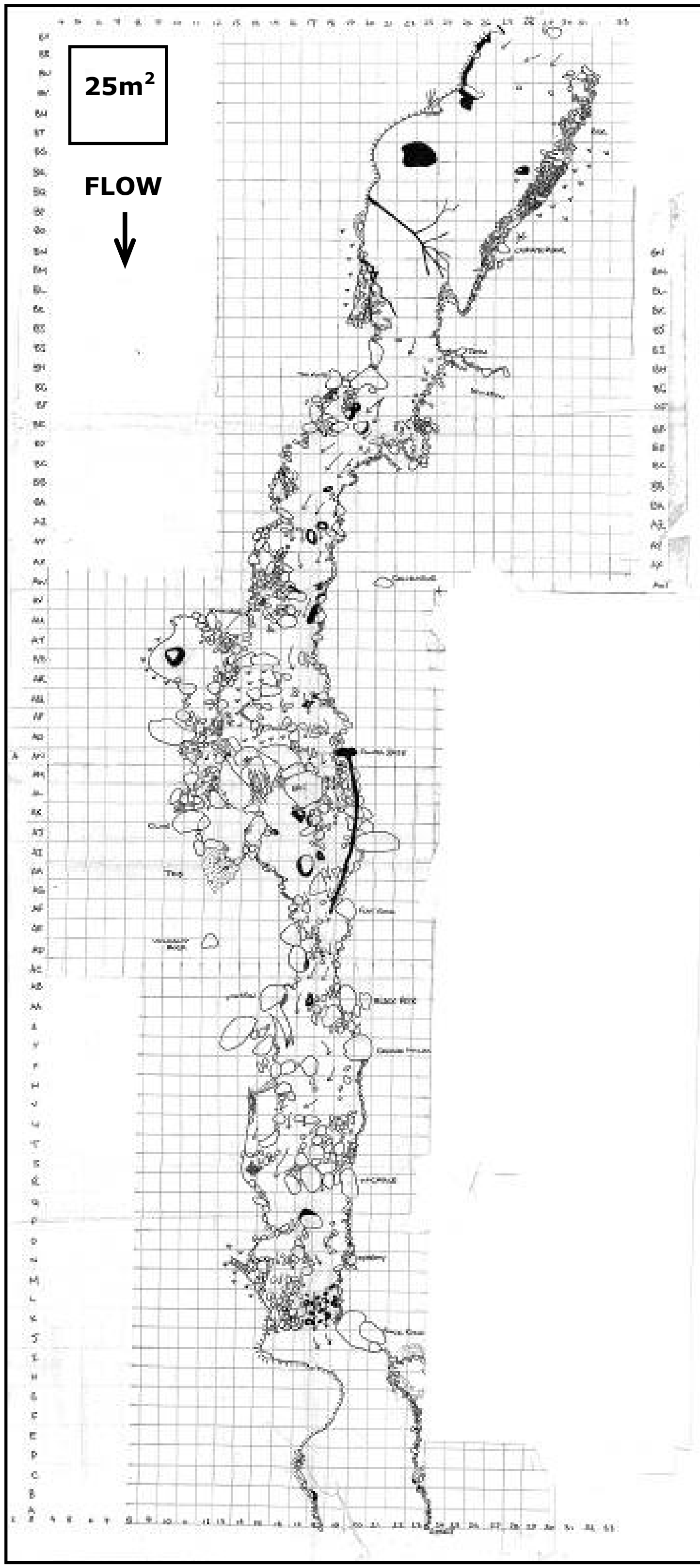

Figure 2. Map of the 100m study reach drawn to scale. A copy of the map (field copies were ~3.5 times larger than the image depicted) was carried for each sampling session in order to record the locations of tagged fish.

Table 1. Microhabitat variables collected for each 0.25m^2 of stream.

Microhabitat Variable	*Assessment Method*	*Units*	*Min*	*Max*	*Mean ± SD*
Velocity at substrate	Marsh-McBirney™ Model 2000 Flowmate	m/s	0	2.1	0.2 ± 0.3
Surface Turbulence	Visual	Zero (0), low (20), medium (40), high (60), very high (80)	0	80	23 ± 23
Depth	Ruler	cm	1	88	20 ± 14
Non-rock Instream Cover	Visual with bathyscope	Proportion of coordinate where present	0	0.8	0.0 ± 0.0
Non-rock Outstream Cover	Visual with bathyscope	Proportion of coordinate where present	0	1	0.0 ± 0.1
Interstitial Refuge Space Large (IRS large)	Visual, defined as approximately how many redfin bullies would be able to achieve total shelter in intertices.	Zero (0), one (20), <5 (40), ≥5 (60)	0	60	19 ± 24
Interstitial Refuge Space Small (IRS small)	Visual, defined as approximately how many redfin bullies would be able to achieve total shelter in intertices.	Zero (0), one (20), <5 (40), ≥5 (60)	0	60	38 ± 22
Bedrock	Visual with bathyscope	Proportion of substrate	0	1	0.0 ± 0.1
Boulders (>256mm)	Visual with bathyscope	Proportion of substrate	0	1	0.3 ± 0.3
Large Cobbles (128-256mm)	Visual with bathyscope	Proportion of substrate	0	0.9	0.2 ± 0.2
Small Cobbles (64-128mm)	Visual with bathyscope	Proportion of substrate	0	0.8	0.1 ± 0.1
Large Gravel (16-64mm)	Visual with bathyscope	Proportion of substrate	0	0.8	0.1 ± 0.2
Small Gravel (2-16mm)	Visual with bathyscope	Proportion of substrate	0	0.9	0.1 ± 0.1
Sand	Visual with bathyscope	Proportion of substrate	0	0.9	0.0 ± 0.1
Silt	Visual with bathyscope	Proportion of substrate	0	0.9	0.0 ± 0.1
Leaves	Visual with bathyscope	Proportion of substrate	0	0.6	0.0 ± 0.1

All tagging was assisted with a hand-held 12-gauge implanter and all implanters, tags, hands and implant sites were washed with an iodine solution (Betadine™) prior to implantation. Fish were allowed to recover from anaesthesia in in-stream cages and, when fully recovered, were released back into the approximate area of the study reach where they were caught. Monitoring of the study reach was conducted by a single researcher systematically moving upstream, scanning the entire bed of the study reach with the PIT tag antenna fixed onto the end of a wooden handle and the PIT tag reader attached to a harness so that the screen could be read (Fig. 3).

Figure 3. Modifications made to equipment to render it portable. Care was taken while sampling to cause as little physical disturbance as possible.

The antenna was moved slowly over the substrate and upon detection of a tag, repositioned a number of times until the position of the tag could be determined with an accuracy of approximately 50-100mm. A copy of the stream map was carried on each sampling occasion and the location of each tag entered in the corresponding coordinate on the map, which could be then matched up with the microhabitat variables measured in that coordinate. Sampling was conducted slowly and precisely, with care taken to cause as little physical disturbance as possible and maximise the number of redetections per sample. If a tag was repeatedly detected in the same location on more than five consecutive occasions then the tag was physically searched for by disturbing the substrate until either the tag stopped emitting (the fish swam away) or sufficient disturbance had occurred for the still-emitting tag to be classified as lost.

Day surveys were carried out between 9am and 3pm and night surveys were carried out between 7pm and midnight, commencing at least one hour after sunset. The reach was sampled 25 times during the day and 20 times at night (assisted by a spotlight) over March to July 2008. On 14 of the night surveys, positions of visible untagged fish were also noted.

Statistical analysis

The substrate composition variables were condensed for each coordinate into a single variable – substrate size, by summing the products of the minimum axis length of each particle size class (with sand, silt and bedrock being assigned lengths of 0.5mm, 0.1mm and 0mm respectively) multiplied by the proportion of the benthos covered by that particle size class and the proportion of the benthos covered by leaves was added to the variable "non-rock instream cover". Eight microhabitat variables remained for analysis.

Non-parametric Wilcoxen Mann-Whitney tests (PROC NPAR1WAY in SAS 9.1) were performed on each individual microhabitat variable to ascertain whether there were significant differences between the coordinates used by each species and the coordinates not used by each species. The strength and direction of the exposed relationships between fish and microhabitat variables were inferred from the Z-scores generated from this testing. Day time data and night time data were examined separately. Data collected during March and April (median water temp 13.7 ºC) were compared with data collected during May, June and July (median water temperature 8.8ºC) to examine seasonal effects and data for small fish (redfin bullies <70mm; shortjaw kokopu <100mm; koaro <100mm) was compared with data for large fish (redfin bullies >80mm; shortjaw kokopu >180mm; koaro >120mm) to examine size related effects (size class thresholds were derived according to size distributions of tagged fish). In addition, all testing was carried out on 3 separate matrices: tagging data only, spotlighting data only (untagged fish) and both tagging and spotlighting data to explore any differences in results occurring with each experimental method.

As a large number of univariate relationships were examined, all p-values generated during analysis were corrected for false discovery (PROC MULTTEST in SAS 9.1).

Ward's minimum-variance cluster analysis (PROC CLUSTER in SAS 9.1) was performed on the microhabitat variables directly related to the stream channel (depth, velocity, surface turbulence, interstitial refuge space small, interstitial refuge space large, substrate size and substrate stability) to establish *a posteri* "macrohabitats" similar to traditionally used pool-run-riffle scales and Chi-square goodness of fit testing (see McDonald 2008) was carried out on the proportions of species found in each cluster versus the proportional availability of each cluster type to show whether utilisation of these macrohabitats was random or showed patterns. The number of clusters was manually reduced in a step-wise fashion to remove undue influence of any outliers, thereby producing clusters of a reasonable size.

RESULTS

One hundred and seventeen individual fish were tagged and monitored (Table 2) and detection rates were 76%, 71%, and 83% respectively for redfin bully, shortjaw kokopu and koaro. Sixty five percent of all individuals were redetected five times or more. Observations of redfin bully and shortjaw kokopu were supplemented by 323 and 89 spotlighting records respectively, giving a total of 1094 datapoints for analysis.

Redfin bullies showed significant associations with all variables except outstream cover, shortjaw kokopu with all variables except outstream cover and depth and koaro with all variables except instream cover and interstitial refuge space small (Table 3). The type and strength of relationships between fish and microhabitat variables differed markedly between day and night for redfin bullies and shortjaw kokopu, whereas koaro showed similar habitat utilisation patterns regardless of diel period (Fig. 4). Redfin bullies and shortjaw kokopu also shared similar variable associations to each other, both being strongly associated with higher than average interstitial refuge spaces and substrate sizes during the day, then shifting to associate with smaller substrates, lower velocities and lower surface turbulence at night.

Table 2. Characteristics of data obtained from monitoring regimen for three native freshwater fish species.

Common name (SPECIES CODE)	*Number of tagged individuals (size range mm_{TL})*	*Number of tags detected at least once*	*Number of tags detected at least 5 times*	*Total number of datapoints from tagged fish*	*Number of datapoints from spotlighting (size range mm_{TL})*	**Total datapoints**
Redfin bully (RFB)	67 (75-111)	51	43	488	323 (30-110)	811
Shortjaw kokopu (SJK)	21 (99-204)	15	11	69	89 (100-200)	158
Koaro (KOARO)	29 (79-155)	24	22	125	0 (N/A)	125
Total	117	93	76	682	412	1094

Koaro on the other hand, strongly favoured shallow areas of high velocity and surface turbulence, while also being associated with large substrates and interstitial refuge sizes. With the exception of koaro and outstream cover, for all associations that were present during both day and night, the association was strongest during the day. Redfin bullies were more strongly associated with small interstitial refuge spaces than large and shortjaw kokopu and koaro were more strongly associated with large interstitial refuge spaces than with small. With the exception of koaro, one (redfin bullies) and both (shortjaw kokopu) of the refuge space variables had larger Z-scores than substrate size. No significant differences were found between variables used by fish during March – April and during May – July (all p values > 0.46) or between small and large fish (all p values > 0.42).

Clear differences in type and strength of night time variable associations were found between the two methods with regards to redfin bullies and shortjaw kokopu (no koaro were observed by spotlight) (Table 4).

Table 3. Descriptive statistics for microhabitat variables in which fish were found. P values were derived from Mann Whitney testing of the physical characteristics for coordinates where fish were found versus coordinates where fish were not found. * <0.05; ** <0.01; *** <0.001. All P values were post hoc corrected for false discovery.

	Redfin Bully				*Shortjaw Kokopu*				*Koaro*			
	Day (n=145)		Night (n=304)		Day (n=18)		Night (n=97)		Day (n=38)		Night (n=42)	
Microhabitat Variable	Mean ± SE	P	Mean ± SE	P	Mean ± SE	P	Mean ± SE	P	Mean ± SE	P	Mean ± SE	P
Velocity at substrate	0.1 ± 0	-	0.1 ± 0	*	0.2 ± 0.1	-	0.1 ± 0	***	0.5 ± 0.1	***	0.3 ± 0.1	*
Surface Turbulence	26 ± 2	*	16 ± 1	***	33 ± 6	-	14 ± 2	***	55 ± 4	***	49 ± 4	***
Depth	21 ± 1	-	22 ± 1	**	22 ± 4	-	22 ± 1	-	11 ± 1	***	12 ± 1	***
Non-rock Instream Cover	2.2 ± 0.6	-	2.8 ± 0.5	**	2.2 ± 1.1	-	3.8 ± 1	***	0.9 ± 0.4	-	1.5 ± 0.6	-
Non-rock Outstream Cover	0.8 ± 0.2	-	1 ± 0.4	-	0 ± 0	-	1.3 ± 1.1	-	1.1 ± 0.4	*	1.8 ± 0.8	*
Interstitial Refuge Space Large	33 ± 2	***	23 ± 1	*	48 ± 5	***	29 ± 2	***	32 ± 4	-	27 ± 4	**
Interstitial Refuge Space Small	51 ± 1	***	42 ± 1	***	56 ± 3	**	45 ± 2	**	44 ± 3	-	39 ± 3	-
Substrate Size	156 ± 5	***	119 ± 4	-	192 ± 11	***	130 ± 6	*	168 ± 11	***	148 ± 12	*

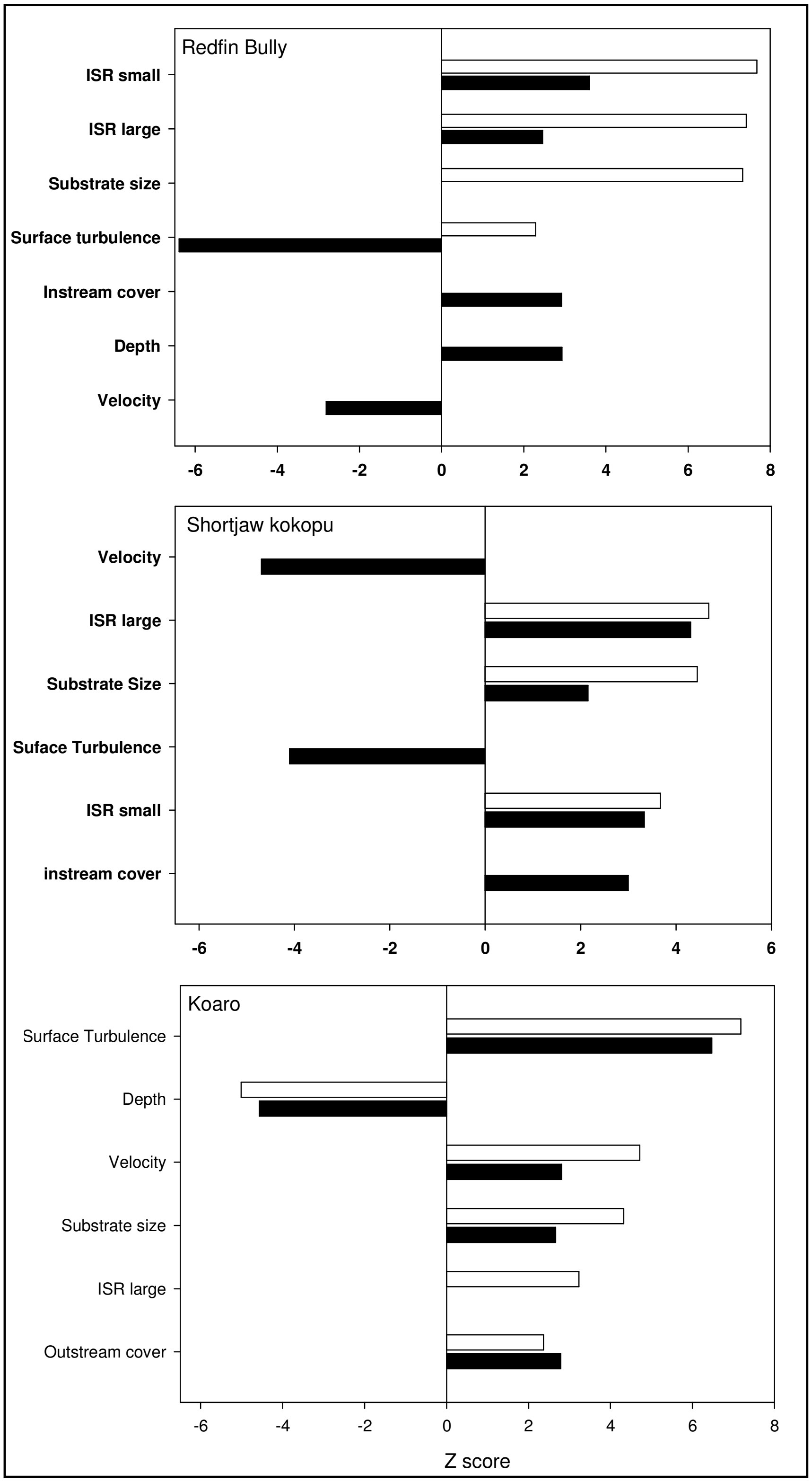

Figure 4. Significant associations between fish and microhabitat variables drawn from Mann Whitney testing of coordinates where fish were found versus coordinates where fish were not found. Microhabitat variables are listed in order of importance for each species. Solid bars represent night time associations and hollow bars represent day time associations. Length of the bar denotes the strength of the association and the direction of the bar shows whether the association is positive or negative.

Table 4. Results of Mann Whitney testing on three separate matrices – data from tagged fish only, data from untagged fish obtained by spotlighting and both types of data combined. Only night time tag data is used to facilitate a valid comparison. No koaro were observed by spotlight. X indicates a statistically non-significant association.

Z scores from Mann-Whitney testing

Microhabitat variable	Redfin bully			Shortjaw kokopu			Koaro		
Method:	Tags	Spotlight	Both	Tags	Spotlight	Both	Tags	Spotlight	Both
n:	(145)	(323)	(468)	(48)	(89)	(137)	(39)	(0)	(39)
Depth	x	3.16	2.93	2.22	x	x	-4.57	n/a	-4.57
Velocity at substrate	x	-4.86	-2.78	-2.19	-5.01	-4.55	2.81	n/a	2.81
Surface Turbulence	x	-9.89	x	x	-6.03	x	6.47	n/a	6.47
Non-rock Instream Cover	x	3.90	2.93	x	4.18	3.01	x	n/a	x
Non-rock Outstream Cover	x	x	x	x	x	x	2.78	n/a	2.78
Live Overhanging Vegetation	x	x	x	x	x	x	-4.18	n/a	-4.18
Interstitial Refuge Space Large	5.95	x	2.48	5.60	2.19	4.32	2.14	n/a	2.14
Interstitial Refuge Space Small	6.15	x	3.62	3.87	2.13	3.35	x	n/a	x
Substrate Size	4.95	-3.18	x	4.04	x	2.17	2.66	n/a	2.66
Substrate Stability	2.56	2.26	2.75	4.64	4.37	5.88	x	n/a	x

Clustering of the microhabitat variables produced 4 distinct clusters within the microhabitat variables (Table 5), which were assigned names according to the variables that characterised the groups. Cluster one ("unstable pools") grouped coordinates with low substrate size, low refuge space availability and low surface turbulence. This cluster represented mainly the wide gravel pools found where the stream turns a corner although a, shallow, slow-flowing area of larger substrates adjacent to a riffle has been included in this cluster, which is most likely responsible for the large standard deviation values for the substrate size and refuge variables.

Table 5. Descriptive statistics for four macrohabitat types determined by cluster analysis performed on the stream channel microhabitat variables. A descriptive title was assigned to each cluster based on its physical characteristics.

Cluster:	*One Unstable pools (n=523)*	*Two Flow channel (n=301)*	*Three Stable pools (n=224)*	*Four Bedrock edge (n=64)*	*Overall variable availability (n=1112)*
Microhabitat Variable	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Depth (cm)	17 ± 10	19 ± 10	17 ± 11	59 ± 12	20 ± 14
Benthic velocity	0.1 ± 0.2	0.3 ± 0.4	0.0 ± 0.1	0.0 ± 0.1	0.2 ± 0.3
Surface turbulence	18 ± 20	43 ± 20	11 ± 17	14 ± 15	23 ± 23
ISR small	23 ± 17	58 ± 7	48 ± 18	31 ± 20	38 ± 21
ISR large	2 ± 6	41 ± 19	33 ± 23	17 ± 23	20 ± 24
Substrate size	79 ± 48	180 ± 53	138 ± 65	72 ± 47	118 ± 69

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Cluster two ("flow channel") included all the runs and riffles in the study reach. This cluster consisted of coordinates with high velocity, high surface turbulence and high levels of large substrates and interstitial spaces. Cluster three ("stable pools") is distinct from unstable pools (cluster one) by being smaller, discrete areas made up of large substrate particles around the edges of the river bed, rather than part of the main channel. Cluster four ("bedrock edge") was characterised by steep-banked, deep areas dominated by bedrock – erosion zones that are associated with the depositional zones identified in cluster one.

Redfin bullies and shortjaw kokopu again showed very similar utilisation patterns with regard to the four macrohabitat clusters, while koaro again distinguished themselves from the other two species with regard to the type of habitat utilised and a high degree of similarity between day and night utilisation patterns (Fig. 5-7). Observed and expected proportions of cluster use were significantly different for all species at all times (Chi-square goodness of fit testing; all p values < 0.05). Redfin bullies and shortjaw kokopu were found in all clusters although only to a negligible degree in bedrock edge environments. During the day these two species were found mostly in the flow channel but also to a lesser degree in stable and unstable pools. At night, these associations were inverted, with both species being found much less often in the flow channel and more often in both stable and unstable pools. Habitat use by koaro was highly specific, with all individuals being found almost exclusively in the flow channel.

DISCUSSION

This study found clear associations between fish and microhabitat variables at both a $0.25m^2$ and a pool-run-riffle scale and found clear similarities and differences between species. These associations did not vary according to season or body size of fish. The observed overall strong dependence on interstitial refuge space, the clear differences between day time and night time habitat use and the differentiation between 2 types of pools have strong implications for future freshwater management in New Zealand. The use of spotlighting data to complement PIT tag data appeared appropriate in future similar studies where only a subset of a population is tagged.

Shortjaw kokopu and redfin bully occurrence was highly dependent on substrate characteristics and both species showed very similar microhabitat (at a $0.25m^2$ scale) and macrohabitat (at a pool-run-riffle scale) requirements. In addition, both species showed distinct differences in habitat utilisation patterns at night when compared to patterns during the day. Although shortjaw kokopu microhabitat requirements appeared more restrictive than those of redfin bullies, they are very similar at these observational scales. Elsewhere, in similar stream types, shortjaw kokopu and redfin bullies are often found occurring together (e.g. see Chadderton and Allibone 2000, Joy and Death 2000, Allibone 2002). Shortjaw kokopu have small mouths compared to other native fish species and have no obvious canine teeth (McDowall 1990). Dietary analyses (McDowall et al. 1996) have found only invertebrates in shortjaw kokopu diet so it can be assumed that no predator-prey interactions exist between these species. Competition for food or habitat may be occurring and some degree of spatial segregation is likely as these species are sharing the same habitats at a $0.25m^2$ observational scale and both feed to varying degrees by foraging in the benthos (McDowall 1990; McDowall et al 1996). While further research would be required to discover and define any such biotic interactions, from a management

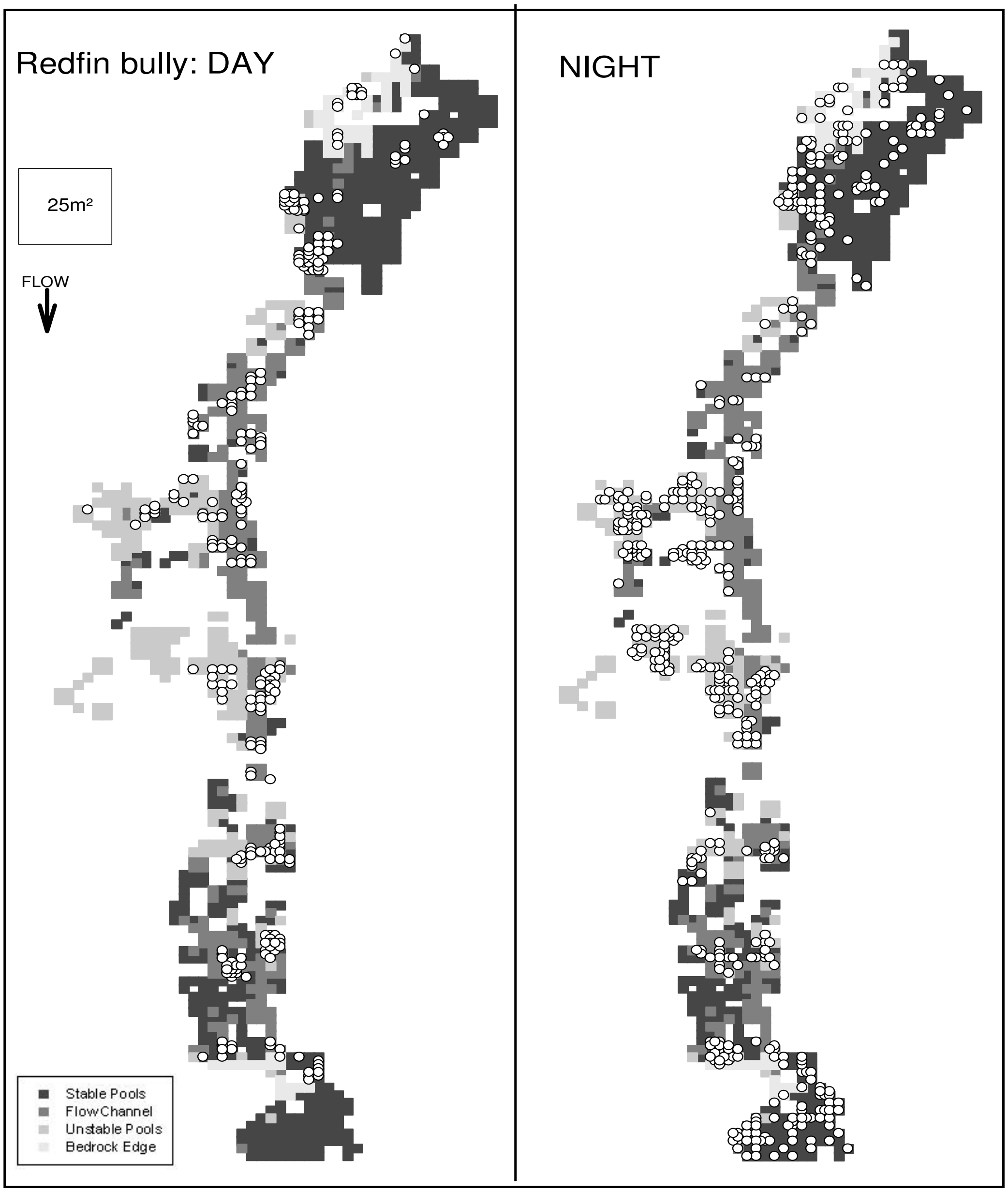

Figure 5. Plots of the study reach, with each coordinate coded according to cluster membership. Locations where redfin bullies were found are superimposed. Redfin bully cluster use was significantly non-random (χ^2goodness of fit) day = 7.68, 3df, P = 0.053; night = 45.24, 3df, P < 0.001.

Figure 6. Plots of the study reach, with each coordinate coded according to cluster membership. Locations where shortjaw kokopu were found are superimposed. Shortjaw kokopu cluster use was significantly non-random (χ^2goodness of fit) day = 45.37, 3df, P = <0.001; night = 11.68, 3df, P = 0.008.

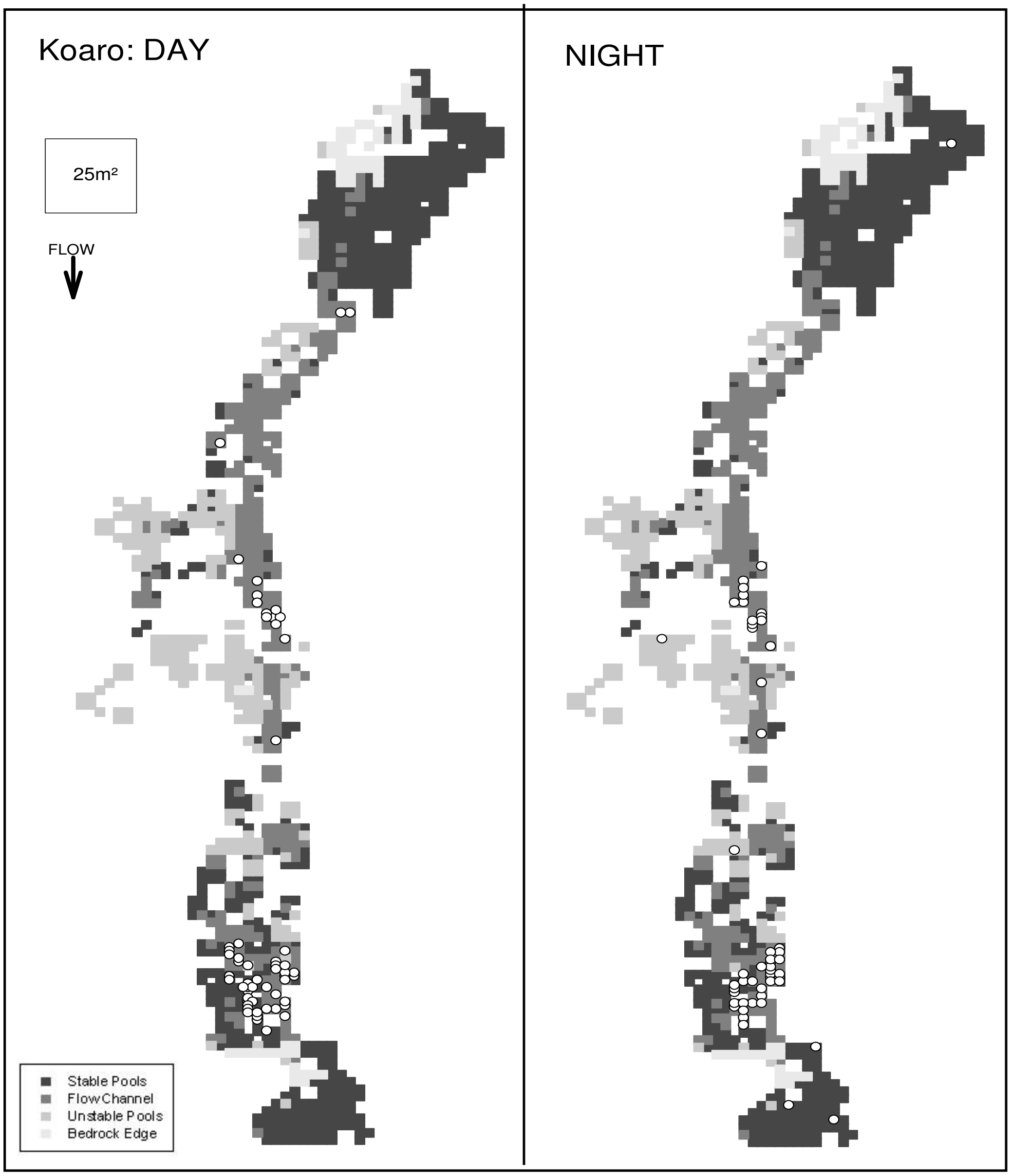

Figure 7. Plots of the study reach, with each coordinate coded according to cluster membership. Locations where koaro were found are superimposed. Koaro cluster use was significantly non-random (χ^2goodness of fit) day = 26.08, 3df, P < 0.001; night = 16.20, 3df, P = 0.001.

efficiency perspective this study has shown that habitat criteria that are assessed as suitable for shortjaw kokopu can also be assumed suitable for redfin bullies. The converse however, can not be assumed as redfin bullies occupied a wider range of habitats than shortjaw kokopu during this study and are known to have a much wider distribution on a national scale (McDowall 1990).

In contrast to redfin bullies and shortjaw kokopu, koaro showed strong dependence on depth and flow and were virtually exclusively found in fast flowing, highly turbulent zones and for koaro, these associations varied only slightly with diel period. While koaro possess physical characteristics suited to fast flowing turbulent environments (streamlined, "aerofoil" body shape, large pectoral fins), they are also found in lakes (Mcdowall 1990) and have been observed feeding in stream pools (Hayes 1996). The high degree of microhabitat specificity exhibited by the study population could be partly due to the presence of shortjaw kokopu, as both Main (1988) and Chadderton & Allibone (2000) found that koaro living in sympatry with banded kokopu (*Galaxias fasciatus* Gray, 1842) in streams restricted themselves to riffle habitat to a higher degree than when banded kokopu were not present. Similar segregation may be occurring in the Mangaore stream as shortjaw kokopu share a similar size and body shape with banded kokopu and may present similar types of aggression towards or competition with koaro.

Seasonal differences in microhabitat use of freshwater fish species have been observed in a number of long term studies. Most researchers attribute such changes to concurrent physical habitat changes (Grossman and Freeman 1987, Grossman and Ratajczak 1998), although some show that changes in water temperature (David 2003; Gillette et al. 2006) can also be implicated. Most species of New Zealand native freshwater fish are typically less noticeable during winter (McDowall 1990), when water temperatures are at their lowest which can be attributed to lowered activity levels associated with lowered metabolic needs, resulting in increased time spent concealed within available substrates. The methodology used in this study is independent of fish activity so while fish may have been less active and spent more time lying "dormant" within the substratum during the colder months, such changes were not detected. Regardless of potential changes in activity levels the physical characteristics of the locations where fish carried out any given activity did not change. However, differences in microhabitat use unrelated to habitat change by the New Zealand giant kokopu *Galaxias argenteus* (Gmelin, 1789) have been found between winter and summer (David 2003) – similar behaviours may be expressed by the species studied here that were not evident during the less extreme temperature differences between autumn and winter.

No intraspecific differences in microhabitat use were observed between small and large individuals. Such differences have been observed in rainbow trout (Baltz and Moyle 1984) and giant kokopu (Whitehead et al. 2002; Hansen and Closs 2005) although these species are pelagic and predominantly drift/surface feeders and thus, when feeding in pools would be faced with the choice of a limited number of positions to occupy with differing amounts of access to drifting invertebrates. While shortjaw kokopu and koaro have both been found with terrestrial items in their stomach (McDowall 1990; McDowall et al. 1996), both show morphological specialisations for picking/grazing invertebrates off the substrate and redfin bullies are apparently wholly dependent on aquatic invertebrates in terms of diet (McDowall 1990). These feeding strategies likely render these species less disposed towards food competition in a heterogeneous benthos as benthic invertebrate prey is typically more widely distributed compared to column or surface drifting prey. However, habitat competition could be occurring that was not detected due to the observational scale used here. For example, both small and large shortjaw kokopu showed positive associations with large interstitial refuge spaces - if refuge space was able to be quantified and measured on a finer scale, intraspecific spatial segregation (and thus fine differences in some microhabitat parameters) may become apparent.

This study has shown that the definition and measurement of interstitial refuge availability is not only applicable and size specific to native fish but is highly important in terms of habitat requirements in streams physically similar to the Mangaore stream. The higher relative importance of interstitial refuge space during the day observed here indicates that large interstitial spaces are indeed being used for resting/refuge purposes, rather than sources of benthic invertebrate prey. These spaces become less important for redfin bullies and shortjaw kokopu or not important at all for koaro at night time when all three species do most, if not all of their foraging (Glova and Sagar 1989; McDowall 1990; McDowall et al 1996). New Zealand native freshwater fish are known as secretive and rarely encountered during the day when they take cover in a variety of ways – using rocks, undercut banks and submerged logs (Mcdowall 1990). A requirement for refuge space is logically born from a need to hide from something. The New Zealand native freshwater fish fauna is conspicuous for its absence of specialized piscivores (McDowall 1990), therefore the widespread requirement for daytime cover exhibited by freshwater fish most likely evolved to avoid terrestrial predation from birds – especially the formerly abundant seabird species that used to nest in high densities throughout mainland New Zealand (Rayner et al. 2008). The observed much lower association with interstitial refuge space shown by koaro possibly indicates that their requirement for daytime cover is less than for redfin bullies and shortjaw kokopu as, by restricting themselves to riffle areas, koaro also achieve cover from terrestrial predation through surface turbulence.

The observed clear differences in habitat use between day time and night time exhibited by redfin bullies and shortjaw kokopu serve to illustrate the importance of appropriate sampling regimens. The results of this study show that the widely used IFIM is likely to be missing a significant data component, while information regarding daytime refuge requirements is taken into account, habitat requirements associated with night time foraging are not.

Both clustering of microhabitat data and the behaviour of the fish themselves clearly differentiated between two types of pools in the study reach. This distinction is important as traditional habitat classification methods only recognise one type of pool (e.g. Chadderton and Allibone 2000; Allibone 2002; Rowe and Smith 2003; Baker and Smith 2007), which are viewed as suitable habitat for shortjaw kokopu (Chadderton & Allibone 2000; Allibone et al 2003). This study has shown that, while "unstable pools" (those usually formed by ongoing erosion and deposition) provide suitable foraging habitat at night, they provide much less suitable sheltering habitat during the day than "stable pools (those formed by large boulders and "islands" from past large scale disturbance events), which were used during both day and night by shortjaw kokopu. The same patterns were observed for redfin bullies. This finding can most likely be extrapolated to the majority of second and third order streams with similar hydrographs and catchment geology as the main differences between the two pool types is directly related to the size of the substrate particles and the size of the interstices between them.

The different conclusions reached by the different sampling methods are not surprising as the PIT tag method covered all macrohabitat types in the study section, while the spotlighting method covered only areas of zero or low surface turbulence – pools where microhabitat variables tended towards uniform values. Because of this, using spotlighting data only would obviously lead to biased conclusions as the PIT tag method showed that all three species utilised a wide range of habitat types other than pools. However, use of PIT tag data alone could produce an opposite, albeit smaller bias - difficulty was often experienced in detecting tags in these wide pool environments as fish were occasionally spooked by the spotlight and would seek cover, thereby while still facilitating a placement record in a coordinate, also removing any chance of the researcher getting close enough to read whether they had a tag or not. This was especially true for shortjaw kokopu. This, together with the fact that obviously only a very small proportion of the resident population had been tagged (as large amounts of untagged fish of both species were observed) leads us to believe that the addition of the spotlighting data has complemented the PIT detection dataset and we consider that the two methods used in conjunction provide the most accurate representation of freshwater fish microhabitat use.

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Chapter 4.

Behavioural responses to flooding of three native fish species in a small, upland New Zealand stream.

ABSTRACT

Sixty seven redfin bullies (*Gobiomorphus huttoni*), 21 shortjaw kokopu (*Galaxias postvectis*) and 29 koaro (*Galaxias brevipinnis*) were tagged with Passive Integrated Transponder (PIT) tags and monitored in a 100m section of a small, upland stream before, during and after 3 flood events in 2008. A total of 31 individuals were detected during flood conditions and were found either within 0.5 metres of the base flow stream bed edge or inside the base flow stream bed in areas with large boulder substrates. A subset of the population was found returning to the same locations during multiple floods, indicating that individuals may have specific areas that they utilise in a habitual fashion during high discharge events. Individual fish detected during high flows were significantly less familiar in comparison to the subset of individuals that were commonly resident in the study reach during base flow conditions, showing that tagged fish made larger scale movements during flood conditions. While small changes in community composition occurred that were able to be attributed to flood-induced microhabitat changes, overall a remarkable level of persistence was observed in the tagged community, with over half of all individuals remaining in or returning to the same 100m section of stream following each flood.

Keywords freshwater fish; floods; behaviour; PIT tags; habitat mapping

INTRODUCTION

Relatively little research has been conducted regarding the immediate effects of flooding on freshwater fish. The limited studies that have been carried out show that such effects can vary greatly, be species specific (Matthews 1986, Jowett and Richardson 1989), size specific (Allen 1951, Elwood and Waters 1969) and habitat specific (Jowett and Richardson 1989, Godlewska et al. 2003). However, those studies that conducted follow up sampling (two or more weeks after a flood) consistently found that most fish community parameters returned to a pre-flood state i.e. they showed that fish persist through flood events, providing significant habitat alteration does not occur (Matthews 1986 and references therein; Chapman and Warburton 2006). Obviously, freshwater fish can express behaviours that enable them to cope with periods of high discharge and the ongoing persistence of fish communities in lotic habitats characterised by high disturbance suggests that these behaviours are adaptive and hydrograph specific (David and Closs 2002).

Most research on freshwater fish responses to flooding has been conducted in a before and after framework and very little empirical behavioural data has been obtained due to the difficulties associated with surveying during flood conditions. However, advances in radio telemetry have shown that northern hog suckers *Hypentelium nigricans* (Matheney and Rabeni 1995), giant kokopu *Galaxias argenteus* (David and Closs 2002) and river blackfish *Gadopsis marmoratus* (Koster and Crook 2008) make directional movements towards the waters edge during episodes of high flow.

The importance of various flow elements (such as discharge magnitude, frequency and timing) to the New Zealand native freshwater fish fauna is high as many species actively use high discharge events to spawn in temporarily inundated riparian margins (McDowall 1990, Allibone and Caskey 2000, Charteris et al. 2003). This study aimed to contribute to the existing knowledge base regarding freshwater fish behaviour before and after, but especially during flood events.

METHODS

The Mangaore stream, in the lower North Island of New Zealand is a relatively short stream with a steep gradient catchment located in the foothills of the Tararua ranges. Due to its geographic position, this stream exhibits a high degree of flashiness, characterised by brief yet intense periods of high flow and is typical in this respect of many New Zealand streams when viewed in a global context (Winterbourn et al. 1984). This particular stream also possesses a diverse and abundant native fish community, therefore providing an ideal situation to examine behavioural responses in a varied hydrological environment.

The substrate and flow characteristics of a 100m reach of the Mangaore stream were mapped and the reach was drawn to a $0.25m^2$ grid scale during base flow conditions. Sixty seven redfin bullies *Gobiomorphus huttoni* Ogilby, 21 shortjaw kokopu *Galaxias postvectis* Clarke and 29 koaro *Galaxias brevipinnis* Günther (common names are used hereafter) were collected from the study reach using a combination of multiple pass electrofishing and repeated spotlighting on two separate occasions: 01-03 January 2008 and 21-24 March 2008 (Table 1). All fish were anesthetised using 2-phenoxyethanol ($0.2ml\ l^{-1}$), weighed and measured (to the nearest 0.1g and $1mm_{TL}$ respectively) and implanted with a 12.5mm, 0.06g PIT tag (30cm read range) to the right of the ventral midline, directly under the pectoral fin. All tagging was assisted with a hand-held 12-gauge implanter and all implanters, tags, hands and implant sites were washed with an iodine solution (Betadine™) prior to implantation. All PIT tagging equipment was sourced from Biomark Inc., Boise, Idaho, North America. Following tagging, fish were allowed to recover in in-stream cages before being released back into the approximate region of the study section where they were caught.

Table 1. Summary information for 117 native freshwater fish that were implanted with 12.5mm PIT tags in 2008.

Scientific name (FAMILY)	*Common name*	*Size Range (mm_{TL})*	*Tagged January*	*Tagged March*	**Total**
Gobiomorphus huttoni (ELEOTRIDAE)	Redfin bully	75-111	26	41	67
Galaxias postvectis (GALAXIIDAE)	Shortjaw kokopu	99-204	7	14	21
Galaxias brevipinnis (GALAXIIDAE)	Koaro	79-155	18	11	29
		Total	51	63	117

Tagged fish were monitored using a portable PIT transceiver and a waterproof antenna mounted on the end of a pole, which was moved gradually through the stream section, above and around the benthos, in an upstream direction. A copy of the stream map was carried on each sampling occasion and the location of each tag entered in the corresponding coordinate on the map. The methodology described here formed part of a larger project involving repeated monitoring of the stream section over January and July 2008 (see Chapter 2). Three significant floods occurred during this period (in January, April and July), facilitating the collection of data regarding the associated locations of tagged fish.

Before and after data related to individual fish presence/absence was obtained for the January flood and the April flood and in-flood sampling was conducted for the April flood and the July flood (the January flood occurred before the monitoring regime had started and ended directly following the July flood). Local rainfall data from a site-based rain gauge and a fixed instream stage depth gauging station were used as a proxy measure of flood magnitude and duration.

On all three flood occasions the stream broke bank full (Fig. 1). The first flood event occurred four days after the first group of fish were tagged and although depth gauging stations were yet to be installed, rainfall in surrounding catchments and resident testimony show this was the largest Mangaore stream flood on record. Over the 7th to the 8th of January 127mm of rainfall was recorded at the site, while the closest Regional Council gauging station recorded the highest rainfall (360.5mm in 48 hours) in the western Tararuas since record keeping began in 1991 (Watts 2001). This flood resulted in the main flow within the study section being shifted from the true left to the true right of the riverbed.

Figure 1. The downstream area of the study section. The photo on the left was taken in May during base flow conditions. The photo on the right was taken on the 12th July during flood sample J1.

The April flood (during which the stream was surveyed twice, once during the day and once at night (samples A1& A2 – Fig. 2), was a product of 91mm of rainfall in 24 hours which produced a stage depth increase to 380mm (from a non-flood median of 180mm). The July flood (J1 & J2), when 72mm of rain fell in 24 hours (following several rainy days) raised staging depth to 460mm and produced the opportunity to survey twice over two days.

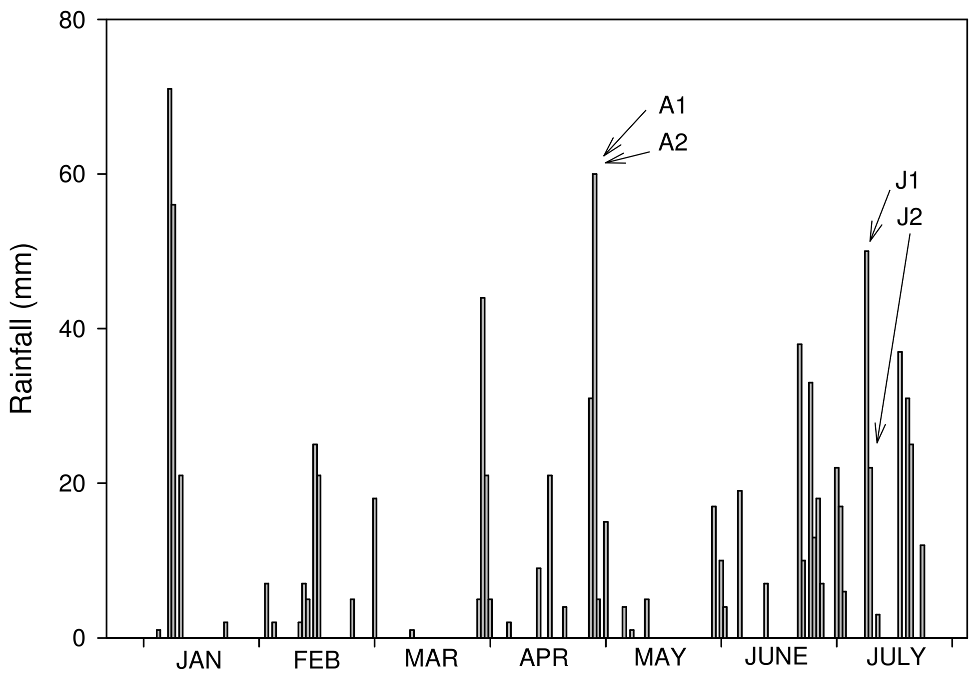

Figure 2. Rainfall levels at site from January to July 2008. In-flood surveying occasions are indicated by arrows.

During flood conditions, comprehensive surveying of some sections of the stream was limited but reasonable coverage of mid – marginal areas was still possible from large exposed boulders and outcrops scattered throughout the stream. Tags located during flood conditions were recorded and examined for position relative to the base flow stream bed (i.e. inside or outside the bed) and relationships with substrate parameters for those tags that were found inside the base flow stream bed (as substrate data had been collected as a component of the larger study).

Locations where tags were found inside the stream bed were divided into two groups based on mean substrate size and tested using a Mann Whitney test (PROC NPAR1WAY in SAS 9.1). A high proportion of tags detected during floods were relatively unfamiliar in comparison to the subset of tags that were commonly resident in the study reach during base flow conditions. To investigate this, a simple index of “familiarity” was developed whereby each individual tag detection would be assigned a score between zero and ten based on when that tag was last detected – for example, if a tag was found during the previous sample then that detection would score ten (highly familiar); if it hadn’t been detected during the previous ten samples then it would score zero (highly unfamiliar). All scores were then summed and divided by the total number of tags detected to produce an average familiarity score for each sampling occasion. To ascertain whether familiarity scores were related to flow level, sampling occasions were divided into two groups – where stage depth at sample was equal to or less than median stage depth and where stage depth at sample was greater than median stage depth – and compared using a Mann Whitney test (PROC NPAR1WAY in SAS 9.1).

RESULTS

In total, 53% of all tagged fish present in the study section before the January flood were subsequently redetected despite the significant physical changes that occurred. This figure was slightly higher for the April flood, with 59% of all resident pre flood individuals being detected post flood. The proportion of redetected tagged shortjaw kokopu was the same for both flood events, but redfin bullies and koaro showed differences. The January flood resulted in less of the pre-flood tagged redfin bullies and more of the pre-flood tagged koaro being redetected when compared to the April flood (Fig. 3).

Thirty one out of 117 tags were detected within the study section while the stream was in flood (Table 2). Twelve (30%) of these were found outside the base flow stream bed and of those that were found inside the original bed, 17 (65%) were found within 0.5 metres of the base flow wetted edge (Fig. 4A). Three redfin bullies and one koaro were found during more than one flood sample. Without exception, these individuals were found in distinct locations during floods when compared to the range of locations they were found in during base flow conditions (Fig. 4B).

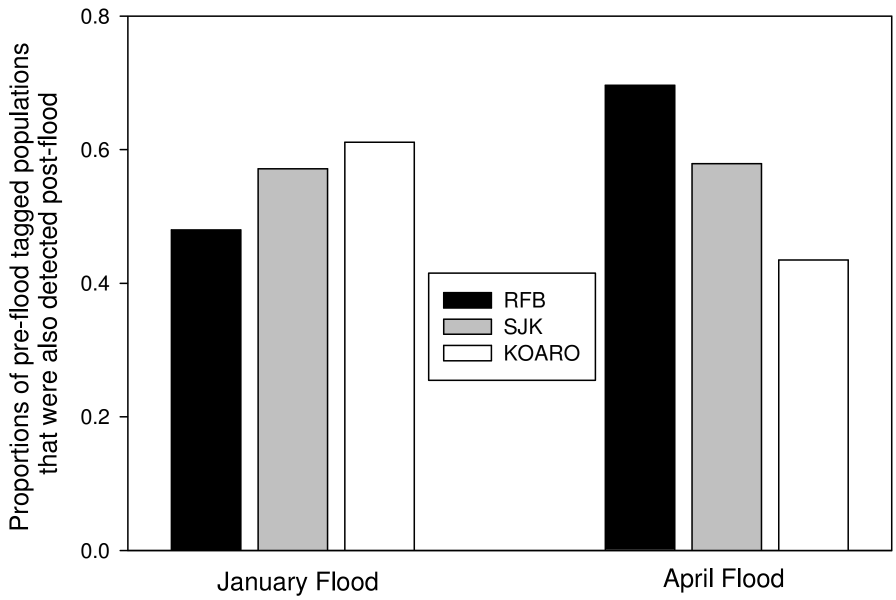

Figure 3. Before and after fish community changes in relation to two flood events. Each bar represents the proportion of each pre-flood species group that was detected following each flood. RFB=redfin bully; SJK=shortjaw kokopu; KOARO=koaro.

Table 2. Information regarding all individuals that were located during four in-flood surveys of PIT tagged fish. Sexual dimorphism allowed redfin bullies to be sexed during tagging. As a component of a concurrent study, (McEwan et al, unpubl. data) substrate size information was available for most of the locations where fish were found inside the base flow stream bed

Tag Code Suffix	***Species*** *(RFB=redfin bully; SJK=shortjaw kokopu; KOARO=koaro)*	***Sex***	***SAMPLE*** *(A=April; J=July; 1=sample 1; 2=sample2)*	***Location*** *(I=inside stream bed; E= within 0.5m of edge ; O=Outside stream bed)*	***Substrate Size*** *(mm on longest axis)*
40059F	RFB	F	A2	IE	131.2
545DFE	RFB	F	A1	O	-
			A2	O	-
59B1E1	RFB	F	A2	IE	21.4
5C7BBA	RFB	F	A2	O	-
5E97A5	RFB	F	A2	I	-
5EA631	RFB	F	A2	O	-
5EB11E	RFB	F	A2	IE	-
5EB03A	RFB	F	A2	IE	-
600D66	RFB	F	A1	O	-
601980	RFB	F	A1	O	-
601967	RFB	F	A2	O	-
601752	RFB	F	A2	I	87.0
5496B8	RFB	F	J2	O	-
5C7DC9	RFB	F	A1	IE	186.5
			J1	IE	186.5
5C950B	RFB	M	A2	I	86.5
5434A3	RFB	M	A2	IE	117.7
548C87	RFB	M	A2	IE	122.4
5EB54D	RFB	M	A2	O	-
601B1C	RFB	M	A2	IE	67.6
5C9F28	RFB	M	A2	O	-
			J1	I	104.0
			J2	IE	101.6
54884E	RFB	M	J2	IE	233.6
548C87	RFB	M	J1	IE	205.6

54513E	SJK	-	A1	I	-
5E8851	SJK	-	A2	I	160.0
5EAFE8	SJK	-	A2	IE	122.5
5C88EB	KOARO	-	A1	IE	219.2
600E8F	KOARO	-	A2	IE	230.4
548F8E	KOARO	-	A2	I	-
5489A1	KOARO	-	A2	I	256.0
				IE	134.5
545910	KOARO	-	A2	IE	205.7
				I	180.0
5EA877	KOARO	-	A1	O	-
			A2	O	-

Those individuals that were found inside the base flow bed were found in areas with significantly higher than average substrate size (Z_{1df} = 2.08, P=0.038).

Throughout the sampling period, whenever stage depth was highest the mean familiarity score was lowest (Fig. 5) and the study section tagged community contained significantly less familiar individuals when stage depth was above median (Z_{1df} = -2.35,. P = 0.018).

DISCUSSION

The findings of this study agree with and expand on previous research which showed that fish move to the waters edge during episodes of high flow. All fish that remained in the study section during floods were either found in or close to the flood margins or in areas of the base flow stream bed that were characterised by large boulders.

Although the high proportion of individuals found in edge habitats could be partially due to the comparative ease of sampling those habitats during floods, other researchers have observed such edge seeking behaviour (Jowett & Richardson 1994; Matheney and Rabeni 1995, David and Closs 2002, Koster and Crook 2008). Matthews (1986) first postulated that fish move towards edges to avoid potential harm, as inundated riparian zones will be slower flowing than other areas. However, many New Zealand galaxiid species use inundated areas to reproduce (McDowall 1990, Allibone and Caskey 2000, Charteris et al. 2003), and both individual shortjaw kokopu and koaro were observed to be gravid during both the January and March tagging sessions. Accounts also exist of freshwater fish using newly wetted terrain to exploit new food resources that become available during floods (Ross and Baker 1983, Turner et al. 1994). Therefore, observed

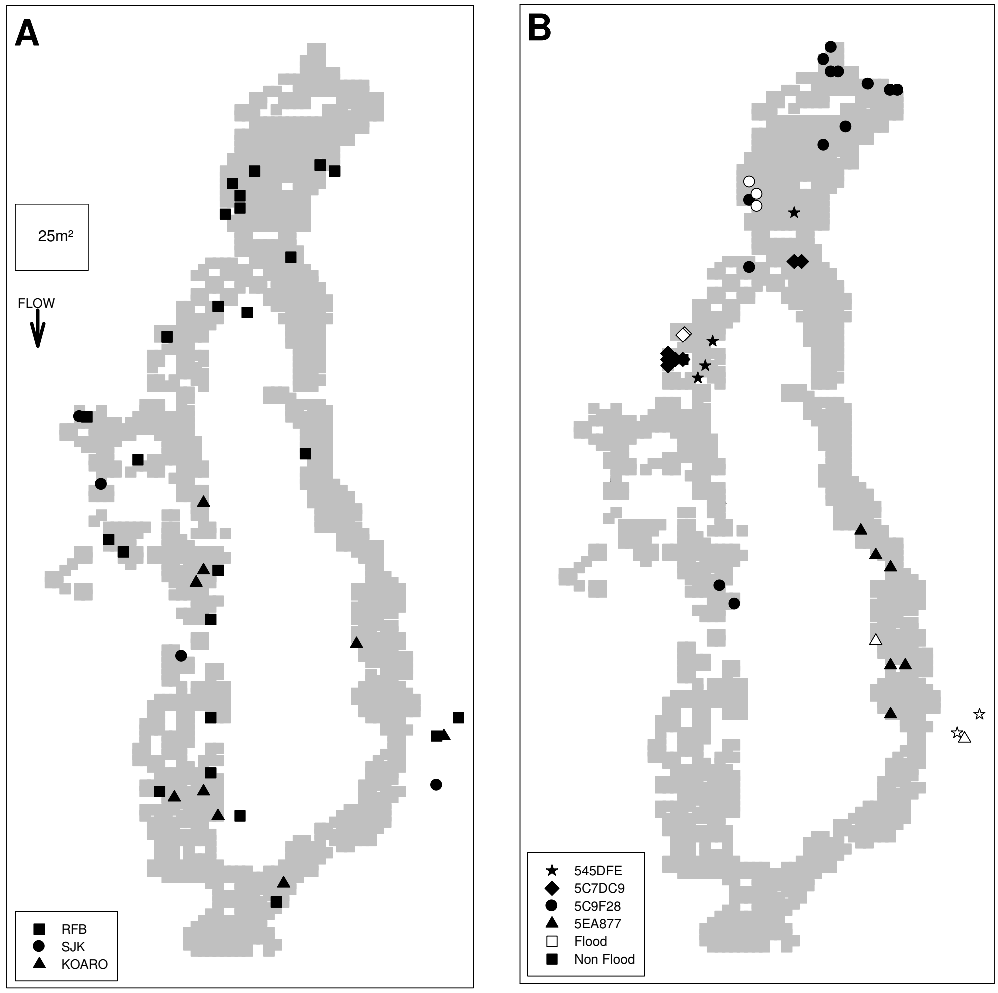

Figure 4A. Diagram of the study section showing the locations of tagged fish found during in-flood sampling; **B**. Showing all collected tag locations for each of four individual fish that were found during both the April flood and the July flood. The grey region shows the wetted area of the stream during base flow conditions.

movements towards low velocity edge habitats could represent refuge seeking, opportunistic feeding, reproductive attempts or a combination of all three.

Movements into areas with large boulders most likely represent refuge seeking as such areas would be more likely to remain stable during flooding and thus offer a degree of protection from potential physical trauma caused by mobile substrate particles. In addition, a subset of the population was observed returning to the same 1 square metre area during multiple floods which indicates that some fish could potentially have areas that they utilise in a habitual fashion during floods.

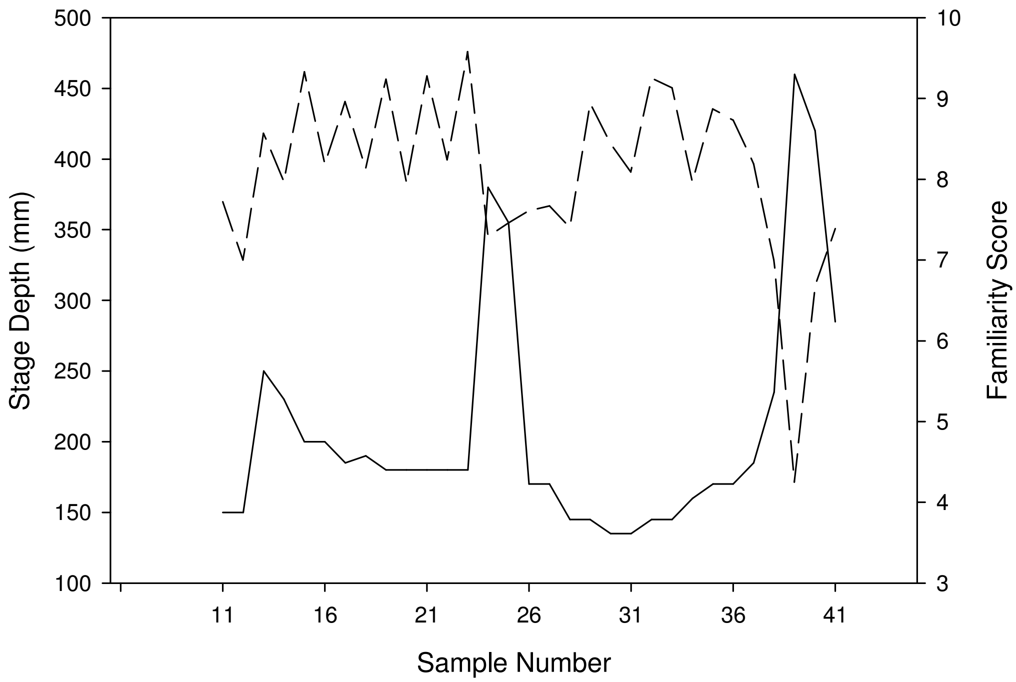

Figure 5. Plots showing correlation between (solid line) stage depth at each sampling occasion and (dashed line) community familiarity score – calculated for each sampling occasion based on the number of times each individual fish was found during the previous 10 sampling occasions. 0=highly unfamiliar; 10=highly familiar

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Observed reductions in the familiarity of tags during high flow conditions indicate higher mobility in the tagged population as a whole during elevated flows and these behaviours may contribute to any temporary, semi-permanent or permanent community redistribution that may occur at a 100m reach scale.

Both Matthews (1986) and David & Closs (2002) found that individuals and communities were less likely to return to a pre-flood state if local habitat parameters were altered as a result of high flows. This appears to have been demonstrated again here, as less redfin bullies and more koaro were redetected following the severe January flood when compared to the smaller April flood. Prior to the January flood, the study reach contained a high proportion of shallow, slow flowing pools containing large substrates and high amounts of interstitial refuge space – highly suitable conditions for redfin bullies and less suitable for koaro (see Chapter 3). The January flood caused wide scale scouring, resulting in a greater proportion of run and riffle zones available than previously, thereby reducing amounts of suitable microhabitat for redfin bullies and creating more microhabitat suited to koaro. The April flood resulted in the opposite (albeit smaller scale) physical habitat changes. Material was washed downstream and deposited in the study section which resulted in a general reduction in high velocity riffle zones. These changes rendered the section less suitable than previously for riffle dwelling koaro (McDowall 1990).

In cannot be ruled out however, that the observed reduction in redfin bully numbers following the January flood could also represent actual mortality. A number of studies have found that smaller trout are more likely to be affected by floods than larger trout (Allen 1951, Elwood and Waters 1969, Jowett and Richardson 1989). The same phenomenon has not been reported in other species but neither has it been refuted, and it could have occurred here as redfin bullies were the smallest-bodied species included in the study. If the apparent loss of redfin bullies is due to mortality (whether related to body size or other species specific characteristic), then clear differences in such mortality were shown relating to flood magnitude – of all the tagged redfin bullies that were found in the study section before the April flood, 30% were not found after the flood; this figure increased to 52% following the more severe January flood. This is potentially an area of concern for freshwater conservation as climate change is predicted to increase the frequency and severity of extreme weather events such as high rainfall causing flooding.

While small scale changes did occur, overall a remarkable level of persistence was observed in the tagged population. Despite the severity of the January flood event and the large scale resultant changes to the study reach topography, over half of the individuals that were found before the flood were also found there afterwards. This figure was close to two-thirds for the less severe flood during April.

In New Zealand, the highly endemic native freshwater fish fauna is in a general state of ongoing decline (Joy, in press) - for effective decisions to be made regarding water allocation and riparian management, policies must be backed by solid science.
Overall, this study has shown that these three New Zealand native fish species appear to express adaptive behaviours that allow them to avoid harm during episodes of high flow, although these behaviours may be less effective in especially severe floods.
While greater mobility and at least temporary community redistribution can occur -

especially if habitat parameters have undergone change - individual small-scale site fidelity is very high and a substantial proportion of the community remain in or return to the same area that they occupied prior to any given flood event.

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Synthesis

This thesis reports the findings of a fine scale, high intensity field study on movements and microhabitat use of a New Zealand native fish community in a small stream. The methodologies used allowed the locations of cryptic, benthic nocturnal fish to be repeatedly catalogued with high spatial resolution and minimal disturbance, thus generating previously undocumented empirical data regarding aspects of natural freshwater fish behaviour. Such data is of high value to New Zealand freshwater managers working to develop policy to protect the native fish fauna, which has little in common with faunal groups in Europe and North America, from where most freshwater research originates.

Chapter 2 of this thesis describes and assesses the first study in New Zealand to use a portable PIT monitoring system on tagged native fish in the wild. The subjects showed a high level of site fidelity and were able to be redetected multiple times in the same 100m reach of a small stream over a 5 month period. The locations of PIT tagged fish were able to be pinpointed to 50-100mm at any time of the day or night, regardless of local habitat type and with no physical recapture necessary. This method improves on commonly used sampling methods such as electrofishing, which is invasive, prone to spatial inaccuracy and less effective in still water or spotlighting, which is restricted to night time use in certain habitat types.

The research potential of this study was broadened by fine scale habitat mapping and microhabitat inventorying of the reach where the tagged fish resided, which facilitated direct comparisons between variables which fish did and did not associate with. This approach revealed previously undocumented high levels of dependence of some native fish on large interstitial spaces for refuge and significant differences in microhabitat use between day time and night time. These findings, which are detailed in Chapter 3, have important implications as they highlight a number of shortcomings of the Instream Incremental Flow Methodology, which is currently widely used in New Zealand to determine minimum flow standards, despite being subject to numerous criticisms by freshwater biologists. The results of this research add to the growing consensus that

IFIM should be either replaced or significantly modified in order to be applicable to New Zealand freshwater environments.

The advantages of using a PIT monitoring regime were further illustrated during flood conditions, when tagged individuals were still able to be located. Alternative sampling methods are either very difficult or impossible to implement while a stream is in flood, thus very little empirical data exists in this area. Chapter 4 of this thesis describes aspects of freshwater fish behaviour during high flows and thus constitutes a significant contribution to the global literature base. The tagged community showed low levels of change attributed to habitat alteration caused by flooding but overall most individuals remained in the same area of stream by moving to stable areas and newly inundated riparian margins during floods – a finding which highlights the importance of effective riparian management practices.

An important general theme that can be extracted from this research is that the unique characteristics of the New Zealand native freshwater fish fauna must be taken into account by freshwater managers tempted to use methodologies developed overseas. In recent years freshwater management has come to the forefront of public concern over environmental degradation in New Zealand. This concern is primarily due to rapidly increasing levels of freshwater abstraction for irrigation of pastoral land and the associated increased levels of contaminated runoff as New Zealand experiences unprecedented growth and intensification in the dairy farming sector. The highly endemic New Zealand freshwater fish fauna is in a state of ongoing decline and current high levels of demand for freshwater abstraction for economic gain are only growing. Freshwater managers must either use solid, New Zealand specific science or employ the precautionary principle when developing management policy or New Zealand's unique freshwater heritage will be further eroded and ultimately lost for good.

Appendix

Differences between freshwater fish and decapod crustacean communities in urban and forested streams in Auckland, New Zealand.

ABSTRACT

Freshwater fish and decapod crustacean communities at 39 sites in urbanized catchments and 57 sites in forested (reference) catchments within the greater Auckland region were compared. Twelve native fish species, 2 native decapod crustaceans and 1 exotic fish species were collected. Species richness and fish IBI scores were lower overall in streams in urbanised catchments. Shortfin eels and mosquitofish were more dominant in urban streams, all other commonly occurring species were found significantly more often in reference streams. Non-diadromous native species (Cran's bullies and koura) were absent from urban streams, but relatively abundant in reference streams. This, together with the urban occurrence of five diadromous species suggests that migratory barriers are less of an issue than physico-chemical disturbance in streams in the Auckland urban region. Alternatively, these absences could be due to historical disturbance and thus able to be remediated through translocation.

Keywords: Urban streams; freshwater fish; freshwater crustaceans; disturbance

INTRODUCTION

The relationships between urbanisation and freshwater communities can be complex as the pressures that freshwater ecosystems are subjected to in urban areas are highly variable with regard to type, intensity and duration (Paul and Meyer 2001). While urbanisation typically impacts negatively on freshwater habitat quality through initial channelisation and disturbance during construction processes, these impacts are temporary, and disturbed riparian vegetation is often able to subsequently recover (Miltner et al., 2004). Less temporary and more predictable are the effects of impervious surface cover - urban stream flows are typically much flashier than their non-urban counterparts due to increased runoff rates from impervious surfaces – roads, roofing etc (Finkenbine et al. 2000; Wang et al. 2000; Paul and Meyer 2001; Wang et al. 2001; Roy et al. 2005). In comparison to the physical effects of imperviousness, the chemical effects of urbanisation on waterways are highly variable (see Paul and Meyer 2001) but increases in biological oxygen demand, conductivity, ammonium, hydrocarbons and heavy metals have consistently been observed in a number of studies on urban streams (Porcella and Sorenson 1980; Lenat and Crawford 1994; Latimer and Quinn 1998).

Two recent comprehensive reviews of this area of research (Paul and Meyer 2001; Walsh et al. 2005) state that while the direct relationships between urbanisation and physical and chemical changes to waterways have been comparatively well documented, fewer studies have gone further to define relationships between urbanisation and freshwater ecosystems. Especially noted is the low incidence of research involving freshwater fish communities. Those studies that have used fish as focal organisms have found declines in freshwater fish species richness (Klein 1979; Boet et al. 1999), species diversity (Klein 1979; Schueler and Galli 1992), fish Index of Biotic Integrity (IBI) (Steedman 1988; Wang et al. 1997) and increases in occurrence of invasive fish species (Boet et al. 1999). These studies are all from overseas and very little comparative research has been done in New Zealand - a country where around 87% of the population live in towns and cities.

This study examines the similarities and differences between freshwater fish and decapod crustacean communities in streams with catchment land use dominated either by urbanisation or indigenous vegetation. All sites examined are from the greater Auckland Region, to avoid any effect of geographical variation. While being the most highly urbanised area in New Zealand, Auckland still contains some largely pristine watersheds that are protected as municipal water supply catchments, characteristics which make Auckland a suitable place to investigate these differences.

METHODS

A total of 96 stream sites in the Auckland region (Fig.1) were drawn from two sources: 57 reference sites with more than 60% of their upstream catchment covered in indigenous forest and scrub were selected and surveyed in 2002 by Massey University researchers using in-stream trapping techniques (see Joy and Death 2003 for details). In addition, 39 urban sites with more than 60% of their upstream catchment in urbanised areas were selected and surveyed in 2002 as part of a report prepared by NIWA for the Auckland Regional Council and these sites were backpack electrofished (Allibone et al. 2001). All sites were less than 50 metres above sea level and less than 10km inland (Fig. 2), so control for the high influence that these parameters have on freshwater fish distributions in New Zealand (Joy and Death 2001).

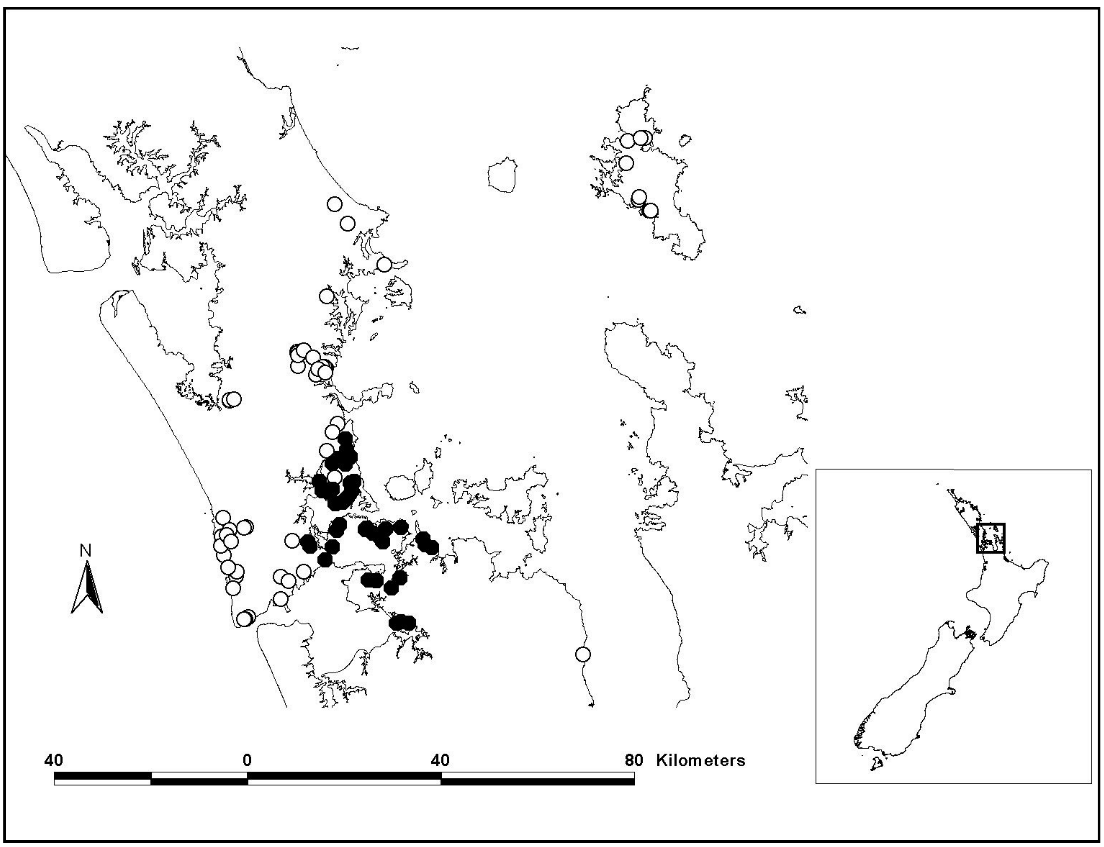

Figure 1. Map of the Auckland region showing urban sample sites (closed circles) and reference sample sites (open circles).

As the reference site communities were sampled using trapping techniques whereas the urban sites were electrofished, all records for inanga (*Galaxias maculatus* (Jenyns, 1842)) were discarded as they are known to be more likely to be captured in traps than by electrofishing. For all other species only presence/absence was used in analysis. Also, some species were only sparsely represented across all sites so only the relatively common (occurring at ≥ 10% of sites) species were used in analysis.

Differences between the two site types were examined in terms of species richness, fish IBI score and relative occurrence of individual species. Species richness and fish IBI scores (see Joy and Death 2004) for urban and reference sites were compared using Mann-Whitney U testing (PROC NPAR1WAY in SAS 9.0) and the community structure of the site types was compared using a Multi Response Permutation Procedure (MRPP: PC-ORD 5.0).

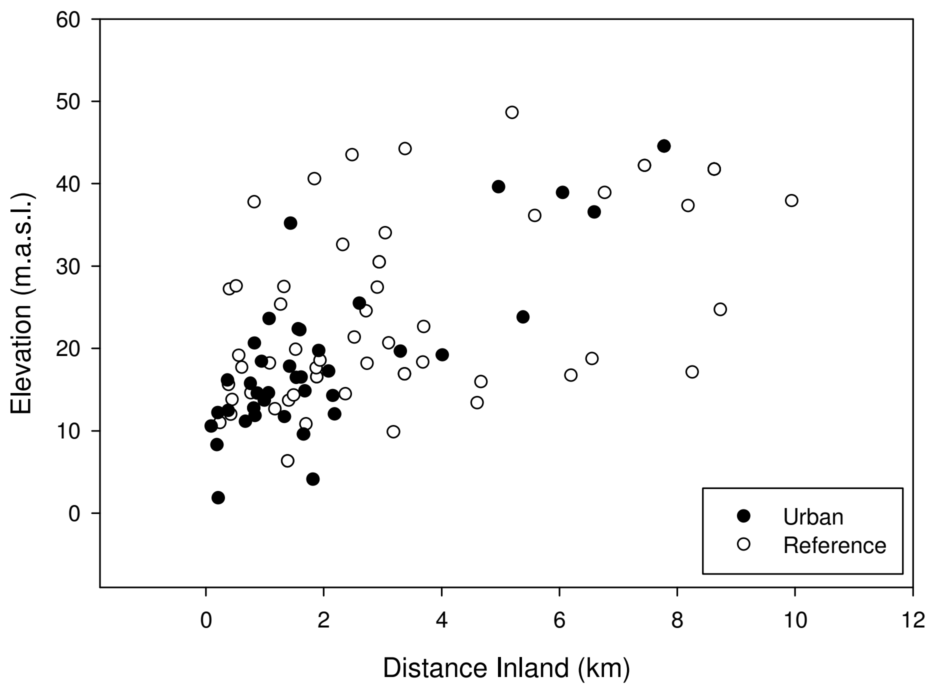

Figure 2. Elevation and distance inland of 96 sites in the Auckland region, either in urban or forested catchments.

Catchment land use and elevation and distance inland parameters were obtained from the Freshwater Environments of New Zealand database (FWENZ: Wild et al. 2004). Fish IBI scores were calculated using purpose-designed software (Joy 2004).

RESULTS

Twelve native fish species, 2 native decapod crustaceans and 1 exotic fish species were found in the sites sampled (Table 1: common names used hereafter). Nine of these species were found in ≥ 10% of either urban sites or reference sites. No fish were collected from 4 urban sites.

Table 1. Species composition of fish and crustacean communities from 96 sites sampled in the wider Auckland region. * denotes non-diadromous species ** denotes exotic species.

Family	***Scientific Name***	***Common Name***	**Proportion of Sites with each species present**	
			Reference (n = 57)	Urban (n =39)
Anguillidae	*Anguilla australis*	Shortfin Eel	0.37	0.79
Anguillidae	*Anguilla dieffenbachia*	Longfin Eel	0.81	0.44
Atyidae	*Parataya cuvirostris*	Freshwater Shrimp	0.60	0.31
Eleotriidae	*Gobiomorphus basalis*	Crans' Bully*	0.25	0.00
Eleotriidae	*Gobiomorphus cotidianus*	Common Bully	0.26	0.18
Eleotriidae	*Gobiomorphus gobioides*	Giant Bully	0.02	0.00
Eleotriidae	*Gobiomorphus huttoni*	Redfin Bully	0.46	0.05
Galaxiidae	*Galaxias argenteus*	Giant Kokopu	0.02	0.00
Galaxiidae	*Galaxias fasciatus*	Banded Kokopu	0.60	0.33
Parastacidae	*Paranephrops planifrons*	Koura*	0.58	0.00
Pinguipedidae	*Cheimarrichthys fosteri*	Torrentfish	0.02	0.00
Poeciliidae	*Gambusia affinis*	Mosquito Fish**	0.00	0.10
Retropinnidae	*Retropinna retropinna*	Common Smelt	0.04	0.00

An average of 3.3 species was caught at each reference site compared to only 1.9 at each urban site (Fig. 3) and Mann Whitney testing showed this difference in species richness to be significant ($Z = -5.16$; $p < 0.0001$). The Mean IBI score for urban sites was 22 and was

35 for reference sites (Fig. 4), a difference that was also statistically significant ($Z = -5.42$; $p < 0.0001$).

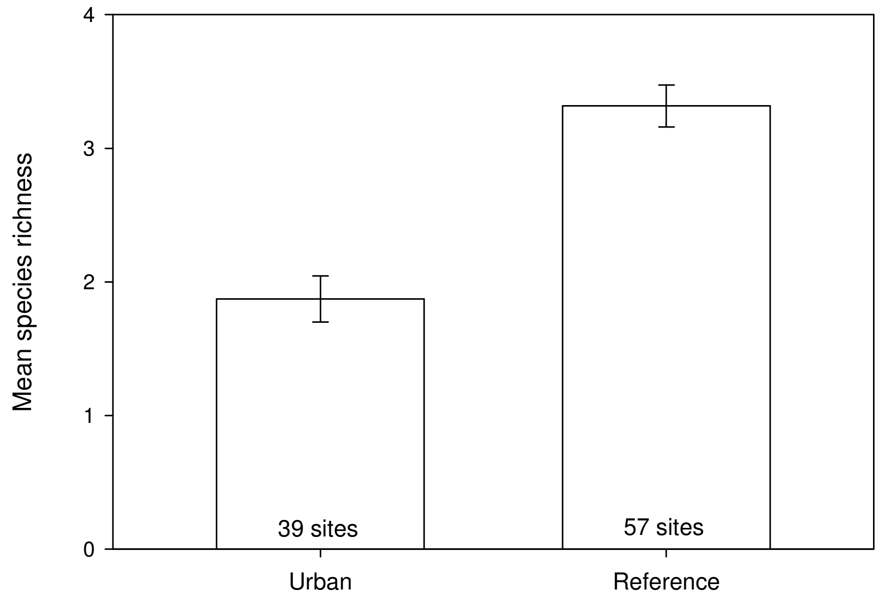

Figure 3. Mean number of species occurring at each site (species richness) in each of two site-types: urban and reference sites. ($Z = -5.49$; $p < 0.0001$). Error bars indicate 1 standard error either side of the mean.

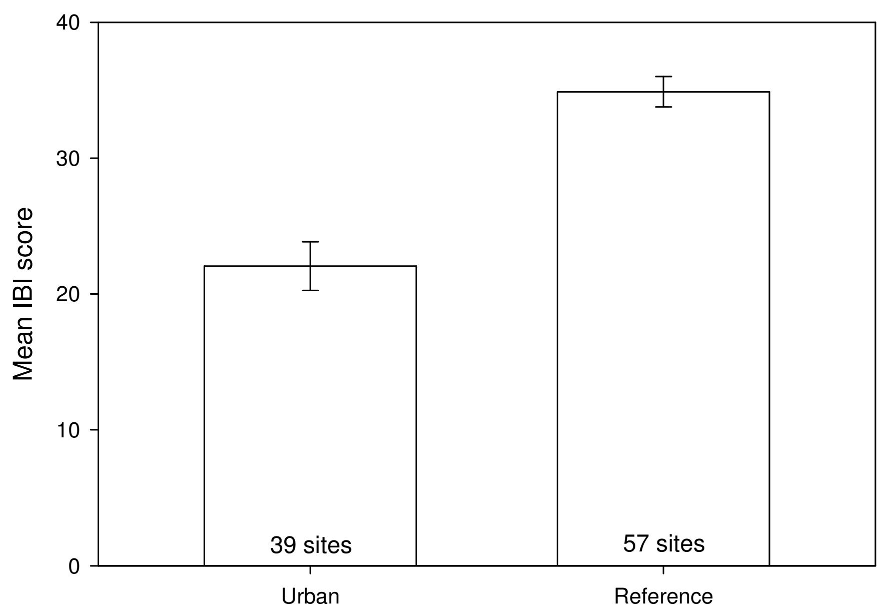

Figure 4. Mean IBI score for fish communities in either urban or reference streams ($Z = -5.42$; $p < 0.0001$). Error bars indicate 1 standard error either side of the mean.

All nine commonly occurring species showed different distributions in urban streams when compared to reference streams (Fig. 5). Cran's bullies and koura were found in 29% and 59% of reference sites respectively but both species were absent from urban sites. Banded kokopu, freshwater shrimp, redfin bullies, common bullies and longfin eels were present in a larger proportion of reference sites compared to urban sites. Conversely, shortfin eels were present in a much larger proportion of urban sites and the exotic mosquitofish was found in 10% of urban sites but was absent from reference sites. Results from MRPP showed that urban streams possessed significantly different communities than reference streams ($A = 0.169$; $p < 0.001$). According to McCune and Grace (2002), values of $A > 0.3$ in community ecology should be considered to indicate a high degree of similarity between groups.

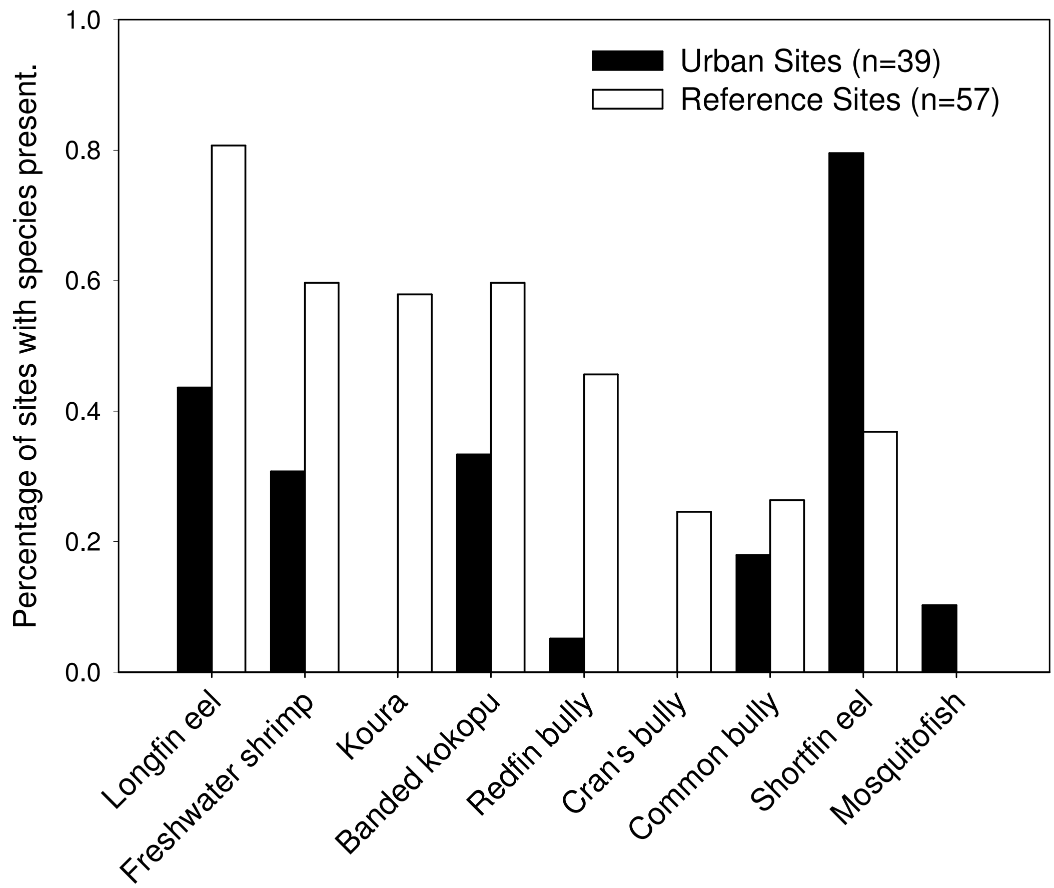

Figure 5. Differences in common (occurring at ≥ 10% of sites) species' distributions between reference and urban sites.

DISCUSSION

Clear differences exist between fish and crustacean communities in urban areas and those in relatively unmodified (reference) areas in the Auckland region and these differences agree with similar studies conducted overseas. Fish IBI scores and species richness was lower overall in streams in urbanised catchments. Shortfin eels and mosquitofish were more frequently found in urban streams, while all other commonly occurring species were found more often in reference streams. Of special interest is the conspicuous absence of non-diadromous Cran's bullies and koura in urban streams.

As freshwater degradation often causes community shifts from sensitive to tolerant species (Walsh et al. 2005), in some cases species richness *per se* does not change (Morgan and Cushman 2005). Despite this, species richness was significantly lower in Auckland urban streams compared to reference streams, potentially suggesting that the nature of the impacts these communities are exposed to are relatively severe. Fish IBI scores, which take into account the relative tolerances of various species to pollutants, were also significantly lower in urban streams, representing lower occurrences of sensitive species such as redfin bullies, longfin eels and banded kokopu.

Shortfin eels have been found to be relatively more tolerant to physical and chemical habitat degradation than other species of freshwater fish in New Zealand, and the significantly higher incidence of shortfin eels combined with the much lower incidence of any other species in the urban sites in this study is consistent with findings in highly modified streams in agricultural areas of New Zealand (Hanchet 1990; Hicks and McCaughan 1997; Rowe et al. 1999).

Cran's bullies and koura are freshwater species also commonly found in agricultural streams (Swales and West, 1991), whereas in this study they were consistently absent from urban streams. Cran's bullies and koura are the only non-diadromous native species found in the Auckland region and are widespread in reference streams – a distinctive distribution which could provide information regarding the nature of anthropogenic impacts on freshwater ecosystems in urbanized areas.

The absence of non-diadromous species in urban Auckland could be due in part to the high flashiness typical of urban stream flows in conjunction with the high incidence of channelisation commonly found in urban areas. The effect of any flash flood event on a freshwater community depends on the immediate physical state of the stream bed. Unmodified streams have naturally occurring areas of low flow such as meanders, margins and boulder shelter-zones which provide refuge for stream life during high flow events (David and Closs 2002; McEwan 2009). Non-diadromous species could potentially be incrementally driven out of systems that are subject to frequent high flows and that lack the physical complexity that provides areas of shelter for stream life during these events. Chemical pollution could also have especially strong impacts on non-diadromous species. In the event of a stochastic lethal pollution event –such as would be more common in urban areas than unmodified areas - diadromous species can recolonise via coastal dispersal or from within-catchment tributaries once the pollutant(s) has dissipated. Non-diadromous species are unable to do this and a severe enough pollution event could effectively wipe out an entire population.

It has been suggested that migratory barriers (culverts, weirs etc) present a significant issue in urban regions and in the Auckland region in particular (Allibone et al. 2001). While this is undoubtedly true, the presence of five diadromous species and the conspicuous absence of two non-diadromous species suggests that migratory barriers may be less of an issue than physico-chemical disturbance in the Auckland urban region.

It is important to note however, that the absence of non-diadromous native species in at least some urban streams could be due to historical impacts. This hypothesis is tentatively supported by the presence of the introduced mosquitofish - also a non-diadromous species - in 10% of the urban streams. Although highly tolerant of low oxygen levels, high salinity, inorganic pollutants and pesticides (McDowall 1990), mosquitofish have been present in Auckland since the 1930's (McDowall 1990) and populations in the streams studied here could be relatively long term residents. While unlikely, due to their high tolerance levels, mosquitofish could potentially identify streams that provide adequate habitat in current times for previously extirpated non-diadromous native species, which raises the possibility of remediating their absences via translocation. Somewhat ironically, however, if the presence of mosquitofish was used a an indicator of potentially viable habitat for such translocation, that viability would be greatly reduced by the presence of mosquitofish themselves as they are known to aggressively attack some species of New Zealand native fish (Rowe 1998).

This study has highlighted the importance of using a reference condition for comparison when investigating patterns of degradation. The authors of the recent report on Auckland urban streams (Allibone et al. 2001 - from which the urban sites used in this study were drawn), failed to attribute importance to the absence of native non-diadromous species, as they did not have a complementary dataset showing that these species are relatively abundant in streams in non-urbanised catchments in the same area.

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