Population dynamics and migrational history of torrentfish (*Cheimarrichthys fosteri,* Haast 1874) in two Waikato streams on the North Island of New Zealand

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Raymond Tana

Department of Biological Sciences
The University of Waikato
Hamilton

THE UNIVERSITY OF
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Abstract

Torrentfish (*Cheimarrichthys fosteri* Haast 1874) are a freshwater fish species endemic to New Zealand and information pertaining to their general distribution, abundance as well as feeding ecology has been well documented. However, there are still fundamental gaps in torrentfish understanding that relate to aspects of their reproductive biology and migration history. In this study the population dynamics and reproductive aspects of torrentfish in two small Waikato streams as well as small scale sampling in the Mangamuka River on the North Island of New Zealand were investigated. The aim was to describe seasonal distribution patterns of male and female torrentfish within study streams as well determine the timing of spawning events by way of gonad assessments. Results indicated that females were significantly more abundant than males in upper reach sites of both streams but were not exclusively dominant as was the case for torrentfish in the Rakaia River. However, in lower reach sites females were equally if not more abundant than males demonstrating considerable overlap between the sexes.

Seasonal assessments of male and female gonads using gonosomatic indices (GSI) suggests that spawning occurs over a single protracted period in both streams. Fully ripe females were observed from January through to peak spawning condition in April in the Rangitukia Stream. While in the Mangauika spawning was delayed for a month with ripe females observed from February through to peak condition in May. The distribution of ripe and spent males and females between upper and lower reach sites of both streams during observed spawning periods suggests spawning occurs throughout the upper and lower reaches of both streams.

In the second part of this study, known differences in freshwater chemistry (low Sr/Ca ratios) and saltwater chemistry (high Sr/Ca ratios) were used as a premise to track torrentfish movements between fresh and saltwater by analysing the chemistry of their earbones (otoliths). Otoliths from fish in both study streams were analysed by laser ablation inductively coupled mass spectrometry (ICP-MS).

Overall trends in otolith Sr/Ca ratios for torrentfish at distance from the otolith core clearly reflected patterns indicative of movements between fresh and saltwater environments demonstrating a marine life history for torrentfish. However, the overall concentration of Sr/Ca ratios in otoliths (3) did not reflect sea water molar ratios (8.6) and were more aligned with estuarine water molar ratios (4). Lower than expected Sr/Ca core ratios may have been due to physiological constraints and a shorter marine life history whereby Sr uptake would occur over a shorter time period. However, as these ratios are the first reported for this species using laser ablation (ICP-MS) further otolith work is necessary to determine if the range in Sr/Ca core ratios is more variable.

Additionally, multivariate discriminant function analysis (DFA) of otolith edge values in torrentfish were used to determine whether fish could be classified to their stream of capture or whether male and females could be discriminated between upper and lower reach fishing sites. The results suggested there were significant differences in concentrations of Sr in the Rangitukia and Cr and Mg in the Mangauika Stream. DFA analysis of the same elements including Ba and Mn' correctly classified 100 % of all water samples to their stream of collection. However, elemental concentrations of otolith edge values in torrentfish from both streams demonstrated no significant differences using the same elements identified in water samples or a wider range of elements These indifferences in water chemistry and otolith chemistry may have been attributed to laser spot bias and fish physiology as a result of torrentfish's adaptation to fast flowing streams which may influence brachial uptake of elements in otoliths.. However, despite indifferences DFA analysis correctly classified 80% of fish to their stream of capture.

Acknowledgements

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For much of the fieldwork the biggest debt of gratitude must go to the “fishing guru” Warrick Powrie whose patented reverse back hand between the legs scoop method was truly magnificent. His enthusiasm for the fieldwork was above and beyond the call of duty, very much appreciated and contributed greatly to this research “thanks mate”. I am also very grateful to laser ablation technician Steve Cameron who also put a lot of time in to help run the otoliths through and get the calibration right. Thanks also to fellow otolith microchemists Matt Riceman and Jen Blair for all your help in running laser samples and for the laughs. Also a big thanks to Dr Barry O Brien for help with the microscopy work and to Grant Tempero for assistance with gonad staging methods and for anything and everything else I bothered him with (there was a lot). I’d also like to thank Steve Pohe for his welcome comments and review of the write up. Most importantly this research would not have been possible were it not for the support and guidance of my supervisor Associate Professor Brendan Hicks. His knowledge and experience in aspects of this research and always positive attitude was critical to me developing my own understanding and the confidence to do the work. This was invaluable and for that I am grateful. Finally I would like to thank my parents Henry and Janie Tana, the rest of the family and Mia for your unconditional, support.

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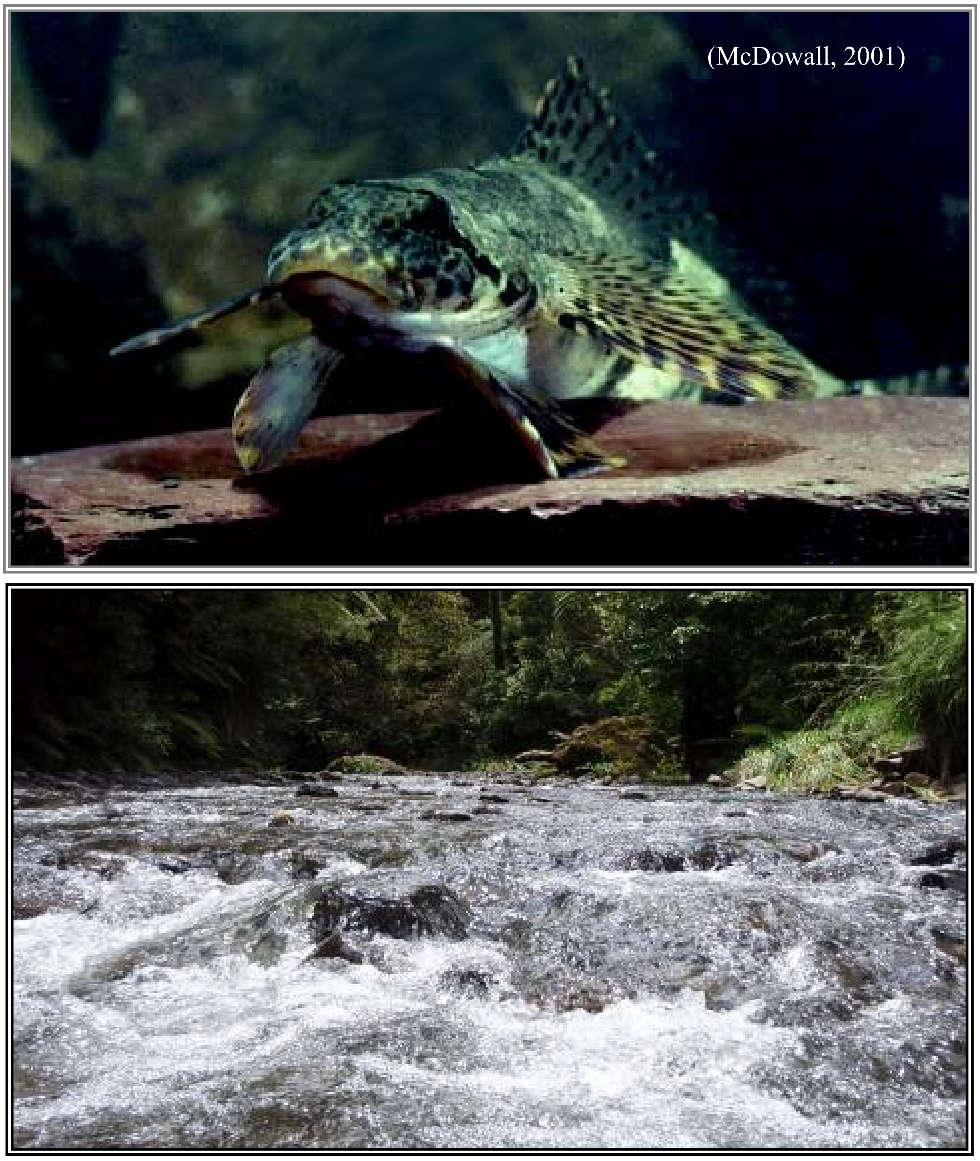


(Top) New Zealand’s endemic and highly specialised torrentfish (Cheimarricthys fosteri Haast 1874) known to early Maori as Te ika huna a Tane Mahuta – The hidden fish of Tane god of the forest. (bottom) The fast flowing habitat of torrentfish.

CHAPTER ONE
General Introduction

1.1 Background and historical knowledge

Torrentfish (*Cheimarrichthys fosteri*, Haast 1874) are a little known freshwater fish species endemic to New Zealand (McDowall, 1990). Their closest living relative is the blue cod (*Parapercis colias*) which lives exclusively in coastal marine environments (McDowall, 1973). Torrentfish are widely distributed and can be found throughout much of the North and South Island, but are not found on offshore islands (Stokell 1955; McDowall, 2000), (Fig 1.1). Despite being widespread few New Zealander's will be acquainted with this fish as they typically live beneath the white wash of shallow fast flowing streams where they are not easily observed (Glova and Duncan, 1985; Jowett and Richardson 1995). This preference for fast flowing currents makes torrentfish one of our most specialised freshwater fish species (Jowett and Richardson, 1995).

The first detailed accounts of torrentfish in New Zealand were from specimens collected from the Otira River (Canterbury) in March 1873 by Mrs J C Foster of Sunmer. Upon examination by Sir Julius von Haast, a German geologist, renowned New Zealand explorer and director of the Canterbury Museum the specimens were found to belong to '*a genus hitherto undescribed and therefore new to science*' (Haast, 1874). Haast went on to provide the first meticulous description of torrentfish morphology and in noting their particular preference for fast flowing currents, accordingly drew its name from the Greek – *cheimarros* (a torrent) and *ichthys* (a fish). Similarly, he drew the species name from the original specimen collector Mrs J C Foster.

However, as reported by Mair (1880), torrentfish were of considerable importance to early Maori who knew them by several names including *Papanoko, Panepane, Panekoreia, Panonoko, Papanei, Papauma, Parikoi and Te ika huna a Tanemahuta,* 'the hidden fish of Tane' God of the forest (Mair 1880). Mair's observations of Maori in the Whanganui River were considerably informative and demonstrated an in-depth knowledge of torrentfish spawning activity which based on current understanding is still observed in North Island rivers today (Phillipps, 1929; McDowall, 1973). Similarly, these observations also provided an insight into traditional fishing practises most notably how large quantities of whitebait, bullies and spawning torrentfish were collected in the upper Whanganui River by constructing a single line of wooden stakes at the head of rapids 50–60 feet long and about 10 degrees across the current. Fish which appeared to swim down the middle of the river would be funnelled into hinaki (wicker baskets) placed at the base of each weir (Mair 1880). Additionally, great ceremony was bestowed upon torrentfish by Whanganui Maori with fish always prepared away from the village in order to ensure further catches would be good (Mair 1880).

Early accounts of torrentfish were also reported by Phillipps (1929) in the Rangitukia River on the east coast of the North Island of New Zealand. However, these observations were more descriptive of reproductive aspects regarding female fecundity, egg size, and evidence of prolonged spawning activity occurring in June and July and then December–February. Similarly to Mair (1880), mention was also made of the relationship Maori in the region (Ngati, Porou) had with torrentfish. These included descriptions of an alternative fishing method whereby papanoko snares fashioned out of wooden stakes and flax were often used to snare medium sized torrentfish that sat on the sheltered side of boulders and rocks in the Rangitukia Stream (Phillipps, 1929).

Figure 1.1: Geographic distribution of torrentfish throughout the North and South Island of New Zealand. Source: New Zealand Freshwater Fish Database (NZFFD).

1.2 Recent knowledge

Despite historical accounts information on torrentfish has been less forthcoming and up until the early 1990's torrentfish were often referred to as the least known of our freshwater fish fauna (McDowall 1973; 1990; West 1989; Glova et al. 1995; Meyer-Rochow and Coddington, 2003). However, recent research has shown marked increases in our knowledge of this species resulting in the availability of a wide range of information covering the torrentfish's general distribution and abundance (Davis et al. 1984; Eldon and Greager, 1983; Hayes 1989; Jowett and Richardson, 1995), habitat (Glova and Duncan, 1985; Jowett and Richardson, 1995), biology (Scrimgeour and Eldon, 1989; Montgomery and Milton, 1993; McDowall, 1994; Montgomery et al. 1997; Carton and Montgomery, 2004), feeding ecology (Scrimgeour, 1986; Glova, 1987; Scrimgeour and Winterbourn, 1987), taxonomy (Topp, 1963; McDowall, 1973; Imamura, 2003), and biogeography (McDowall, 2000).

1.3 Research overview

Although considerable information on torrentfish biology and ecology now exists there are still fundamental gaps in torrentfish understanding (McDowall, 2000). These relate to aspects of their migratory life history such as their movements between fresh and saltwater (diadromy) as well as spawning habitats and spawning behaviour which are yet to be described for this species.

1.3.1 Population structure and reproductive aspects

It is apparent that torrentfish establish separate male/female populations as they mature within the same river with males occupying lower reaches and females the upper reach sites (Davis et al. 1984; Scrimgeour and Eldon, 1989; West, 1989). Not surprisingly, at some point in time the sexes must meet in order to reproduce.

Subsequently, it is the females that migrate downstream to males to spawn before returning to inland habitats (Mair 1880; Davis et al. 1984; Scrimgeour and Eldon, 1989). Collectively, the reported timing and occurrence of female spawning migrations is drawn from a variety of sources. The earliest of which includes indigenous knowledge by Maori of female spawning runs to lowland sites in the Whanganui River by Mair (1880), and observations of egg laden females in the lower reaches of the Rangitukia River by Phillipps (1929). More recently ripe torrentfish were observed in the upper reaches of the Waikanae River by McDowall (1973). Evidence of male and female separation behaviour has also been reported from a population study of native fish in the Mangauika Stream near Hamilton by West (1989). However, probably the most revealing study to date of spawning and separation behaviour has been from Scrimgeour and Eldon (1989).

This study described aspects of the reproductive biology of torrentfish in the Rakaia and Ashley Rivers on the South Island of New Zealand. The results of which provided detailed information on the ratio of male and females with distance from the sea and the timing of spawning events based on male and female egg development patterns over a twelve month period (Scrimgeour and Eldon, 1989). However, it is apparent that earlier work in the Rakaia by Davis et al. (1983), Eldon and Greager (1983) and Glova et al. (1987) also contributed considerably to this understanding.

In general reproductive evidence regarding gonosomatic indexes (egg development) indicated that peak spawning occurred in both the Rakaia and Ashley rivers from January–April (Scrimgeour and Eldon, 1989). However, based on the seasonal variability of reported spawning periods in studies by Glova et al (1987) and Scrimgeour and Eldon (1989) in the Rakaia and Ashley's River, the evidence of reported spawning periods were thought to be less compelling (McDowall, 2000).

1.3.2 Migration history

Existing information on the migratory life history of torrentfish is incomplete and often conflicting (Eldon and Greager, 1983). The current understanding is that torrentfish spend early growth at sea before returning to freshwater as juveniles (23–30 mm) to mature (McDowall, 1973; Davis et al. 1984; Eldon and Greager, 1983; Scrimgeour and Eldon, 1989). These movements are indicative of a large portion of New Zealand's native freshwater fish fauna which undertake similar movement patterns as hatchlings, and include well known galaxiid species such as the widespread inanga (*Galaxias maculatus*) and banded kokopu (*G. fasciatus*), sparsely distributed giant kokopu (*G. argenteus*), and rare shortjaw kokopu (*G. postvectus*), (McDowall, 1990).

However, as reported by McDowall (1994), there have been no reported accounts of torrentfish larvae being captured at sea. This is not surprising given the task of successfully capturing torrentfish larvae (< 20 mm) in the open ocean at any given time could be likened to finding a needle in a haystack. Needless to say there are major limitations in the ability to track small larval across large spatial and temporal scales using conventional tagging techniques (Limburg et al. 2001). This is because tags often exceed the size of larval migrants. Tagging also becomes a less viable option whereby large numbers of tagged fish, with typically poor recapture rates are required (Limburg et al. 2001, Munro, 2004).

As a result, natural tags (fish otoliths) using beam based microprobe technologies such as Laser Ablation Inductively Coupled Mass Spectrometry (LA- ICP-MS) have been used to track fish movements across fresh and saltwater gradients (Campana, 2001). The ability of otoliths to incorporate trace elements from the water (daily) relative to a fishes movements through time and space has made chemical analysis of otoliths a more feasible and less costly option compared to tagging techniques (Munro, 2004). Subsequently, known differences in the chemical composition of freshwater (low Sr/Ca) and saltwater (high Sr/Ca) has been detected in fish otoliths, demonstrating their movements between fresh and saltwater environments (Tzeng, 1999; Limburg, 2001; Closs et al. 2003; Hicks, et al. 2005). In New Zealand laser ablation (ICP-MS) has only recently been introduced and yet to be fully utilised. For torrentfish much of the evidence to support a marine rearing growth phase is drawn from observations of small juveniles (< 30 mm) collected in the lower reaches of rivers (Phillipps, 1929), near river mouth entrances (Davis et al. 1983; Scrimgeour and Eldon, 1989) or at the entrances to small estuaries (Glova et al., 1995). Similarly, the presence of juveniles in lowland river reaches and not from upstream sites has been interpreted as evidence that torrentfish recruits most likely came from the sea as fish that small were only collected in lower reach sites (Davis et al. 1983; Scrimgeour and Eldon, 1989). Based on these reports it is probable that torrentfish do indeed spend early life at sea yet short of collecting larvae in the open ocean there is still reasonable uncertainty surrounding early marine migrations.

1.4 Research objectives

This study investigates two aspects of torrentfish understanding that are still relatively uncertain. Specifically, this relates to aspects associated with the torrentfish’s population characteristics (male/female separation and spawning period), and torrentfish migration history. The aim was to investigate temporal and spatial changes in the distribution of male and female torrentfish in two small Waikato streams on the basis of determining evidence of separation behaviour as described by Scrimgeour and Eldon (1989) as well as assessing male and female gonad development patterns to determine the timing at which spawning may occur in both study streams. For the second part of this study the aim was to document the movements of torrentfish between fresh and saltwater by tracking known differences in the chemistry of these environments within fish otoliths (fish earbones) using laser ablation (ICP-MS). Collectively, this study aims to shed light on the torrentfish’s as yet uncertain diadromous life history and provide further information on their movement patterns within streams.

CHAPTER TWO

Torrentfish population study

2.1. Introduction

Until recently, New Zealand's endemic torrentfish (*Cheimarrichthys fosteri*) was widely considered to be the least known of our freshwater fish species (McDowall, 1973; West, 1989; Glova et al. 1995). However, in more recent times the range of available information on this species is quite extensive and includes detailed knowledge on the torrentfish's general distribution and abundance (Davis et al. 1983; Eldon and Greager, 1983; Hayes, 1989; Jowett and Richardson, 1996; Joy 2000; Jowett et al. 2005), habitat (Glova and Duncan, 1985; Jowett and Richardson, 1995), biology (Scrimgeour and Eldon, 1989; Montgomery and Milton, 1993; McDowall, 1994; Montgomery et al. 1997; Carton and Montgomery, 2004), feeding ecology (Scrimgeour 1986; Glova, 1987; Scrimgeour and Winterbourn, 1987), taxonomy (Topp, 1963; McDowall, 1973; Imamura, 2003) and biogeography (McDowall, 2000).

2.1.1 Geographic distribution and habitat range

In terms of its geographic distribution torrentfish are found primarily in shallow fast flowing braided or gravel bed river systems common throughout the North and South Island of New Zealand (Stokell 1955; Glova and Duncan 1985; McDowall 1990; Jowett and Richardson, 1995). This widespread distribution yet narrow habitat range is due to their high level of specialisation both in body form and fin structure (McDowall, 1990). This enables torrentfish to inhabit fast flowing riffle habitats within rivers (McDowall, 1994). Subsequently, torrentfish are classified as being one of New Zealand's most specialised freshwater fish species (Glova and Duncan, 1985; Jowett and Richardson, 1995). Field and laboratory flume studies by Glova and Duncan (1985) indicated that torrentfish preferred water velocities around 1.5 ms^{-1} and depths ranging between 200-350 mm. Similarly, Jowett and Richardson (1995) found that torrentfish frequently, occurred at depths greater than 200 mm and velocities exceeding 0.6 ms^{-1}. In the same study fish were also found in greater abundances in streams with cobble or gravel substrate sizes measuring 50–100 mm. However, despite the torrentfish's specific habitat preferences they are known to migrate through larger deeper river systems such as the Waikato River (Palmer et al. 1929; West, 1989) and Whanganui Rivers (Mair, 1880), in order to gain access to inland streams which have suitable maturing habitats.

2.1.2 Biology and feeding ecology

The general biology of torrentfish is well known, for example adult and juvenile torrentfish have a distinct body form and colouration making them unlikely to be confused with other freshwater fishes in New Zealand (McDowall, 1994). However, the physical characteristics of hatched larvae are yet to be documented (McDowall, 1994). Torrentfish have a flattened underbelly and torpedo-shaped head with an arched back (Phillipps, 1929) that is dotted with four distinct stripes sloping forward and then down towards the belly (McDowall, 2000), (Fig 2.1).

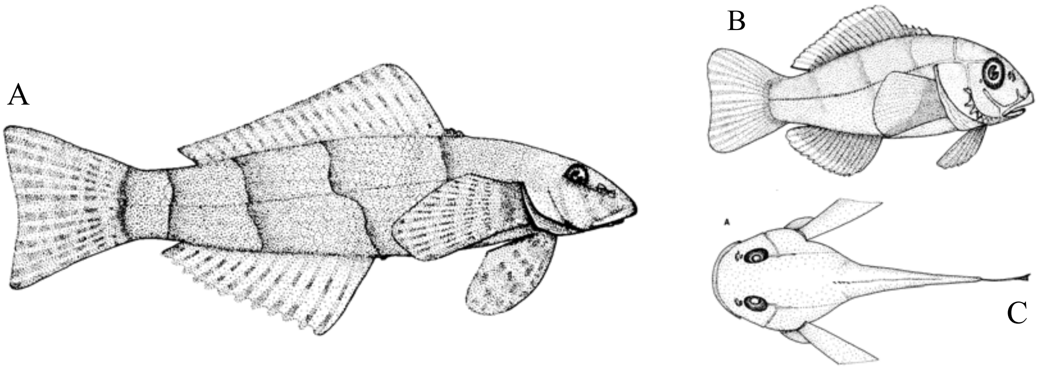


Figure 2.1: Mature 105 mm (total length) torrentfish taken from the Waikanae River (A) along with a side (B) and overhead (C) profile view of a small juvenile 23 mm taken from the Rakaia River mouth (source McDowall, 1994).

They have a single dorsal fin with 4–5 stout spines at the front and an anal fin which extends back towards the tail from midway below the dorsal fin. Torrentfish have a sub-terminal mouth (lower jaw undercuts the upper jaw) which opens below the head an aspect which is thought to aid them in grazing invertebrates on the surface of rocks (Scrimgeour, 1986; Glova, 1987; Scrimgeour and Winterbourn, 1987).

2.1.3 Size and age at maturity

Torrentfish are typically small in size ranging from 100–125 mm fork length (Davis et al. 1983; Glova et al. 1995) although males maybe smaller than females. Based on the size frequency distribution of torrentfish taken from the Rakaia River (Canterbury) on the South Island of New Zealand Scrimgeour and Eldon (1989) suggested that size at sexual maturity for torrentfish occurred in their second year (1+) with males exceeding 63 mm and females 65 mm in fork length. Few individuals exceed 150 mm in length although Phillipp's (1929) reported specimens ranging from 150–200 mm in the Rangitukia Stream in the Bay of Plenty on the North Island of New Zealand. Fish more recently have been found as large as 161 mm by McDowall (1990) and 156 mm by West (1989) in the Mangauika Stream near Hamilton. Although the hatched larvae of torrentfish are yet to be described in the wild (McDowall, 1994) the size range of juveniles returning to freshwater rivers from the sea appear to vary but generally range between 20–30 mm (Davis et al. 1983; Eldon and Greager, 1983; Scrimgeour, 1989; McDowall, 1994; Glova et al. 1995). Based on an analysis of seasonal growth checks in the microstructure of otoliths (fish earbones) torrentfish are thought to be relatively short lived, with a lifespan of four years (West, 1989) though size frequency data collected by Davis et al. (1983) and Scrimgeour and Eldon (1989) suggests some individuals may live three years.

2.1.4 Feeding patterns and behaviour

Field and laboratory studies on the diel feeding patterns of torrentfish by Glova et al. (1987) and Glova (1996) suggest that fish are nocturnal and remain hidden in, River (Canterbury) on the South Island of New Zealand. The results indicated that for large (71–109 mm) and small (51–64 mm) individual's food was predominantly made up of slow moving chironomid (midge) elmid (beetle) and caddisfly larvae (Scrimgeour, 1986). In a similar study Sagar and Eldon (1983) surprisingly found that torrentfish take chironomids at far greater proportion than were observed in the benthos. Although this suggested that fish were selective in their feeding behaviour selectivity was disputed on the basis of the torrentfish's specific sub-terminal feeding morphology (lower jaw shorter than the upper) (McDowall, 1973). This aspect was thought to enable torrentfish to graze the surface of rocks for slow moving chironomids, but not so for faster moving mayfly (*Deleatidium* larvae) which may evade capture (Sagar and Eldon, 1983). However, in the same study it was also suggested some *Deleatidium* spp (mayflies) were an important dietary component to larger mature torrentfish (Sagar and Eldon, 1983). Little is known about the diet of smaller post larval torrentfish (< 30 mm) although Glova et al. (1995) examined the stomach contents of eight 19–30 mm torrentfish collected after dusk at the river mouth of the Kakanui River estuary (North Otago). Fish indicated a preference for the endemic amphipod *Paracorophium excavaum* a species typically found on the mudflats and fine sediments of estuaries and harbours (Schnabel et al. 2000).

2.1.5 Reproductive biology and spawning patterns

Scrimgeour and Eldon (1989) described aspects of the reproductive biology of torrentfish in the Rakaia and Ashley's River (Canterbury), on the South Island of New Zealand and found that male and females occupied separate longitudinal habitats within both rivers. Overall, males were significantly more abundant than females in lower reach sites, whereas females were increasingly more abundant in upstream sites and only exclusively found at the furthest inland site. As a consequence of this unusual separation behaviour Scrimgeour and Eldon (1989) suggested that spawning migrations were probably instigated by females migrating to males in the lower reaches.

However, given the variability in the timing of spawning events reported between studies (Table 2.1), it was suggested that the evidence was not compelling (McDowall, 2000). In terms of egg fecundity, Phillipps (1929) reported estimates of a 83 mm female having approximately 12,546 ova each around 0.62-0.63 mm but also noted estimates by Elsdon Best for a 150 mm female from the Whanganui River of about 30.000 at 0.75 mm in diameter (Phillipps 1929). Scrimgeour and Eldon (1989) estimated fecundity of fish from the Rakaia range from 6800–55100 ova and 2800–24800 in the Ashley River some reservations about spawning periods in these studies,

Table 2.1: Summary of research information on rivers in the North and South Island which has suggested possible spawning periods of torrentfish

Study river	River habitat	General location	Spawning period	Researcher (s)
Ashley	braided/cobble	Christchurch - South Island	Jan-Apr	Scrimgeour & Eldon 1989
Ashley	braided/cobble	Christchurch - South Island	Dec-Mar	Glova et al 1987
Rakaia	braided/cobble	Christchurch - South Island	Jan-Apr	Scrimgeour & Eldon 1987
Rakaia	braided/cobble	Christchurch - South Island	Apr-May	Glova et al 1987
Rangitukia	gravel/coble	Bay of plenty - North Island	Dec-Feb, Jun-Jul	Phillipps 1929
Whanganui	deep/sedimented	Whanganui - North Island	Feb-Autumn	Mair 1880
Waikanae	cobble/gravel	Wellington - North Island	Dec-Mar	McDowall 1973

The aim of this study was to assess the size composition and longitudinal distribution patterns of torrentfish in two small Waikato streams over a full year and to evaluate gonad development patterns of male and female torrentfish overtime to gauge peak spawning condition as a measure on when spawning was likely to occur. The basis of this research was to determine if underlying population characteristics and reproductive aspects described by Scrimgeour and Eldon (1989) for torrentfish in the South Island’s Rakaia and Ashley Rivers were indicative of populations in two small North Island streams in particular whether there were similar patterns of male and female separation and spawning periods.

2.2 Methods

2.2.1 Study streams

Torrentfish were collected from three small streams located in the Waikato and the far north of the North Island of New Zealand (Fig 2.2, 2.3) The Mangauika and Rangitukia Streams are draining watersheds located on the slopes of Mount Pirongia. Both streams are short (2^{nd} order) in length and descend Pirongia through a range of landuse cover types.

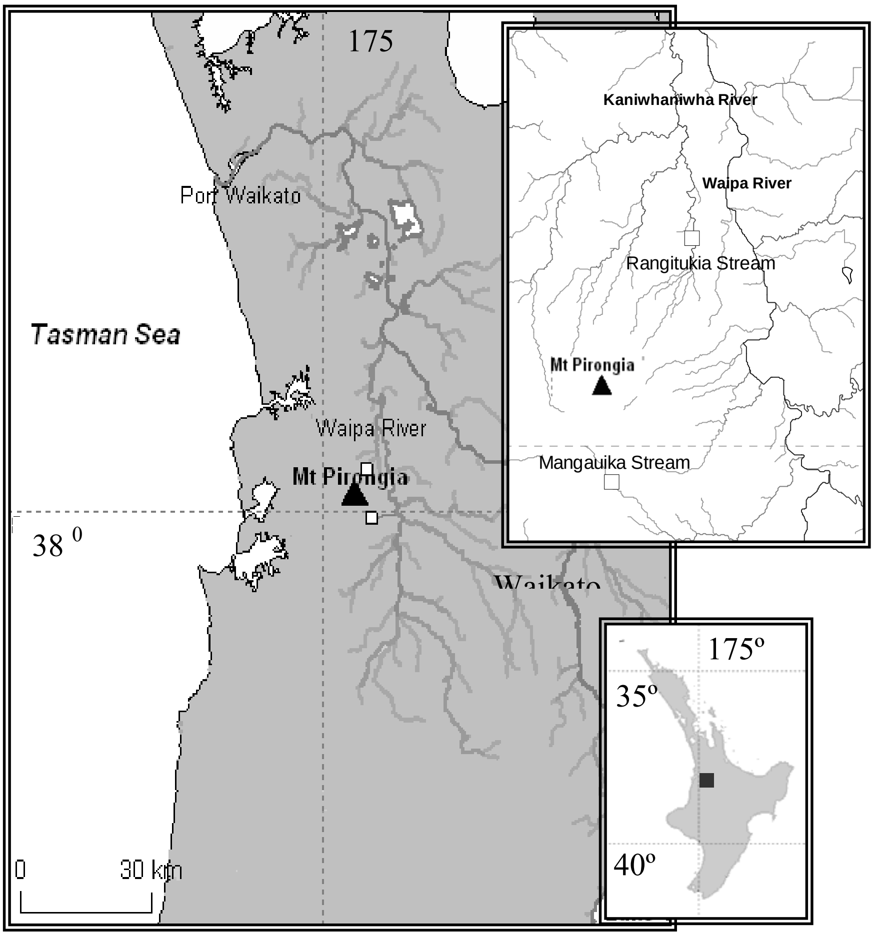


Figure 2.2: Location of the Mangauika and Rangitukia streams on the slopes of Mt Pirongia and their passage to the Tasman Sea via the Waipa and Waikato River on the North Island of New Zealand.

The uppermost ranges of Mt Pirongia (959 m above sea level) consist of the Pirongia State Forest Park which extends around the summit forming much of the headwater catchments of both, streams. Riparian vegetation within the lower reaches of both the Rangitukia and Mangauika streams is predominantly pastoral grazing country with fragments of exotic willow (*Salix* sp), gorse (*Ulex europaeus*), and small remnants of native podocarp.

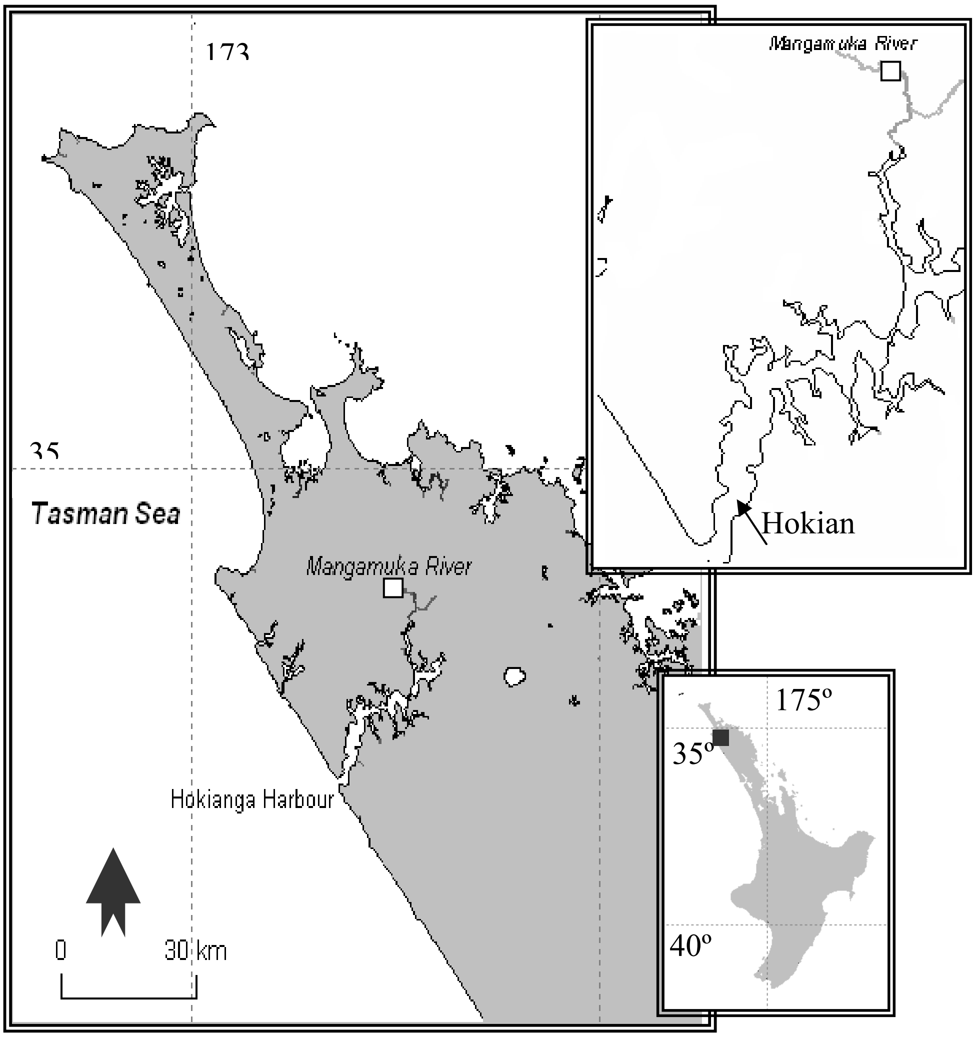


Figure 2.3: Location of the Mangamuka River draining into the Hokianga Harbour and Tasman Sea in the far north of the North Island of New Zealand.

Stream habitat consists of large cobble or boulder strewn substrates in the upper reaches of both streams with smaller grained gravel substrates in the lower reaches (West, 1989). A high number of fast flowing shallow riffle/run sections are scattered throughout the Mangauika and Rangitukia and access to the sea from both streams is gained via a network of interconnecting rivers (Table 2.2) passing through contrasting land cover types with variable degrees of water quality. Rangitukia on the western slopes of Pirongia drains firstly into the larger, deeper, Kaniwhaniwha River where it enters the broader Waipa River.

The Waipa River has a considerably large catchment area (3,059 km^2), the majority of which is used extensively for grazing stock. Dairy farming throughout the catchment is considered to be a major factor contributing to the reduced water quality of the Waipa. The Mangauika and Rangitukia both converge on the Waipa where they enter the greater Waikato River flowing through Hamilton City to Port Waikato and the Tasman Sea (Table 2.2). In contrast the Mangamuka River is the longest of all the study streams (21.2 km), and through its entirety flows from the summit of the south facing Mangamuka Ranges to the Tasman Sea via the Hokianga Harbour. The overall distance from the sea to each fishing site is variable with the Mangamuka River (11.6 km) having considerably shorter distances than the Rangitukia (141 km) and Mangauika streams (170 km), (Table 2.2).

2.2.2 Longitudinal study sites

The population structure of torrentfish was evaluated at a site in the upper and lower reaches of the Mangauika and Rangitukia Streams over a single year (from Nov 2007–Oct 2008), (Fig 2.4, 2.5). However, one off sampling of torrentfish was carried out in a lower reach site of the Mangamuka River during 24 May 2008 (Fig 2.3). Selection of each fishing sites in both Waikato streams was governed by habitat suitability and barriers to migration. The presence of instream culverts in the upper reaches of both streams was deemed likely to prevent torrentfish access further inland (Fig. 2.6, 2.7). However, torrentfish were located at the base of each structure, thus fishing was carried out below each culvert. Additionally, towards the end of this study (August 2008) a fish pass in the upper reach site of the

Mangauika was installed. Selection of lower reach sites was restricted to the confines of the Mangauika and Rangitukia Streams only.

Table 2.2: Stream profile information on the Rangitukia, Mangauika and Mangamuka River including distance to the sea, distance between the upper and lower reach sites, stream order and the river pathway to sea.

Study streams	Stream length (km) and order	Distance between upper /lower reach sites (km)	Distance from the sea (km)	River pathways to sea
Rangitukia	12.6 km (2nd order)	8.6 km	152.3 km	Kaniwhaniwha Stream Waipa River Waikato River Port Waikato Tasman Sea
Mangauika	14.9 km (2nd order)	11.2 km	170.2 km	Waipa River Waikato River Port Waikato Tasman Sea
Mangamuka	21.2 km (3rd order)	one site	11.2	Mangamuka Hokianga Harbour

This was because suitable maturing habitats were only present within study streams. This did not include the Waipa and Waikato Rivers which are deep and sedimented (Fig 2.8, 2.9), thus lower reach fishing sites within the Mangauika and Rangitukia were based near their convergence with the Waipa.

2.2.3 Environmental parameters

Water flow measurements (ms^{-1}), stream width (m) and depth (mm) recorded from the left bank (LB) middle (M) and right bank (RB), of the same upper/lower reach sites in each month of sampling are summarized in (Table 2.3). In general, the upper and lower reaches of the Mangauika are characterised by slightly deeper and wider channels than in the Rangitukia which overall were shallower and narrow (Table 2.1). Similarly, the Mangauika also had faster mean water flows in upper (0.26 ± 0.01 ms-^{1}) and lower (0.45 ± 0.05 ms-^{1}) reach sites, while in the Rangitukia, mean water flows was slower and much the same between the upper (0.17 ± 0.02 ms-^{1}) and lower (0.19 ± 0.04 ms-^{1}) reaches (Table. 2.3).

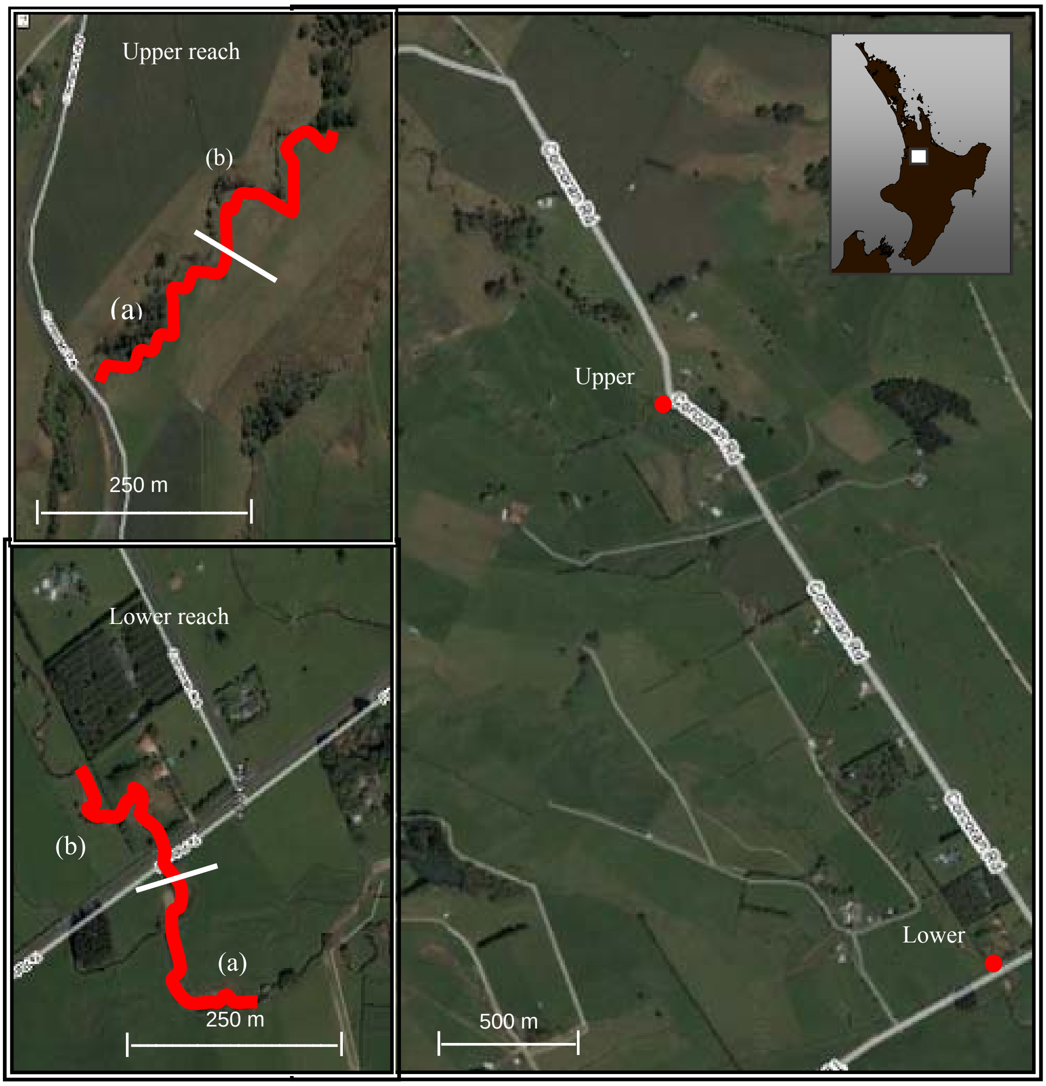


Figure: 2.4: Location of the upper reach (Corcoran Rd) and lower reach (Te Pahu Rd) fishing sites as well as the alternating monthly fishing reaches (a) and (b) in the Rangitukia Stream on the north western slope of Mt Pirongia.

Throughout the year mean water flow was highest in the Mangauika during November (0.28 ± 0.16 ms^{-1}) April (0.54 ± 0.35 ms^{-1}) and August (0.45 ± 0.2 ms-^{1}). Around the same time similar high flows occurred in the Rangitukia Stream during April (0.35 ± 0.31 ms^{-1}) and August (0.47 ± 0.33 ms^{-1}) but was also high in June (0.42 ± 0.36 ms^{-1}). Canopy cover in the Mangauika is predominantly native (*Podocarp, spp*,) mixed with pine (*Pinus radiata*) in the upper reach site with high cover (75%). and patchy canopy cover (23%) from willows (*Salix* spp.) in the lower reach site (Table 2.3).

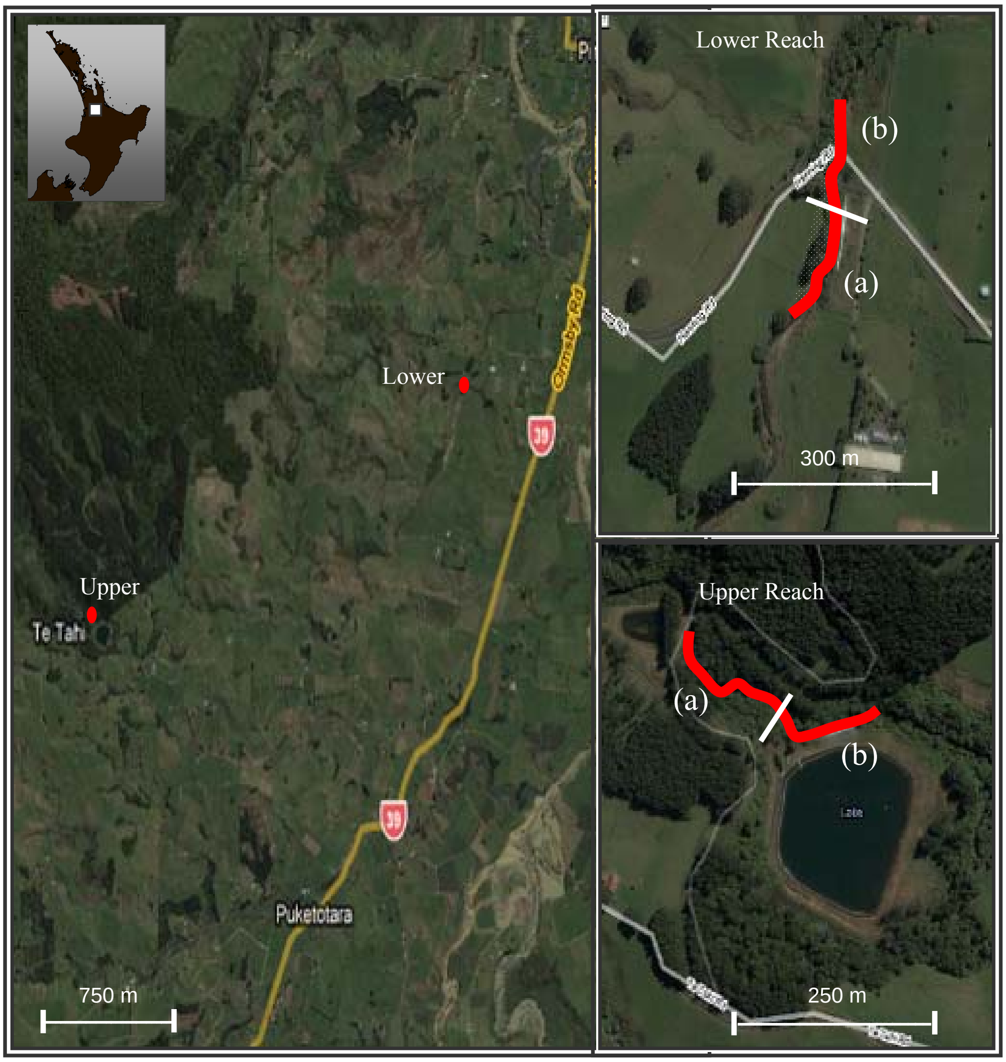


Figure 2.5: Location of the upper reach (Te Tahi Rd) and lower reach (Hanning's Rd) fishing sites in addition to the alternate monthly fishing reaches (a) and (b) in the Mangauika Stream on the eastern slope of Mt Pirongia

Cover in the upper reach site of the Rangitukia was also patchy with willow (12%) while in the lower reach, there is sparse canopy cover (4%) being mostly open pasture.

Figure 2.6: (left) Instream culvert marking the upstream limits of torrentfish in the upper reach site of the Rangitukia Stream on Mt Pirongia.

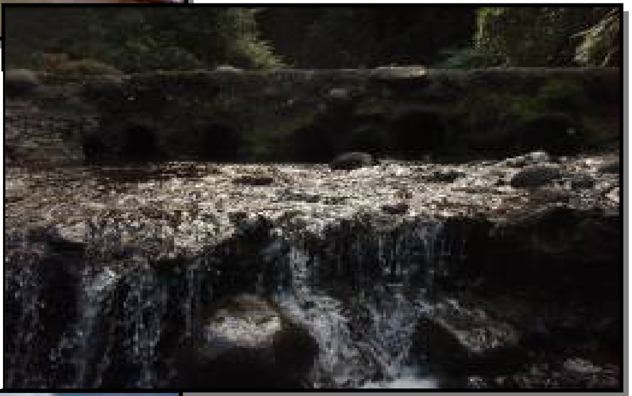


Figure 2.7: (right). Instream culvert marking the upstream limits of torrentfish in the upper reach site of the Mangauika Stream on Mt Pirongia.

Figure 2.8: (left). The Waipa River (without suitable habitat) which receives the draining waters of the Mangauika and Rangitukia Streams

Figure 2.9: (right).The Waikato River at the Huntly thermal Power Station 80 km from Port Waikato and the main access for torrentfish from both study streams to the sea

2.2.4 Fish sampling

Fish sampling was carried out in the Mangauika and Rangitukia Streams at the end of each month from 29 November 2007 to the 22 October 2008. In addition one off fishing sampling in the Mangamuka on 25 May 2008 was carried out using a portable electrofishing backpack machine (Kanga-6000). Fishing sites were selected based on the torrentfish's known habitat preferences described by Jowett and Richardson (1995) which only included shallow gravel type riffle habitats.

Table 2.3: Summary of upper and lower reach study site characteristics, with mean stream depth, width and flow data averaged from monthly readings (left bank, middle and right bank), taken from the same fishing reach site from Nov-2007 to Oct-2008.

	Mangauika Stream		Rangitukia Stream	
Physical characteristics	Upper	Lower	Upper	Lower
Mean stream depth (mm)	336±32.1	196±16.6	183±11.0	155±13.4
Mean stream width (m^2)	5.1±0.35	5±0.91	3.2±0.12	2.3±0.08
Mean mid column velocity ($ms-^1$)	0.26±0.01	0.45±0.05	0.17±0.02	0.19±0.04
Landuse	Native	Exotic	Exotic	Pastoral
Stream canopy cover	71 %	23 %	12 %	4 %

However, torrentfish are known to be adversely affected by the electrofishing pulse, which has resulted in high mortality rates (West 1989). To reduce the impact of repetitive fishing pressure alternating monthly fishing sites were fished in both streams (Fig 2.4, 2.5). To determine fish densities cross section measurements (width and riffle length) in each fishing reach were taken and the total area (m^{-2}) calculated for each alternating fishing site (Table. 2. 4). Fishing always started at the lowest placed riffle section (for each stream) and was progressively fished upstream.

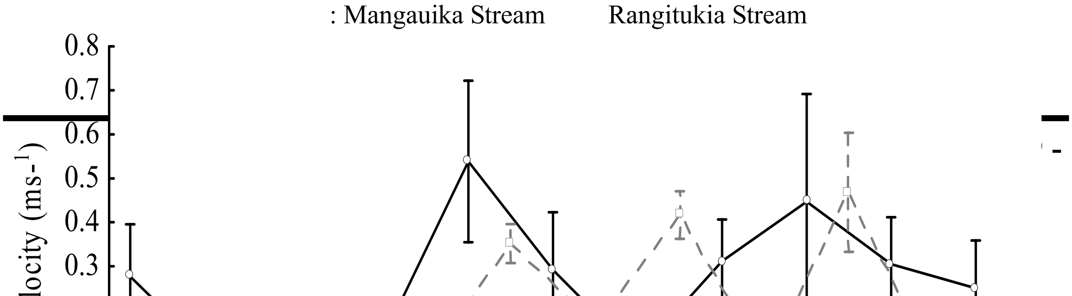


Figure 2. 10: Mean (±SE) ± water velocity (ms-^{1}) measurements recorded prior to fish sampling from the Mangauika and Rangitukia Streams (Nov 2007 to Oct 2008). Cross section (left bank, middle, and right bank, flow data for each reach are pooled to give mean water flow for each stream by month (no flow data collected in Dec 2007).

In general 2-3 passes in each riffle was carried out regardless of whether fish were present or not. However, fishing effort in the second and third pass was less intense as the first. The average fishing time was 32 minutes for all stream sites with an average power setting of 3 amps for the whole study. All fish captured were measured (total length) to the nearest 1 mm and weighed to the nearest (0.1 g). Fish collected for gonad development staging and sex determination were sacrificed in benzacaine, placed in labelled containers filled with stream water so that gonads retained their colouration which would improve sex determination of immature male and female gonads.

2.2.5 Sex determination and gonad development

Sex determination and gonad staging methods were carried out on fresh gonads extracted from torrentfish on either the same or following day of sampling. Maturity scales for male (Table. 2.5) and female (Table. 2.6) torrentfish have been modified from Bowers (1954) macroscopic maturity keys for Atlantic whiting (*Gadus merlangus*, L). Gonads were assigned to one of six maturity stages for females and 5 stages for males and included unsexed, immature, mature/resting, ripe, ripening, and spent stages for females.

Table 2.4: Area (m^{-2}) of each alternate fishing reach in upper and lower reach sites of the Mangauika and Rangitukia Streams.

Fishing reach	Alternating sites	Rangitukia Stream area (m^{-2})	Mangauika Stream area (m^{-2})
Lower	a	86.9	91.7
	b	77.2	101
Upper	a	93.3	91.2
	b	71.7	98.2
	Total area	A = 183.2 B = 148.9	A = 182.9 B = 198.3

The structure of oocytes in ripe females were easily visible by the naked eye and were generally yellow orange in colour and hydrated so that the outline of oocytes could be seen protruding the gonad wall. The overall shape of female gonads was tubular or rotund (Fig 2.11). Gonads of immature and mature females were relatively small, pinkish red and granular in colour with the right lobe slightly larger than the left requiring the use of a stereomicroscope using either transmitted or direct light source (Fig. 2.11).

Figure 2.11: Tubular rotund shaped female gonad extracted from a maturing fish (80 mm TL), (0.0325 grams) taken from the lower reach site of the Mangauika River.

Male testes were typically smaller than females across most stages. Fully ripe males were distinctly pale white in colour, with flattened ventral edges (knife shaped) and wave like outlines. The right lobe was larger than the left lobe for mature males although for ripe running fish differentiation from females was considerably easier. Near ripe and fully ripe testis contained an internal lode which was full of milt and the overall shape of the gonad was long and tapered to a point at the anterior end with distinct grain like strands from around the periphery of the milt sac to the outer periphery of the testis.

2.2.6 Age and fecundity estimates

Although considerable work has been done on torrentfish otoliths in this study (chapter three), and on gonad development staging (this chapter), time constraints meant that age analysis of otoliths and fecundity estimates of female torrentfish was not possible. Similarly, several authors have reported considerable difficulty in ageing torrentfish otoliths (Scrimgeour and Elsdon, 1989; West 1989) much of which is to do with the variability of the internal growth structure and shape. In this study detailed information on otolith preparation techniques which may prove useful in age analysis of this species are discussed in detail in chapter three methods.

2.2.7 Statistical analysis

All statistical analyses were carried out using STATISTICA 8 software. Evidence of normality and homogeneity of variances for abundance and length frequency data recorded from each stream were determined using Shapiro-Wilkes in conjunction with Levenes Test for homogeneity of variances. Data analysis then included longitudinal comparisons of mean fish length between streams using Oneway-ANOVA analysis. The area of each alternating monthly fishing site (Table. 2.4) was combined and total fish densities (per 100 m^{-1}) and biomass (g m^{-1}) of torrentfish were calculated for fish collected from upper and lower reach sites then used for comparisons. Mean differences in fish density and biomass between sex, fishing reach and study, streams were determined using Kruskal-

Table 2.5: Gonad maturity stages for male torrentfish adapted from Bower's (1954), maturity key for Atlantic whiting (*Gadus merlangus*, L). Stage (1) unsexed is included in

females and males as the same number of individuals with no developed gonads that were collected from upper and lower reach sites of the Mangauika and Rangitukia streams for each month.

Male Maturity stages	Torrentfish gonad condition	Bower's (1954) Description of Atlantic whiting
(1) Unsexed	No discernable gonad structure	–
(2) Immature	Testes small in size < 20% of gut cavity internal structure visible under microscope, pale white and transparent inner lobe not yet developed (manipulate transparent light source to gauge colour)	Testes small, no sperm, but sperm bodies discernible under microscope.
(3) Mature/resting	Testes makeup 25% of the gut cavity translucent edges and opaque white towards centre of testis, which are distinctly flattened and pointed with inner lobe developing	Testes enlarged slightly, tending to lose translucent colour and becoming whitish. Density of sperm bodies increases. A little sperm extruded on cutting.
(4) Ripe	Testes small in size 25% of the gut cavity white in colour inner lobe visible and full of milt or developing, appears whitish to creamy opaque in colour not transparent. distinct grain wave like strands extend from inner lobe periphery to outer testis wall,	Testes enlarged and with lobate internal structure, very white. Sperm extruded on cutting.
(6) Spent	Testis shrivelled makeup 20% of the cavity, and appear flaccid and ragged traces of milt evident with the internal lobe still visible but shredded in places with patches of milt	Testes shrunken and crinkled, a little sperm left. Testes slowly revert to stage 2.

Wallis multiple comparison tests (alpha 0.05). To determine which of the sexes was significantly different (based on the highest and lowest sum of ranks) unsexed fish were excluded from any analysis so that significant differences between males and females could be determined. To determine whether the distribution of males and females between fishing sites and streams differed from one another

Table 2.6: Gonad maturity stages for female torrentfish adapted from Bower's (1954), maturity key for Atlantic whiting (*Gadus merlangus*, L). Stage (1) unsexed is included in

females and males as the same number of individuals with no discernable gonads that were collected from upper and lower reach sites of the Mangauika and Rangitukia

Female Maturity stage	Torrentfish gonad condition	Bower's (1954) Atlantic whiting
(1) Unsexed	No discernable gonad structure	–
(2) Immature	Gonads small in size < 20% of gut cavity, oocytes not visible (naked eye), and barely visible under stereo microscope colour pale to red-pink (but need to manipulate light source)	Ovaries very small, translucent, may be slightly bloodshot. Eggs microscopic but discernible, under 500 magnifications by binocular microscope, as a few very small, rounded, discrete bodies
(3) Mature/resting	Gonads makeup 30% of the gut cavity pinkish red in colour tubular shaped lobes with thin outer walls oocytes visible (only via microscope), as opaque globules	Ovaries small to moderate in size, often translucent may be bloodshot. Eggs clearly discernible under 500 magnifications, but still very small; a few granules appear in eggs.
(4) Ripening	Gonads firm and distended make up 50-60% of the gut cavity, pale yellow in colour, blood vessels prominent, oocytes visible with naked eye	Ovaries enlarged and translucent may or may not be bloodshot. Eggs opaque increase in size (visible by eye); granules begin to concentrate in the centre.
(5) Ripe	Gonads hydrated and makeup ≥ 70-80% of the gut yellow orange in colour tubular shaped lobes with thicker outer walls, oocytes visible by naked eye as opaque globules with inner yolk sac visible	Eggs with a dark central mass and a transparent cortical zone make up 50-60% of the total egg mass, rest of eggs a mixture of stages 3 and 4. Ovaries turning orange or orange-yellow enlarged and distended. Differentiating eggs have a narrow cortical zone and a large granulated central area. Tunica easily burst at this stage.
(6) Spent	Gonads shrunken to 30-40% of the gut cavity, gonads visibly bloodshot red to pink in colour, tissue raggedy and watery, loose oocytes appear as opaque globules some large oocytes present.	Ovaries have collapsed, flaccid, or shrivelled appearance. Few residual eggs present. Ovaries quickly revert to stage 2.

2x2 contingency tables using Chi square (x^2) goodness of fit tests were used. Due to low frequency data for males (often < 5 individuals) collected in most months the seasonal distribution of sex ratios could not be determined for torrentfish in the Rangitukia. Instead all months were combined to give an overall indication of male and female distribution patterns. In the Mangauika sex ratio data from only a few months exceeded the lower limit threshold (< 5) to increase frequencies monthly data were combined (Fowler et al. 1997) and Fisher's test correction for lower frequency data was applied. GSI index was calculated according to (Vazzoler, 1996)

2.3 Results

2.3.1 Length frequency distribution

Length frequency classes (TL mm) for torrentfish were not easily distinguishable from combined monthly measurements of fish in both study streams (Fig.2.12). In the Mangauika fish lengths were only aggregated to one major grouping whereas in the Rangitukia only two partly overlapping size classes were apparent. However, size classes were more distinguishable from seasonal length frequency patterns (Fig.2.13).

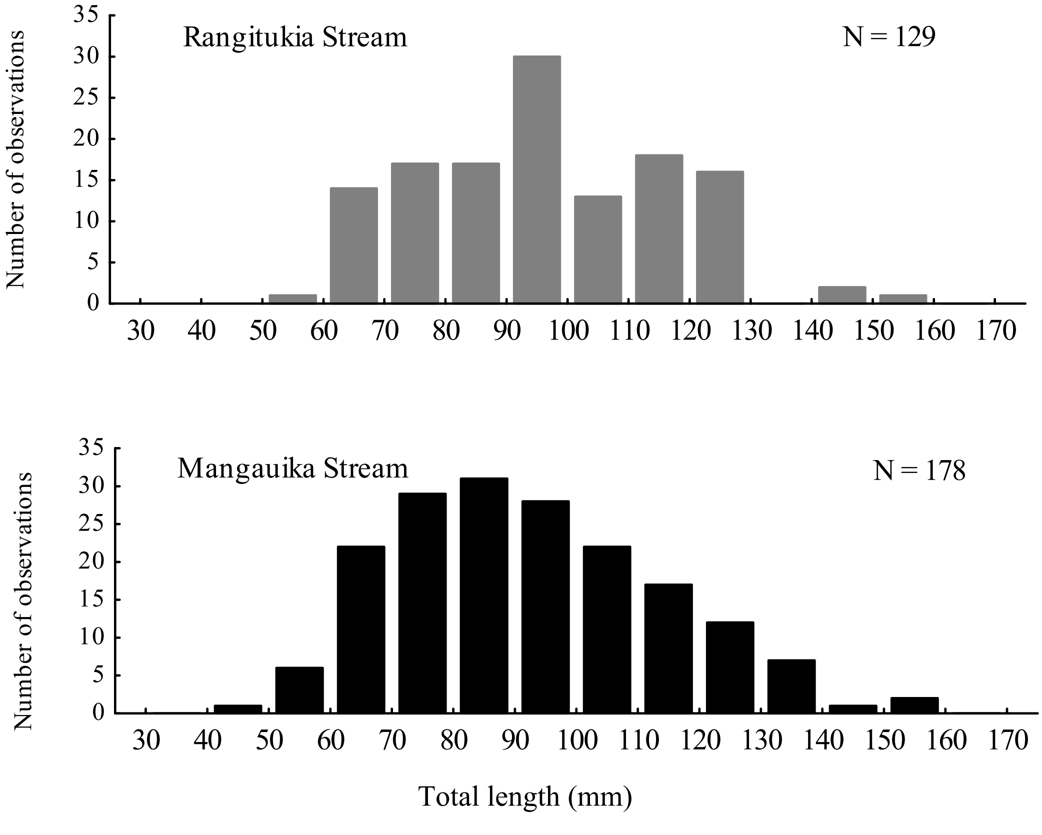


Figure 2.12: Size frequency distribution of torrentfish (TL mm), collected from the Mangauika and Rangitukia Streams.

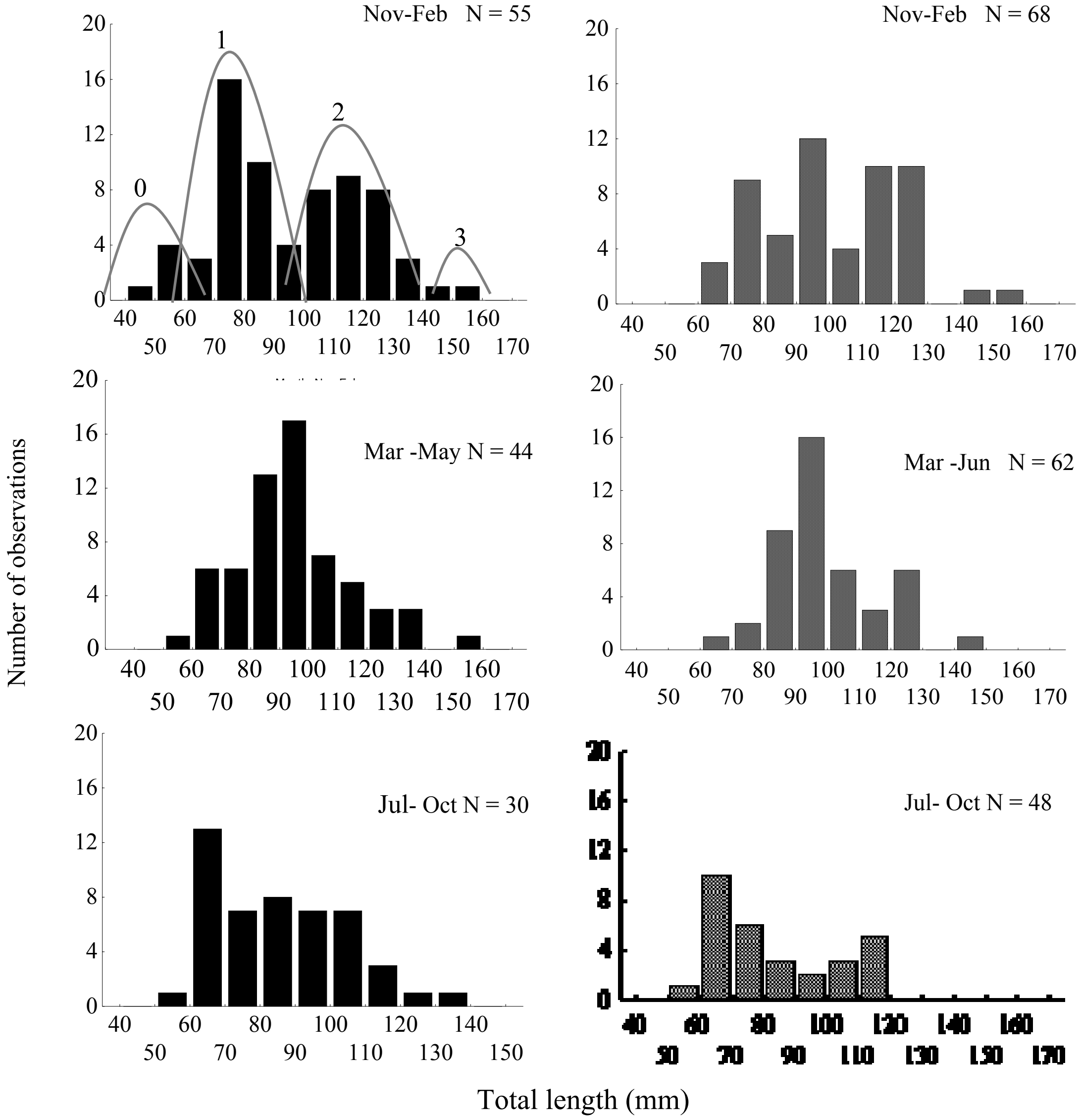


Figure 2.13: Four monthly length frequency distribution patterns of torrentfish (TL mm), collected from the Mangauika and Rangitukia Streams from Nov-2007 to Oct –2008.

Four overlapping size classes were evident between November 2007–February 2008 and are tentatively considered to represent fish in their first (0 +) second (1+) third (2 +) and fourth (3+) year (Fig .2.13). The smallest sized fish (< 50 mm) were only collected in the Mangauika Stream during November–February along with several larger sized fish which exceeded 140 mm in length (Fig.2.13). Throughout the rest of the year few smaller sized fish (< 60 mm) were taken (Fig. 2.13). In the Rangitukia torrentfish size classes from November–February were similarly aggregated into three groups, although the absence of fish (< 60 mm) meant that early age classes could not be allocated. Similarly, to the Mangauika larger sized fish (> 140 mm) were also taken in the Rangitukia although several of the smaller fish (< 60 mm) were only taken between March–May and July–October (Fig.2.13). Differences in fish length between both streams was not significant ($P = 0.131$) with mean fish sizes only slightly smaller in the Mangauika (93.0±1.68 mm), than in the Rangitukia (96.8±1.84 mm), (Table 2.7). Minimum and maximum fish lengths recorded from torrentfish collected in the Mangauika (47–157 mm) and Rangitukia (60–155 mm) were much the same, with only the smallest sized fish in the Rangitukia differing in size (60 mm). Significant differences in the size distribution of torrentfish between the upper and lower reach sites of both streams were indicated (Table.2.7).

Table: 2.7: Minimum, maximum and mean (± *SE*) fish length data (TL mm), along with Oneway ANOVA tests of fish size between site and stream recorded from torrentfish taken from the upper and lower reaches of the Mangauika and Rangitukia Streams (–/ means no data).

Stream	N	Min-Max size TL (mm)	Mean Size TL (mm)	±*SE*	df	ANOVA P < 0.05
Mangauika Stream	178	47-156	93.0	1.68	1	P = 0.131
Rangitukia Stream	129	60-155	96.8	1.84	1	-
Stream reach						
Upper Rangitukia	61	68-155	110.6	2.19	1	P < 0.0001
Lower Rangitukia	68	65-127	84.4	1.78	1	-
Upper Mangauika	62	66-156	111.5	2.45	1	P < 0.0001
Lower Mangauika	116	47-133	83.2	1.48	1	-

Torrentfish taken from the Mangauika Stream were on average significantly smaller in the lower reach site (83.2±1.48 mm $P < 0.0001$) than in the upper reach site (111.5±2.45 mm), (Table 2.7). This was also the case in the Rangitukia Stream with mean fish sizes significantly smaller (84.4±1.78 mm $P < 0.0001$) in the lower reach site compared to fish in the upper reach site (110.6±2.29 mm). The overall distribution of fish sizes and their relative abundance between upper and lower reach sites of both streams are shown in (Fig. 2.14). In general, smaller sized torrentfish were found almost exclusively in the lower reaches of both streams. In the Mangauika fish (< 70 mm) were absent from the upper reach site, while in the lower reaches larger sized fish (> 140 mm) were absent (Fig. 2 14).

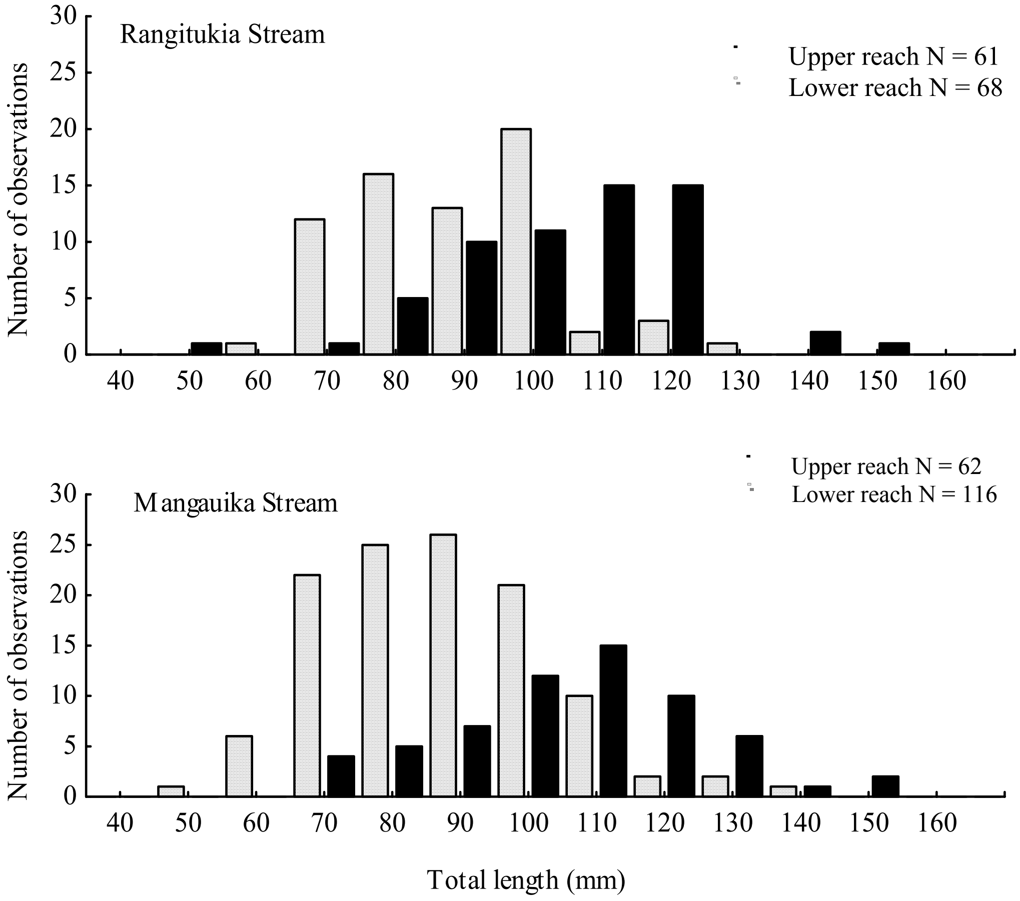


Fig 2.14: Length frequency distribution of torrentfish collected from upper and lower reach sites of the Mangauika and Rangitukia Streams during Nov–2007 to Oct–2008.

Similarly, torrentfish in the Rangitukia were no larger than 130 mm in the lower reach site and generally no smaller than 70 mm in the upper reach site with the exception of one individual (< 60 mm), (Fig. 2.14). This indicates that torrentfish mature in size as they move upstream from lower reach sites of both streams.

2.3.2 Fish density and biomass

The relative density and biomass of male and female torrentfish differed significantly between streams (Table. 2.8). In the Mangauika the total mean number of females (8.3 ± 5.05, P = 0.03) per 100 m^{-1}, taken from both the upper and lower reach sites was significantly greater than males (5.2 ± 3.5) per 100 m^{-1}. Females also had the highest overall mean biomass (1.17 ± 0.92; P = 0.03) g m^{-1} compared to males (5.2 ± 3.5) g m^{-1} in the Mangauika (Table.2.8). In the Rangitukia significant differences in male (3.8 ± 4.32) per 100 m^{-1} and female (9.2 ± 4.82) densities per 100 m^{-1} were not evident (P = 0.06), although female biomass was significantly (1.29 ± 0.98; P = 0.03) g m^{-1} greater than males (0.36 ± 0.49) g m^{-1}, (Table. 2.8).

Table 2.8: Total mean (±SD) biomass (g m^{-1}) and density (per 100 m^{-1}) of male and female torrentfish from the Mangauika and Rangitukia Streams and Kruskal-Wallis multiple comparison tests Significant differences (P < 0.05) between sexes are highlighted in bold.

River		N	Female	N	Male	Kruskal-Walis H values	
Mangauika	Biomass (g m^{-1})	96	**1.17 ± 0.92**	62	0.49 ± 0.36	**7.11**	**P < 0.007**
	Density (per 100 m^{-1})		**8.3 ± 5.05**		5.2 ± 3.5	**4.51**	**P < 0.031**
Rangitukia	Biomass (g m^{-1})	85	**1.29 ± 0.98**	34	0.36 ± 0.49	4.62	**P = 0.033**
	Density (per 100 m^{-1})		9.2 ± 4.84		3.8 ± 4.32	2.25	P = 0.062

Torrentfish densities between upper and lower reach sites of both study streams, differed considerably (Table.2.9). In the Rangitukia the mean biomass of females (1.21 ± 0.78, $P < 0.001$) g m^{-1} and their overall density (6.91 ± 3.0, $P < 0.01$) per 100 m^{-1} was highest in the upper reach site (Table.2.9). In the lower reach site only male biomass was significantly different weighing more (0.22 ± 0.27, $P = 0.01$) g m^{-1} than males in the upper reach site (0.22 ± 0.12) g m^{-1}.

Table 2.9: Total mean (±SD) biomass (g m^{-2}) and density (per 100 m^{-1}) of male and female torrentfish between upper and lower reach sites of the Mangauika and Rangitukia Streams and Kruskal-Wallis multiple comparison tests. Significant differences in biomass and density between sexes and fishing reach are highlighted in bold.

Stream	Variable	n	Female	n	Male	Kruskal-Walis
Mangauika						
Upper	Biomass (g m^{-1})	46	**1.19 ± 0.7**	13	0.22 ± 0.1	**4.8 P < 0.02**
	Density (per 100 m-^{1})		6.91 ± 3.0		1.71 ± 0.5	0.2 P = 0.86
Lower	Biomass (g m^{-1})	50	0.37 ± 0.1	49	**0.34 ± 0.2** $^{(2)}$	0.2 P = 0.62
	Density (per 100 m-^{1})		4.27 ± 2.2		**4.46 ± 2.5** $^{(3)}$	2.9 P = 0.08
Between reach	Biomass (g m^{-1})		**37.2 - P < 0.001**		**11.61 - P < 0.001**	
	Density (per 100 m-^{1})		3.3 - P = 0.06		**6.38 - P = 0.01**	
Rangitukia						
Upper	Biomass (g m^{-1})	51	**1.21 ± 0.7**	9	0.16 ± 0.2	2.1 - P = 0.14
	Density (per 100 m-^{1})		**6.71 ± 2.8**		1.25 ± 1.7	1.3 - P = 0.25
Lower	Biomass (g m^{-1})	34	0.29 ± 0.1	25	**0.22 ± 0.2**	1..4 - P = 0.22
	Density (per 100 m-^{1})		3.74 ± 2.2		2.74 ± 2.8	0.008 - P = 0.92
Between reach	Biomass (g m^{-1})	85	**34.1 - P < 0.001**	38	**6.53 - P = 0.01**	
	Density (per 100 m-^{1})		**5.7 - P = 0.01**		0.21 - P = 0.2	

In contrast the biomass (0.34 ± 0.26, $P < 0.001$) g m^{-1}, and density of males (4.46 ± 2.54, $P = 0.01$) per 100 m^{-1} were significantly greater at the lower reach site whereas only the biomass of females was significantly different (1.19 ± 0.76), g m^{-1}, $P = 0.01$), being highest in the upper reach site (Table. 2.9).

2.3.3 Male and female distribution patterns

The longitudinal distribution of males and females within both study streams differed (Fig. 2.15, 2.16). Sex ratios in the upper Mangauika site were primarily dominated by females throughout each sampling month, although males were also present in smaller numbers throughout most of the year (Fig. 2.15).

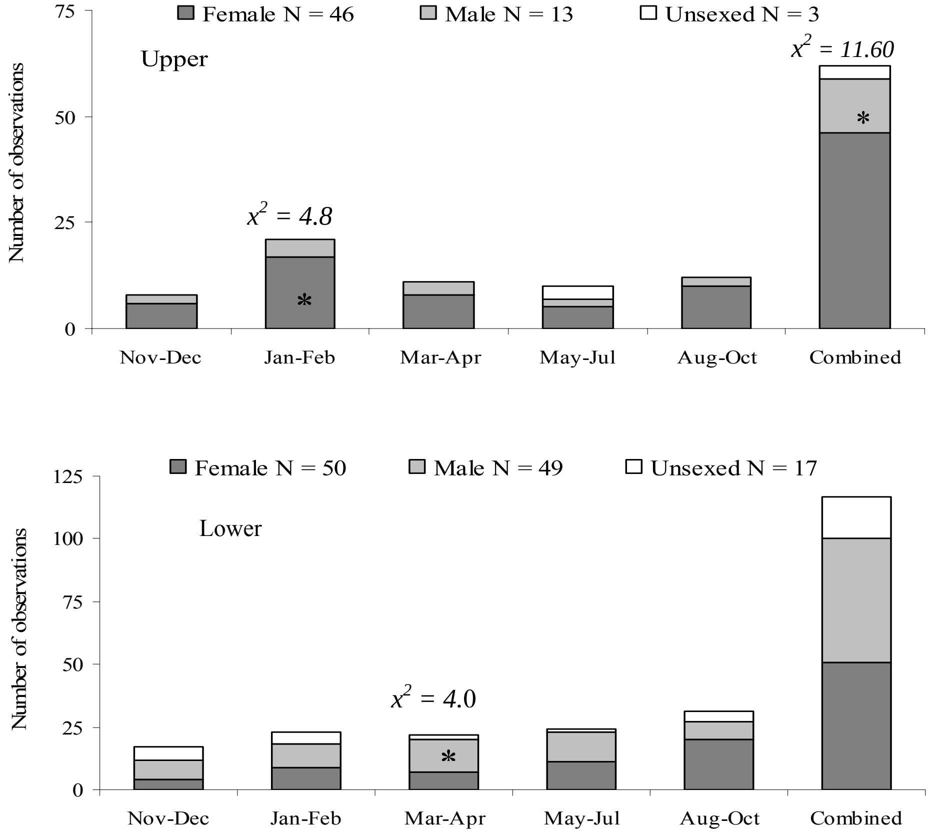


Figure 2.15: Seasonal and combined monthly distribution patterns of male, female and unsexed torrentfish from the Mangauika Stream. Unsexed fish were excluded from analysis due to low monthly numbers. Chi square statistic (x^2) and significant differences between sex and fishing reach are highlighted as (*) $P < 0.05$, (**) $P < 0.001$.

The ratio of females in the Mangauika was highest during January–February ($x^2 = 4.8$, $P < 0.05$) in the upper reach site. In the lower reach site sex ratios were much the same, although males were significantly more abundant ($x^2 = 4.0$, $P < 0.05$), than females during March–April. Sex ratios were also high for males during

November–December but with a low number of males and females taken from the lower reach site in December data analysis of these months could not be carried out (Fig.2.15). The ratio of females in the lower Mangauika site outnumbered males during August–October, but was much the same as males during January–February and May–July (Fig.2.15). Unsexed fish were not evident in the upper reach site until May–July, but were present throughout much of the year in the lower reach site mainly from November–December, January–February and August–October. Combined monthly data illustrated no significant differences in females between upper or lower reach sites of the Mangauika, but did indicate that males overall were outnumbered by females in the upper reaches throughout the year (Fig. 2.15). Sex ratios in the Rangitukia Stream were also predominantly female dominated in the upper reach site in every month of sampling (Fig. 2.16).

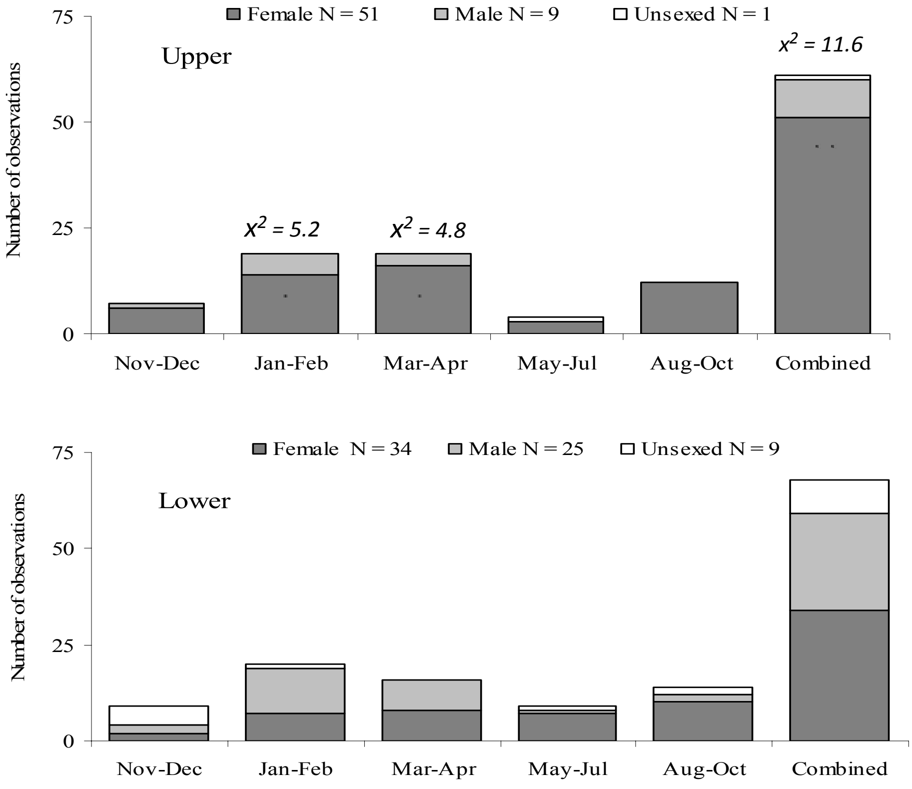


Figure 2.16: Seasonal and combined monthly distribution patterns of male, female and unsexed torrentfish from the Rangitukia Stream. Unsexed fish were excluded from analysis due to low monthly numbers. Chi square statistic (x^2) and significant differences between sex and fishing reach are highlighted as **(*) P < 0.05, (**) P < 0.001**.

The ratio of males to females in the Rangitukia overall was similar to sex ratios in the Mangauika with females outnumbering males significantly ($x^2 = 11.6$; $P < 0.0001$) in the upper reach site (Fig.2.16). Like the Mangauika unsexed fish in the Rangitukia were only evident from May–July (Fig 2.15, 2.16), and in the lower Rangitukia from every month except March–April (Fig.2.16).

2.3.4 Gonad development and size at maturity

Adult male and female torrentfish with mature gonads (stage 3) were common throughout much of the year in the Mangauika Stream (Table 2.10). Fish less than 56 mm were always at stage 1–2 indicating immaturity, while first maturity was reached at 76 mm for males and 81 for females (Table. 2. 11). The main breeding period for torrentfish was in late autumn (May), although breeding males (stage 4) were present in spring (November 2007, and September 2008), and summer (January 2008), (Table.2.10). Ripe females (stage 5) were only present during autumn (March–May). Juveniles and immature fish were present throughout most of the year with the exception of May (Fig. 2.10). With only one breeding male (100 mm TL) taken from the Rangitukia stream relationships in spawning period and size at maturity could not be determined (Table. 2.12). Ripe females in the Rangitukia were present throughout much of the year including spring, summer, autumn and winter however, no spent females were taken (Table 2.12). Mature females (stage 3) were present throughout most of the year with mature males (stage 3) only present from January–April and October (Table. 2.12). Fish less than 61–65 mm were always at stage 1–2 indicating immaturity (Table 2.13).

Table 2.10: Relationship of gonad maturity to month for male and female (in parentheses) torrentfish from the Mangauika Stream. Maturity stages for females include 1 – unsexed, 2 – immature, 3 – mature/resting 4 – ripening, - 5 – ripe and 6 – spent. Male gonad stages 1-3 are the same but stage 4 represents "ripe" and 5 spent fish. (no sampling in July due to flood conditions), (--/means no data).

Stage	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Total
1	1	4	3	2	2	-	-	4	-	3	-	1	20
2	1 (-)	- -	(2)	1 (2)	- -	1 (-)	- -	(2)	3 (2)	1 (3)	(4)	(1)	7 (16)
3	6 (7)	1 (2)	4 (9)	6 (9)	9 (9)	6 (2)	8 (3)	(2)	- -	(15)	2 (2)	4 (3)	46 (63)
4	2 (1)	- -	2 (2)	- (1)	- -	- -	3 (2)	- -	- -	- -	1 (2)	- -	8 (8)
5	- -	- -	- -	- -	- (1)	- (2)	- (1)	- -	- -	1 (-)	- -	- -	1 (4)
6	-	-	-	-	-	(1)	(4)	-	-	-	-	-	(5)

This was slightly larger than stage 1–2 fish in the Mangauika Stream (Table. 2.11). Size at first maturity for males 86-90 mm and females 91-100 mm in the Rangitukia were also larger than fish in the Mangauika. (Table 2.13). However, it is apparent that low sample numbers covering a wider size range of ripe males (n = 1) and females (n = 10) poorly represents estimates of first maturity of fish in the Rangitukia Stream and are therefore tentatively placed. Juvenile unsexed and immature fish (stage 1 - 2) were present from November-February absent through March-April and present again from May- October (Table 2.12).

2.3.5 Spawning period and location (GSI Index)

Torrentfish spawn over a 3–4 month period from mid-summer to late autumn in both streams (Fig.2.15). However, in the Rangitukia peak spawning occurred earlier (April) compared to spawning in the Mangauika (May). In the Mangauika the GSI condition of female gonads began to increase from January building to peaking spawning condition in May before decreasing in June and July 2008. Slight increases in GSI condition were also observed in August September and November (Fig. 2.15).

Table 2.11: Relationship of fish length (TL mm) to gonad maturity for male and female (in parentheses), torrentfish from the Mangauika Stream. Maturity stages for females include 1 – unsexed, 2 – immature, 3 – mature/resting 4 – ripening, - 5 – ripe and 6 – spent. Male gonad stages 1–3 are the same but stage 4 represents ripe and 5 spent fish. .(- -/means no data).

	Gonad stage					
Total length (mm)	1	2	3	4	5	6
46-50	1	- -	- -	- -	- -	- -
51-55	3	1 (1)	- -	- -	- -	- -
56-60	1	1 (-)	- -	- -	- -	- -
61-65	2	1 (1)	- (1)	- -	- -	- -
66-70	6	2 (6)	3 (1)	- -	- -	- -
71-75	5	1 (2)	1 (1)	- -	- -	- -
76-80	2	- (4)	7 (4)	1 (-)	- -	- -
81-85	1	1 (1)	4 (4)	- -	- (1)	- -
86-90	-	- -	10 (6)	1 (2)	- -	- -
91-100	-	- (1)	13 (12)	2 (-)	- -	- -
101-110	-	- -	5 (10)	1 (3)	1 (1)	- (1)
111-120	-	- -	2 (10)	2 (-)	- (1)	- (2)
121-130	-	- -	- (10)	1 (-)	- -	- (1)
131-140	-	- -	1 (3)	- (2)	- (1)	- -
141-150	-	- -	- (1)	- -	- -	- -
151-160	-	- -	- -	- (1)	- -	- (1)
Total	20	6 (16)	46 (63)	8 (8)	1 (4)	(5)

Mean GSI indices for female gonad condition in the Rangitukia Stream was generally low from November–January. Slight increases in GSI condition were also observed in August September and November (Fig. 2.15). Mean GSI indices for female gonad condition in the Rangitukia Stream was generally low from November–January before increasing from February-March and peaking in April and then decreasing to low levels in September and October (Fig.2.15). Male spawning patterns in both streams were less varied with only minor increases in GSI condition around March, May and July in the Mangauika. In the Rangitukia GSI condition was the same in every month but was lowest in December and August.

Table 2.12: Relationship of gonad maturity to month for male and female (in parentheses) torrentfish from the Rangitukia Stream. Maturity stages for females include 1 – unsexed, 2 – immature, 3 – mature/resting 4 – ripening, 5 – ripe and 6 – spent. Male gonad stages 1–3 are the same but stage 4 represents "ripe" and 5 spent fish.(--/means no data).

Gonad stage	Nov	Dec	Jan	Feb	Mar	Apr	May	Jul	Aug	Sep	Oct	Total
1	3	2	-	1	-	-	1	1	2	-	-	10
2	- -	2 (1)	- (3)	- -	- -	- (1)	- -	1 (2)	1 -	- (4)	- (4)	4 (15)
3	- (6)	- -	9 (7)	7 (7)	4 (8)	6 (2)	- (8)	- -	- (4)	- (5)	1 (5)	27 (52)
4	1 (-)	- -	- -	- (3)	- (3)	- (2)	- -	- -	- -	- -	- -	1 (8)
5	- (1)	- -	1 (-)	- (1)	- (1)	1 (7)	- -	- -	- -	- -	- -	2 (10)
6	-	-	-	-	-	-	-	-	-	-	-	-

Table 2.13: Relationship of fish length (TL mm) to gonad maturity for male and female (in parentheses), torrentfish from the Rangitukia Stream. Maturity stages for females include 1 –unsexed, 2 – immature, 3 – mature/resting 4 – ripening, – 5 – ripe and 6 – spent. Male gonad stages 1-3 are the same but stage 4 represents ripe and 5 spent fish.

	Gonad stage					
Total length (mm)	1	2	3	4	5	6
46-50	-	- -	- -	- -	- -	-
51-55	-	- -	- -	- -	- -	-
56-60	1	- (1)	- -	- -	- -	-
61-65	4	- (2)	- -	- -	- -	-
66-70	1	1 (3)	- (1)	- -	- -	-
71-75	3	1 (4)	1 (1)	- -	- -	-
76 - 80	1	1 (2)	2 (2)	- -	- -	-
81 - 85	-	1 (3)	2 (2)	- -	- -	-
86 - 90	-	- -	4 (4)	- (1)	- -	-
91-100	-	- -	13 (14)	- (2)	1 (-)	-
101-110	-	- -	3 (6)	1 (-)	1 (2)	-
111-120	-	- -	1 (13)	- -	- (4)	-
121-130	-	- -	1 (8)	- (3)	- (4)	-
131-140	-	- -	- -	- (1)	- -	-
141-150	-	- -	- -	- (1)	- -	-
151-160	-	- -	- (1)	- -	- -	-
Total	10	4 (15)	27 (52)	1(8)	2 (10)	-

Male spawning patterns in both study streams was less variable with only minor increases in GSI condition around March, May and July in the Mangauika. In the Rangitukia GSI condition was the same in every month but was lowest in December and August.

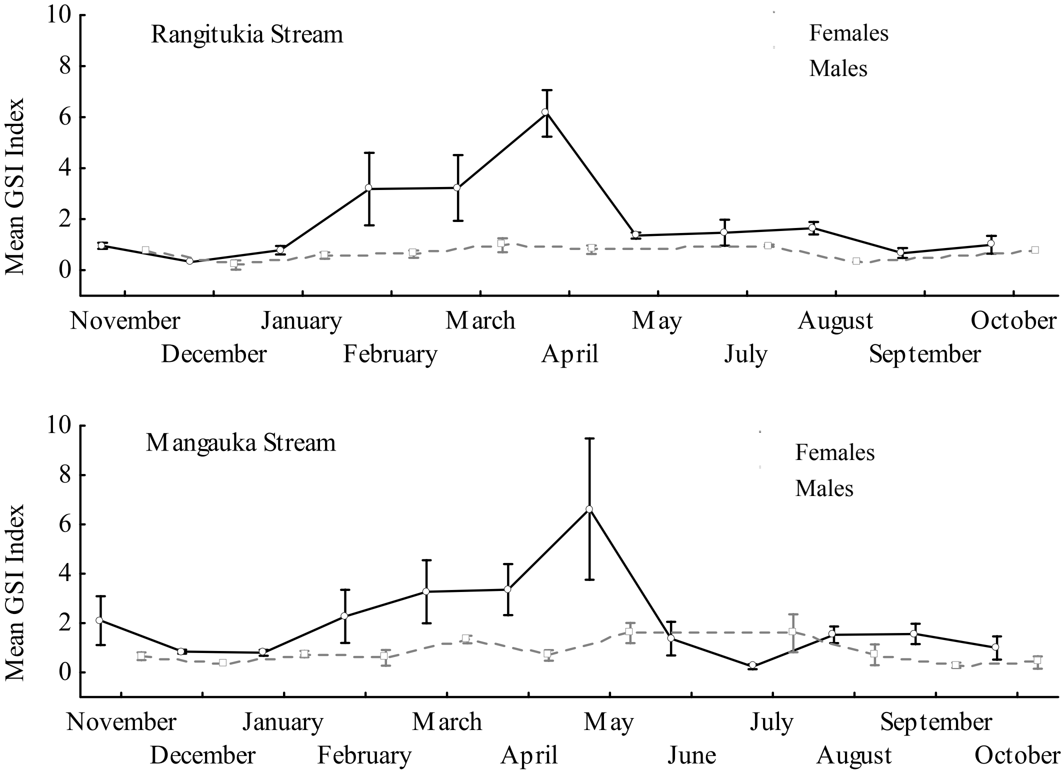


Figure 2.15: Mean Gonosomatic Index (GSI) (± *SE*) calculated from monthly gonad samples extracted from torrentfish from the Mangauika and Rangitukia Streams from Nov-2007 to Oct-2008. (For the Rangitukia the absence of data for June is due to flood conditions).

The general distribution of ripe and spent males and females relative to stream reach varied in both streams (Table 2.14). Spent males and females were only taken from the upper reach site of the Mangauika whereas in the Rangitukia spent males were only present in the lower reach site with no spent females collected whatsoever (Table 2.41). During April and May 3 ripe males and females were taken from the lower reach site in the Mangauika. Additionally, ripe males were also taken in January (1) and September (1), with 2 ripe females taken in

November (Table 2.14). In the upper Mangauika site 2 ripe females and 1 male were taken from January to March, with one spent female taken in April along with another 4 in May. Additionally 1 spent male was taken in August along with 2 ripe males in November (Table 2.14).

Table 2.14: Seasonal distribution of fully ripe and spent male/female torrentfish collected from upper and lower reach sites of the Mangauika and Rangitukia Streams

Stream	Fishing reach	Month	Gonad stage	Females	Males
Mangauika	Lower	January	ripe	-	1
	-	April	ripe	2	-
	-	May	ripe	1	3
	-	September	ripe		1
	-	November	ripe	2	-
	Upper	January	ripe	1	1
	-	March	ripe	1	-
	-	April	spent	1	-
	-	May	spent	4	-
	-	August	spent	-	1
	-	November	ripe	-	2
			Total	12	9
Rangitukia	Lower	January	spent	-	1
	-	April	ripe	2	-
	-	-	spent	-	1
	-	November	ripe	1	-
	Upper	February	ripe	1	-
	-	March	ripe	1	-
	-	April	ripe	5	-
	-	November	ripe	3	1
			Total	13	3

In the Rangitukia a single spent male was taken in January from the lower reach site with another spent male taken in the same site during the main spawning period (April) along with two ripe females (Table 2.14). A single ripe female was also taken in the lower reach in November. In the upper reach site during February and March 2 ripe females were taken along with another 5 ripe females in May. One ripe male and female were also taken in November (Table 2.14).

2.4 Discussion

2.4.1 Torrentfish longitudinal distribution

The longitudinal distribution of torrentfish within the Mangauika and Rangitukia streams illustrate two notable aspects. The first being the almost exclusive absence of small juveniles (< 60 mm) from upper reaches sites and the second being the lack of large fish (> 130 mm) in the lower reach sites of both streams (Fig.2.12). Although not directly related to fish size the distribution of torrentfish within the Mangauika and Rangitukia Streams are probably influenced by habitat availability and sea access (McDowall, 1973). Davis et al. (1983) reported that the size distribution of torrentfish within the Rakaia and Ashley's Rivers (Canterbury) on the South Island New Zealand was a reflection of the torrentfish's early marine life history (Davis et al, 1983). In their study small juvenile torrentfish (< 40 mm) were found solely in the lower reach site of the Rakaia River with no fish of the same size found in upper reach sites (Davis et al, 1983). As torrentfish are widely regarded as having an amphidromous life history, i.e. hatched larvae migrate to see for early growth and return to freshwater several months later as juveniles to mature (McDowall, 1990, Glova et al. 1995), their entry into freshwaters would first occur in the lower reaches. Similarly, Davis et al (1983) noted that the presence of larger fish in the upper reaches illustrates that fish mature in size as they move inland from the sea.

It is evident in this study and from similar work on torrentfish in the Mangauika by West (1989) that the size distribution of torrentfish within the Mangauika and Rangitukia reflect this early marine life history. The general distribution of males and females in both study streams was much the same. Females were significantly more abundant than males throughout much of the year in the upper reaches but were equally if not more abundant than males in lower reach sites. West (1989) found male and female separation to be most pronounced in the Mangauika Stream in his study of fish populations of the Waikato River system (West 1989).

In this study male and female separation was only pronounced in the upper reach site of both streams but not in the lower reaches with considerable overlap in the sex ratios. To some extent small immature torrentfish primarily collected in the lower reaches may have been subject to sex determination bias. Immature fish demonstrated little variation in gonad structure making sex determination difficult. The distinguishing characteristics of males and females were largely based on colour. This was one of the main reasons why gonads were not preserved and staged fresh. Additionally, aspects of shape and whether early developing oocytes were present were also used for sex determination. However, despite possible bias the proportion of immature torrentfish (n = 16) compared to more distinguishable mature–ripe torrentfish (n = 78) in the lower Mangauika was not a major factor likely to bias observed distribution patterns. This was also the case for torrentfish in the Rangitukia with the proportion of immature torrentfish (n = 14) in the lower reach site less than mature–ripe fish (n = 41). Similarly, given that few immature fish were taken from upper reach sites and that fish on average were significantly larger and further developed in gonad maturity, sex determination of fish in the upper reach sites were not subject to staging bias and the distribution of males and females is indicative of their distribution patterns.

2.4.2 Spawning period and location

Spawning occurs over a 3–4 month period from mid-summer peaking around early autumn in both study streams. In the Mangauika spawning occurs over a single protracted period with gonad condition building from January through to peak spawning condition in May. However, in the Rangitukia spawning occurred earlier building from February and peaking around April. Based on the distribution and timing at which ripe and spent torrentfish were collected in upper and lower reach sites, spawning location appears to be quite variable between streams. In the Mangauika ripe females were collected from both reaches, but most notably, spent males and females were only taken from the upper reaches suggesting that spawning may occur throughout. In the Rangitukia no spent females were taken only 2 spent males, which were collected from the lower reach site along with ripe males and females taken throughout both reaches. The scarcity of torrentfish maturity data for the Rangitukia stream evidently limits the ability to interpret the general spawning location of torrentfish in the Rangitukia. However, given the presence of ripe male and females throughout the upper and lower reaches of both study streams spawning appears to occur throughout the entirety of both streams.

It is widely accepted that male and female torrentfish occupy separate longitudinal habitats within the same stream (Davis et al. 1983, Eldon and Greager, 1983; Scrimgeour and Eldon, 1989, McDowall, 1990, 2000). Based on Scrimgeour and Eldon’s (1989), work in the Rakaia River the extent of separation (a little under 45 km) was such that spawning migrations were necessary. These were thought to be initiated by females migrating to males in the lower reaches (Scrimgeour and Eldon, 1989). However, observations of spawning torrentfish collected by early Maori 250 km from the sea in a small tributary of the Whanganui River by Mair (1880) was reported as probable evidence that spawning may occur throughout the entirety of rivers (McDowall, 1973). This was because of the long downstream distances females would have had to migrate (McDowall, 1973). This was later disputed by Scrimgeour and Eldon (1989) who suggested that if torrentfish spawn up stream, then ripe and spent fish should be found together since spawning has been shown to occur over several months. This was proven not to be the case in their study with spent females found only at the lower reach site (site 2) in the Rakaia River and ripe females first appearing in the Ashley River in October, whereas the first spent females were not collected until January. The results of this study support McDowall’s (1973) earlier contention that spawning may occur throughout the entirety of rivers with ripe females and spent males taken throughout the main spawning period in upper reach sites (Mangauika stream) and ripe females and males in lower and upper reach sites of both streams overall. Although results disagree with Scrimgeour and Eldon’s (1989), suggestion of spawning in the lower reaches, several aspects of this study differ significantly from Scrimgeour and Eldon's (1989) work that may have some influenced on observed spawning patterns. McDowall, (1973) earlier recognised that the availability of suitable maturing habitat and clear passage to sea were important factors influencing the distribution of torrentfish within riverine environments. The importance of habitat and sea access is no more evident than in the Mangauika and Rangitukia Streams (Fig.2.8, 2.9). Both are short headwater streams (on Mt Pirongia) that drain into the much deeper and sedimented Waipa and Waikato Rivers (Fig.2.4). Importantly, as major water bodies (providing access to sea) the lowland Waipa and Waikato Rivers do not contain the suitable maturing habitats of torrentfish (Jowett and Richardson 1995; Glova and Duncan, 1999). Thus the longitudinal distribution of torrentfish is somewhat fragmented from these systems and limited to suitable habitats within the Mangauika and Rangitukia streams.

In this regard the characteristics of these streams differ significantly from the Rakaia and Ashley's River which as braided rivers have suitable maturing habitat from the upper reach site (45–50 km) leading almost to the rivermouth (Davis et al. 1983; Eldon and Greager 1984; Scrimgeour and Eldon, 1989). Similarly, the furtherest inland fishing site in the Rakaia River was still relatively close to sea (45-50 km) and Ashley's (16 km) compared to the Mangauika (170 km) and Rangitukia (150 km) streams. These notable differences in habitat availability in relation to distance from the sea between the Rakaia and Ashley's River may limit spawning to within the Mangauika and Rangitukia streams. However, there is considerable evidence to suggest that torrentfish movements in the lower Waikato River may also be spawning related (Palmer et al. 1987).

2.4.3 Torrentfish movements within the Waikato River?

The distribution of torrentfish in catchment streams draining the lower Waikato has been well documented by West (1989). However, their presence within the Waikato River itself has seldom been described although Palmer et al. (1987)

provided compelling evidence that adult torrentfish frequently move throughout the lower Waikato River. In their study the impingement of torrentfish on intake screens at the Huntly Thermal Power Station (Fig 2.10), 80 km from the sea were recorded in all months from October 1985 to June 1986. Impingement was greatest during May (n = 327) and June (n = 177), (Fig.2.16) and thought to be influenced by flooding and season (Table.2.15). Notably, ripe and spent females were taken during April–May with spent females also taken in November. Males were only recorded in November and June being rare overall. Additionally, peak impingement of torrentfish during May-June was thought to be the result of downstream spawning migrations (Table.2.15).

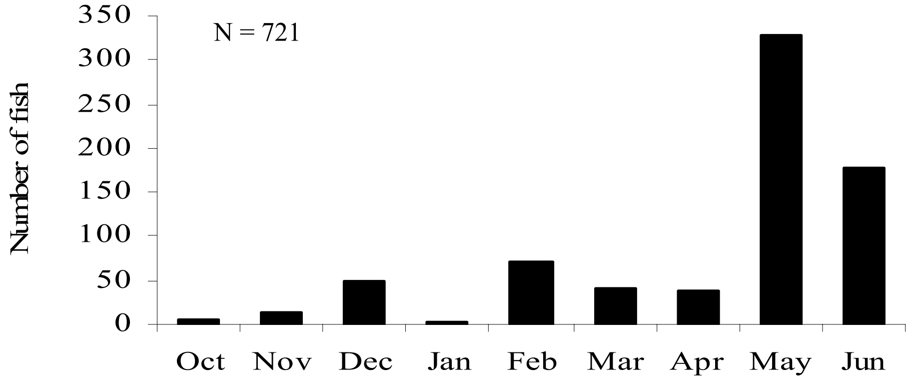


Figure 2.16: Number of torrentfish collected from the intake screens, at the Huntly Thermal Power Station on the Waikato River 80 km from Port Waikato during October 1985 to Jun 1986 data redrawn from Palmer et al. (1987)

If general spawning periods in the present study are a reflection of torrentfish populations in tributary streams around the lower Waikato River (see West 1989), then Palmer et al (1997) suggestion that torrentfish movements in the lower Waikato were spawning related were more than likely correct. However, there is no indication as to where torrentfish originated from or where they were going. This information maybe determined using aspects of the present and Palmer et al's (1987) study. Further seasonal gonosomatic work on torrentfish collected from the Huntly Power Station intakes may provide more spawning information

Table 2.15: Time, month and conditions causing increased impingement of torrentfish at the Huntly Thermal Power Station (table redrawn from Palmer et al. 1987).

	Direction of migration	Time	Month	Moon phase	River level
Torrentfish	Downstream	night	May-Jun	?	High
	Upstream	night	Dec-Jan, Jun-Jul	?	High

based on a wider population of torrentfish which may enter the lower Waikato River system. Otolith microchemistry could then be used to track torrentfish (collected from the intakes) to their maturing stream of origin based on possible water chemistry differences between suitable tributary streams (see West, 1989) which maybe reflected in otoliths (chapter 3).

2.4.4 Size at maturity

Size at maturity estimates (i.e. L_{50} length at which 50% are sexually mature) were not possible in this study as only a small number of sexually mature torrentfish were collected (Table. 2.14). Despite this there is some indication that size at maturity for torrentfish in the Mangauika and possibly the Rangitukia maybe influenced by distance from the sea. Scrimgeour and Eldon (1989) estimated size at sexual maturity for males to be 63 mm and females at 65 mm (Scrimgeour and Eldon 1989). Fish collected from the lower Mangamuka River only 16 km from the sea near Kaitaia on the North Island of New Zealand in May 2008 (Fig. 2.3), reflected similar size at maturity patterns as those described by Scrimgeour and Eldon (1989). Of the 15 gonads examined the smallest ripe females collected were (60 mm. TL) and ripe males (58 mm. TL).e size range as those reported by Scrimgeour and Eldon (1989). Of all the mature–ripe or spent torrentfish collected in this study no fully ripe males (< 79 mm) or females (< 85 mm) were taken from either the Mangauika or Rangitukia streams. It is probable that size at maturity in both streams may be lower than data suggests but the range in size from Scrimgeour and Eldon (1989) estimates would indicate some difference in sizes in maturity. As torrentfish spend early life at sea followed by a return to freshwater to mature, the distance inland at which suitable maturing habitat is available may determine how soon torrentfish can establish. In the braided Rakaia and Ashley Rivers returning juveniles (< 35 mm) are able to establish quickly once they had entered these rivers because maturing habitat is available above the Rakaia Lagoon adjacent to the sea (Davis et al. 1983, Eldon and Greager 1983). In contrast returning juveniles in the Mangauika and Rangitukia would have had to travel 150-170 km inland to reach suitable maturing habitats in both study streams, once fish had reached these streams they would presumably have grown in size and size at maturity would be slightly larger.

CHAPTER THREE

3. The migratory life history of torrentfish in study streams

3.1 Introduction

The migratory life histories of several of New Zealand's native and endemic freshwater fish are known to involve distinct movements between marine and freshwater environments (McDowall, 1990). This phenomenon is often described in the literature by one word "diadromy" (McDowall. 1990). However, the term diadromy is merely used in a broad context and the specific direction at which these movements occur are best described in the form of three categories: (i) anadromy – whereby fish spend most of their maturing life at sea moving to freshwater as mature adults to spawn (i.e., smelt and lamprey), while (ii) catadromy – include fish that spend much of their maturing life in freshwater habitats moving to marine environments as adults to spawn (e.g., eels and black flounder), and finally in contrast to the previous categories (iii) amphidromy – include fish that do not match either of the above categories nor do such migrations occur as a consequence of reproduction (e.g., banded kokopu, redfin bully).(McDowall, 1995).

3.1.1 Tracking amphidromous life histories

The most common form of diadromous migration as observed in New Zealand's native freshwater fish is "amphidromy" (McDowall, 1995). In total ten of the eighteen recognised diadromous fish species including the little known torrentfish are widely considered to be amphidromous (McDowall, 1990). A major feature of amphidromous migration is that early development of larvae will occur at sea followed by a return to freshwater habitats to mature (McDowall, 2000). Therefore, under this premise the most compelling evidence that will determine whether fish have an amphidromous life history would be to capture their early developing larvae at sea. This however is a prospect not easily accomplished. The problem of which lies in the enormity of New Zealand's surrounding coastal waters and the inability to track the movements of small larvae (< 10 mm) within these vast waters.

For torrentfish, McDowall, (1994), noted that larvae have never been identified from either the marine plankton or the benthos of the seas around New Zealand. This also seems to be the case for larvae moving downstream to sea (Glove et al. 1995). However, as difficult a task it maybe in documenting larval fish at sea mention must be made of McDowall and Robertson's (1975) discovery of juvenile inanga (*Galaxias maculatus*), in plankton trawls some 700 km off the coast of New Zealand. This further illustrates the distance at which diadromous fish may range and why such migrations are difficult to track

3.1.2 Otolith microchemistry

Clearly, there are considerable challengers involved in documenting diadromous life histories in fish. Needless to say many researchers have sort alternative methods of tracking these migrations. One relatively simple approach has been to examine the chemical composition of fish otoliths (Tzeng, 1994, Campana, 2000). Otoliths (fish earbones) are small calcium carbonate ($CaCo_3$) bone structures that function as hearing aids while also providing balance (Lowenstein, 1971). However, the principal interests in otoliths lie in their ability to record chemical trace elements from the water that surrounds a fish at any given point in time (Campana and Thorrold, 2001). For the most part chemical uptake occurs primarily by water passing over the gills (brachial uptake) before entering the blood stream. Ions are then transported via the bloodstream to the endolymph fluid (which surrounds the otolith) and subsequently deposited onto the otolith crystalline matrix (Campana, 1999)**.** Other pathways may occur via diet (Limburg, 1995), but overall this may constitute only a smaller portion of deposition (Hoff and Funman 1995). Additionally, chemical uptake occurs daily as growth rings (similar to a tree), with deposited elements neither re-metabolised nor re-absorbed (Campana 1999). Otoliths therefore provide a complete chemical record of the water chemistry experienced by fish from larval development to their time of death (Campana 1999). The most frequently used elements for tracking diadromous migrations is the ratio of strontium to calcium (Sr/Ca). As strontium (Sr) is known to substitute for calcium within the otolith matrix and is not under any major physiological regulation its incorporation onto the otolith is likely to be a reflection of the ambient environment (Thorrold. et al. 1998). For this reason the ratio of Sr over Ca (Sr/Ca), is used to describe fish movements between fresh and saltwater environments particularly as Sr concentrations are higher in seawater (0.088 ppm), than freshwater (0.00018 ppm), (Limburg, 2000;Tzeng et al, 2005).

3.1.3 Laser ablation inductively coupled mass spectrometry ICP-MS

The extraction of chemical information from otoliths (in a solid state) using beam based instruments (microprobes), such as laser ablation ICP-MS has seen major advances in otolith microchemistry research (see reviews by Campana 1997 and Campana et al, 1999). The principle idea behind this technique is relatively simple. Effectively, a high powered laser is directed at pre-determined points across the otolith vaporising the surface into microscopic particles (ideally < 0.5 μm) leaving a pit. These vaporised particles represent a given yield of otolith material (i.e., volume of the pit), that is transported via an argon (Ar) helium (He) carrier gas configuration to an ICP-MS mass analyser typically the same instrument as any solution based mass analyser. Particles then pass through a high temperature plasma torch where they are atomised, ionised and their chemical composition determined by measuring the mass weights of individual elements (generally a suite of 50 elements can be analysed). The end result is a generated list of elemental concentrations (from one laser spot firing), that are present in the otolith sample typically measured in the parts per million (ppm) and spanning an elemental range of upwards of 10-50 elements at any given time (Steven and Ward, 2005). The benefit of sampling otoliths in their solid state is that temporal growth zones in otoliths (in the form of daily, seasonal or annual ring structures), maybe used to document environmental changes that occur throughout a fishes life (Campana, 1999). For example information from otoliths that reflect fresh and saltwater chemistries enable the correlation of differences in chemistry with a fishes age (via growth ring analysis) and thus can be used to determine the timing of specific migration patterns. In New Zealand the use of laser ablation ICP-MS technology in fisheries research is limited as a result of its introduction to this country being only recent. In this regard the technique and its various applications are yet to be fully explored or tested on fish in New Zealand. The aim of this study was to use otolith microchemistry techniques in conjunction with laser ablation ICP-MS to determine evidence of amphidromous migration in two North Island populations of torrentfish located at great distance from the sea. Specifically, as torrentfish are reported as spending larval development at sea followed by freshwater maturing (McDowall, 1990 1994), this study considers that larval development in torrentfish otoliths (an area represented by the otolith core), will reflect marine chemistries (high Sr/Ca ratios) and maturing stages (areas represented outside of the otolith core), will reflect freshwater chemistries (low Sr/Ca ratios). Concurrently, a pattern of high and low Sr/Ca ratios from the core to the edge of torrentfish otoliths would indicate an amphidromous life history (Hicks et al, 2004; David, 2005). Similarly, assessments of Ba/Ca ratios in conjunction with Sr/Ca ratios will be used to satisfy assumptions of marine life histories in torrentfish by describing inverse relationships in the patterns of low Ba/Ca in saltwater and high Ba/Ca ratios in freshwater (Crook et al. 2008). In addition to tracking fresh and saltwater migrations an evaluation of a broader array of elements will be used to test the feasibility of otolith microchemistry to classify fish to their stream of capture and possibly track finer scale movements of torrentfish within study streams.

3.2 Methods

3.2.1 Fish collection sites

Torrentfish were collected from the Mangauika, and Rangitukia streams on the North Island of New Zealand (Fig, 2.1, chapter 2), between Nov 2007 and October 2008. Sea access to both streams is gained via a network of interconnecting rivers at varying distances from the sea (Table. 2.2, chapter two) passing through contrasting land cover types with variable degrees of water quality. Rangitukia on the western slopes of Pirongia drains firstly into the deep and silty Kaniwhaniwha River where it enters the broader Waipa River, whereas the Mangauika drains straight into the Waipa from its headwaters on Mt Pirongia. The Waipa has a large catchment area (3,059 km^2), the majority of which is used extensively for grazing stock. The Waipa flows in a northerly direction where it enters the Waikato River passing through farmland and the city of Hamilton before reaching its final destination at Port Waikato and the Tasman Sea 140 km north west of Mt Pirongia (Table 2.2, chapter two).

3.2.2 Fish sampling

Torrentfish were sampled using a Kainga EFM 300 backpack electrofishing apparatus (NIWA Instrument Systems, N.Z.), and collected with a pole seine and handheld scoop net. Fishing sites were selected based on torrentfish's known, habitat preferences described by Jowett and Richardson (1995). Riffle sites were fished by two people, the backpack operator and the downstream pole seine net holder the area fished at each site and stream as well as relative densities is given in more detail in chapter two (methods). Fishing always started at the lowest placed riffle section (for each river) and was progressively fished upstream. In general 2-3 passes in each riffle was carried out regardless of whether fish were present or not. Fish selected for chemical analysis were sacrificed in benzacaine and transported back to the lab in sealed containers with stream water.

3.2.3 Otolith extraction and preparation

In the laboratory sagittal otoliths were extracted from torrentfish under a stereo microscope. The head of each fish was carefully sectioned with a scalpel along the midline dorsal surface (back of the head to the jaw), and separated completely exposing left and right cranial cavities. Brain matter in each cavity was carefully flushed away with a small pipette of milli–Q water then drained with the pipette to expose the otoliths. Otoliths were located towards the inside dorsal end of the cavity wall within a small indented hollow and carefully removed using fine tweezers before being stored connective nerve tissue was rinsed clear of otoliths with milli-Q water and placed in 21 mm vials to air-dry. Prior to being mounted they were rinsed in milli-Q water then soaked in 2% hydrochloric acid for 15 seconds, and finally rinsed once more in milli-Q water (Secor, 1989).

Torrentfish otoliths were double ground and mounted on glass slides with the groove end (sulcus) facing down using Crystal-Bond thermosetting glue over a heated plate. As the curvature of torrentfish otoliths (grove end raises like a peak) making otoliths difficult to lay directly flat, it was necessary to remove the otolith from the heat source and manipulate it level under microscope as it cooled using a narrow pointed syringe tip. Otoliths were then polished acronss the otolith surface using firstly 2000 then 4000 µm wetted sand paper. Visual assessments were made regularly with transmitted light under a stereo and then compound microscope until ring structures radiating from the centre most region of the otolith (core) had been polished through to the immediate surface of the otolith. The glass slide was then placed over the hot plate again and the otolith carefully flipped over, taken off the heat and the polishing process repeated until clear ring structures could be seen radiating from the otolith core. Double polishing often resulted in large number of otolith breakages and only whole otoliths were used for ablation. Polishing was an important process that involved removing external growth bands that surround the core for laser ablation. Otoliths analysed by laser ablation were mounted in batches of six per glass slide which were coded by date and stream then stored in cover slide trays until laser ablation.

3.2.4 Laser instrumentation and settings

Acquisition of chemical data was carried out with a New Wave Research, Perkin Elmer Elan SCIEX DRCII Laser Ablation Inductively Coupled Mass Spectrometer (ICP-MS) with an industry standard Neo-Demean YAG short wave 213 nm laser. The laser was operated in Q-switched time resolved mode with an average energy reading of 0.124 mJ, a scan speed of 10 milli seconds to enable analysis of all elements more closely in time and a repetition rate of 10 Hz. Spot size was set at 50 µm and spaced according to otolith size (between 65-150 µm) from the core to the edge The laser was fired at 50% power (60% on NIST 612) and subsequent transport of otolith material to the ICP-MS was optimized using a helium (He) and argon (Ar) carrier gas configuration.

This increased ablation efficiency by reducing particle sizes (< 0.5 µm) maximizing ionization and resulting in higher ICP-MS sensitivity. Additionally, smaller particle sizes also improved the transport efficiency of ablated material for mass analysis. A total suite of 12 lithophile isotopes Li^{7}, Mg^{25}, Ca^{42}, Ca^{43}, Cr^{52}, Mn^{55}, Zn^{66}, As^{75}, Rb^{85}, Sr^{87}, Sr^{88} Ba^{137} were analysed both in otoliths and NIST 612 standards. The selection of elements was based on the lack of matrix matched standards, (Morales- Nin, 2002), which will interact differently with the laser beam (Ghazi et al, 2002). This subsequently limited the range of isotopes that could be analysed due to the influence of laser induced elemental fractionation (Longerich et al 1996). For this reason the selection of isotopes was based on the fractionation index described by Fryer et al (1995), which classified lithophile elements first described by Goldschmidt (1923), as having the lowest fractionation potential. Additionally, selection was also based on the effectiveness of each isotope in classifying fish with streams of origin. For example Mg^{25}, Ba^{137}, Ca^{43},Sr^{88} isotopes were used by Wells et al. (2003) to reclassify juvenile westslope cutthroat trout (*Oncorhynchus clarkilewisi)* to their stream of origin with 100% accuracy. While for Thorrold et al, (1998), these same isotopes Mg^{25}, Ba^{137}, Ca^{43}, $\mathrm{Sr}^{88,}$ including Mn^{55} proved useful in classifying American shad (*Alosa sapidissima*) to their stream of origin with 80% accuracy.

3.2.5 ICP-MS optimisation and machine sensitivity

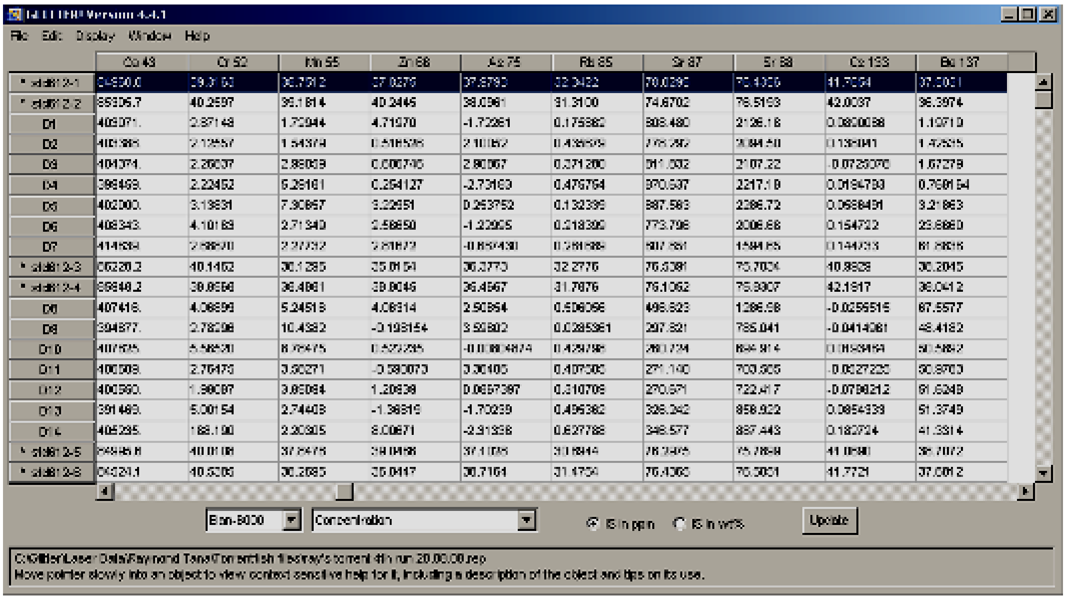
Elemental interferences produced by the presence of oxygen in the ICP-MS, carrier gas transport lines, or on samples may result in combinations of oxygen with different elements causing an interference reading on other isotopes (Steven and Ward, 2005). As a result, optimisation of the ICP-MS involved monitoring oxide production in the ICP-MS by measuring ThO^+/Th^+ ratios. This was carried out at the start of each days run using NIST 612 Standard Reference Material (SRM). The NIST 612 standard was placed in the sample chamber with a single batch of 6 otolith samples and purged clean with an argon carrier gas for 15, minutes.

A continuous line scan set at a repetition rate of 10 Hz with an output power of 60%, spot size of 60 μm and 60 second dwell was then run across the NIST for 2 minutes. As Th^+ has a high affinity for oxygen, the ICP-MS was tuned during the 2 minute line scan by manually adjusting the nebuliser gas flow to give a ThO^+/Th^+ ratio of ≈ 1%. Once this was achieved it was then assumed that all other oxide interferences were negligible (Lichte et al. 1987) and otolith sample analysis could begin. Similarly, during the same NIST analyses a sensitivity check was also carried out by monitoring Th^+/U^+ ratios. As uranium is more volatile than thorium, uranium will vaporize more easily (as it passes through the plasma) and thus convert to more atoms and ions for mass analysis. Subsequently, Th_+/U_+ ratios were closely monitored until counts were >20,000. Nebuliser gas flow rates as well as the lens position were adjusted manually on the ICP-MS and for this study gas flow was generally acceptable between 0.5- 0.7.

3.2.6 Calibration and data acquisition

Pearce et al. (1997) demonstrated that the concentration of trace elements in NIST 612 glass standards (National Institute of Standards and Technology), were homogeneous. Concurrently, elemental concentrations (ppm) from NIST 612 reference material were standardized to internal ICP-MS machine standards using

Ca^{42} (selected from Pearce et al, 1997), by way of GLITTER data reduction software (Version 4.4.1, Macquarie Research Limited © 1991-2000). As laser ablation signals are notorious for being unstable over prolonged periods of use (Steven and Ward, 2005), NIST 612 reference material was analysed before, in the middle, and at the end of each otolith run (Fig 3.1).



	Ca 43	Cr 52	Mn 55	Zn 66	As 75	Rb 85	Sr 87	Sr 88	Cs 133	Ba 137
* std612-1	84930.0	39.3160	36.7912	37.0276	37.8793	32.3422	78.0296	78.4086	41.7664	37.2031
* std612-2	85306.7	40.2597	36.1814	40.2445	38.0961	31.3100	74.6702	76.5193	42.0037	36.3974
D1	409071.	2.87148	1.72944	4.71970	-1.72261	0.175382	808.480	2126.18	0.0800088	1.19719
D2	401386.	2.12557	1.54374	0.518526	2.10162	0.438579	778.282	2084.50	0.138041	1.47515
D3	404374.	2.26037	2.88039	0.000746	2.80067	0.271200	811.002	2107.22	-0.0726070	1.67279
D4	398469.	2.22452	6.29161	0.264127	-2.73163	0.476764	870.637	2217.19	0.0194793	0.768154
D5	402000.	3.19831	7.30867	3.22951	0.263752	0.132399	887.583	2286.72	0.0688491	3.21863
D6	408343.	4.10163	2.71340	2.58850	-1.22905	0.218320	773.798	2006.68	0.154722	23.6860
D7	414639.	2.68870	2.27732	2.81672	-0.857430	0.281689	607.881	1584.65	0.144713	61.8816
* std612-3	86220.2	40.1462	36.1285	35.0154	36.3773	32.2776	76.6381	75.7034	40.8828	36.2045
* std612-4	85848.2	38.8568	36.4861	39.8046	36.4567	31.7876	76.1062	75.8307	42.1917	36.0412
D8	407416.	4.08699	5.24519	4.08314	2.50864	0.506096	496.823	1286.58	-0.0255515	67.5577
D9	394877.	2.78298	10.4382	-0.193154	3.59802	0.0285361	297.821	785.041	-0.0414081	48.4182
D10	407625.	5.58520	8.76475	0.522235	-0.00804874	0.429798	280.724	694.914	0.0150464	50.5842
D11	400508.	2.76473	3.60271	-0.590073	3.30105	0.407303	271.140	703.305	-0.0027220	60.8703
D12	400560.	1.98087	3.85084	1.20638	0.0657387	0.310709	270.671	722.417	-0.0790212	61.6249
D13	391489.	5.00154	2.74403	-1.38819	-1.70239	0.496382	326.242	858.922	0.0854333	51.3749
D14	405235.	188.190	2.20805	8.00671	-2.31338	0.627788	348.577	887.443	0.182724	41.3314
* std612-5	84985.8	40.0108	37.6475	38.0468	37.1085	31.6844	76.2475	75.7848	41.0680	36.7072
* std612-6	84824.1	40.5205	36.2685	35.0417	36.7164	31.4754	76.4360	76.3001	41.7721	37.0012

C:\Glitter\Laser Data\Raymond Tana\Torrentfish files\ray's torrent 4th run 20.00.00.rep
Move pointer slowly into an object to view context sensitive help for it, including a description of the object and tips on its use.

Figure 3.1: GLITTER data output table of a typical otolith run with NIST 612 standards run at the start in the middle and at the end of 14 otolith spots as well as the average peak concentration count (ppm), for each isotope analysed. (additional standards were run if steady signals were not observed).

This was carried out so that machine drift and day to day variation in instrument sensitivity across the atomic mass range could be corrected for by GLITTER. Additionally agreement of Sr and Ca isotopes for each standard run were checked against reported NIST 612 values. Where values were not in good agreement the NIST 612 was run again. Similarly, data from individual laser spots were acquired for each isotope as an average reading of the peak laser signal (Fig.3.2). Prior to sample ablation background readings of residual material within the sample chamber, transport lines, and ICP-MS were collected. Each additional standard analysis (in between sample analyses), were, instantaneously adjusted to account for changes in analytical conditions (instrument drift), with mean background signals automatically subtracted by GLITTER and no further off-line reprocessing of the data was necessary. Similarly, limits of detection (LOD), relative standard deviations (%RSD), and standard errors for each isotope were calculated by GLITTER and averaged from daily runs. Acquisition of material from NIST 612 standards (60 second dwell), was longer than in otoliths (30 seconds), (Fig, 3.2).

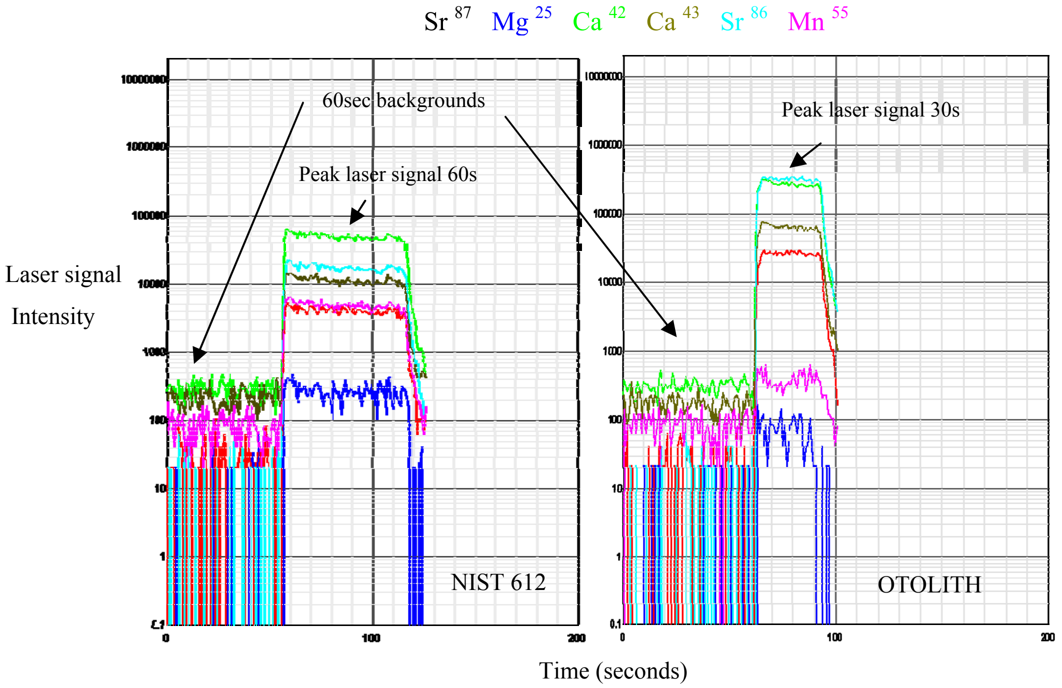


Figure 3.2: Time resolved analysis real-time data acquisition plots (log scale) showing the initial acquisition of 60 second backgrounds, followed by the laser peak signals for Sr^{87}, Mg^{25}, Ca^{42}, Ca^{43}, Sr^{86}, Mn^{55} for a single NIST 612 standard and otolith laser spot.

This was carried out in order to give more stable signal readings (NIST standards) improving calibration between samples. However, it was not possible to acquire otolith material over a 60 second dwell similar to standards as otoliths were double ground (thin sections), and the core section itself would have been thinner still. Longer dwell times on the thin otolith section were likely to obliterate the otolith or include ablated material beyond the preferred timescale of interest (into the edge). A mixed yield of core and edge material may therefore have a reducing effect when the elemental concentrations of Sr in the spot sample are averaged by GLIITER.

3.2.7 Water samples

Water samples were collected from the upper (n = 4) and lower (n = 4) reach sites of the Mangauika and Rangitukia Streams once a month from November 29 2007-February 27 2008. Samples were collected in 15 ml sterile Falcon Tubes, which prior to transport in the field were filled with Milli-Q water to enable the leaching of any residual metals (Elsdon and Gillanders, 2006). In the field, tubes were drained of their contents rinsed thoroughly in the stream and then filled completely to the top and the cap screwed on while submerged. Water samples were then stored in a chilled thermos for transport to the lab. In the lab samples were filtered through disposable 0.45 µm Millipore filters and transferred back into a sterile 15 ml falcon tube at a set, volume of 9.8 ml then topped off with 0.2 ml nitric acid ($HN0_3$) then shaken prior to chemical analysis. All water samples were analysed using a Perkin Elmer Elan SCIEX DRC II Inductively Coupled Mass Spectrometer (ICP-MS) in Aqueous Mode. Prior to analysis, water sample transport tubes were rinsed before and after each sample with Type-1 water and 2 % $HN0_3$ to clean the tube for the next sample.

The ICP-MS was calibrated at two levels of sensitivity using Merck XX1 standards. A calibration blank was run for specified elements at low sensitivity 50 (ppb) and compared with a separate standard with known elements of 50 (ppb), to indicate how close the readings were to the standards. The process was also repeated at high sensitivity 330 (ppb), to determine the level of calibration l to the standards. Given the large temporal variability in the chemistry of fish otoliths (over fishes entire life), relative to discreet water samples (collected in one day), it was not possible to make comparisons between fish otoliths and the ambient water chemistry of both sites. However, as the edge region of otoliths represent the last days of a fishes life and given that water samples were collected within the same time frame of death, we therefore compared the mean ($\underline{+}$*SD*) elemental concentrations (ppb) in water samples from each site with the mean edge values from fish otoliths of the same site.

3.3.8 Statistical analysis

Differences in water and otolith chemistry between streams were determined by Kruskal-Walis multiple comparison tests using STATITICA 8 software. Elemental concentrations (Mn, Mg, Ca, Cr, As, Rb, Cs, Sr, and Ba) in stream water samples (n = 16) and in the otolith edge (ppm) of torrentfish from the Mangauika (n = 22) and Rangitukia (n = 23) were tested for significant differences. Relationships between elements in water samples (n = 16) and otoliths were identified using Spearman's Rank order correlation. Multivariate discriminant function analysis (DFA) was used to classify elements in stream water samples and otolith edge concentrations to stream of collection. Six elements in water samples (Sr, Mg, Cr, Rb, Cs and Mn) were used as predictor variables to classify water samples to stream of collection. Five elements (Sr, Mg, Cr, Ba, and Mn), in torrentfish otoliths (edge) were used as predictor variables to classify torrentfish to stream of capture.

3.3 Results

3.3.1 Standards analysis

A total of 45 sagittal otoliths were analysed by laser ablation ICP-MS (Table. 3.2). Of these, 16 otoliths from the Mangauika and 16 from the Rangitukia were classed as having good steady state signals (Fig.3.4) and were in good overall condition after the ablation process. However, 12 otoliths were excluded from the results as small fractures in the core of these otoliths were obliterated by the laser. This corresponded almost immediately with highly variable signal readings which were observed in the real time data acquisition plots and subsequent data were excluded.

Table 3.2: Total number of sagittal otoliths analysed from torrentfish collected from both the Mangauika and Rangitukia Streams and the otolith condition (good/poor) after Laser ablation ICP-MS.

Stream	Total number otoliths ablated N	Signal reading and otolith condition after ablation Good n	Poor n
Mangauika	22	16	6
Rangitukia	23	16	6
Total	45	32	12

A summary of preferred mean isotope readings for NIST 612 Certified Reference Material (CRM) reported by Pearce et al. (1997) and by the National Institute of Standards and Technology are shown as a comparison of NIST 612 standards run in this study (Table 3.3). In general there was good overall agreement in the reproducibility of mean isotope readings for Mn^{55}, Mg^{25}, Ca^{42}, Ca^{43} Zn^{66}, Cr^{52}, As^{75}, Rb^{85}, Cs^{133}, Sr^{88}, and Ba^{137}, reported for NIST 612 standards. This was evident both within and between each day of laser ablation compared to the same mean isotope readings reported by Pearce et al. (1997) and by NIST (Table 3.3).

Table 3.3: Mean (± *SD*) analytical data of isotopes measured in NIST 612 standards for this study compared to Pearce et al. (1997) and NIST 612 mean preferred values. Analytical data for isotopes of interest are shown in relation to date within and between each day of ablation. (note: standards were run at the start, middle and end of each otolith run additional standards were run if steady signal readings were not observed)

Ablation date	N = Otoliths	N = NIST 612	Mg^{25}	Ca^{42}	Ca^{43}	Cr^{52}
20-Aug-08	7	30	77.7 ± 3.3	85247 ± 170	85268 ± 618	39.8 ± 0.7
28-Aug-08	1	6	77.5 ± 2.5	85262 ± 0.01	85266 ±196	39.8 ± 0.6
18-Sep-08	4	29	77.7 ± 4.4	85262 ± 0.004	85187 ± 687	40.5 ± 7.6
23-Sep-08	5	25	78.6 ± 5.7	85262 ± 0.005	85090 ± 1113	39.8 ± 1.7
2-Oct-08	1	5	76.8 ± 5.3	85262 ± 0.05	85315 ± 802	39.6 ± 1.3
23-Oct-08	4	15	77.5 ± 2.2	85262 ± 0.03	85258 ± 358	39.8 ± 0.7
30-Oct-08	5	15	77.3 ± 1.6	85262 ± 0.012	85183 ± 329	39.8 ± 0.7
5-Nov-08	2	9	77.5 ± 3.5	85262 ± 0.006	85259 ± 459	39.8 ± 0.5
6-Nov-08	3	9	77.4 ± 2.9	85262 ± 0.005	85264 ± 391	39.8 ± 0.3
10-Nov-08	3	10	77.5 ±2.3	85262 ± 0.001	85272 ± 514	39.8 ± 0.8
3-Dec-08	3	10	77.7 ± 3.0	85262 ± 0.04	85283 ± 1241	40.1 ± 2.1
4-Dec-08	5	15	77.5 ± 2.0	85262 ± 0.03	85266 ± 573	39.8 ± 0.5
Total	41	169	77.7 ± 3.6	85259 ± 79.1	85224 ± 698	39.9 ± 3.2
Pearce et al 1997	-	-	77.4	-	-	39.8
NIST 612 *			-	-	-	39.0

Table 3.3: (Continued) Mean (±*SD*) analytical data of isotopes measured in NIST 612 standards for this study compared to Pearce et al. (1997) and NIST mean preferred values. Analytical data for isotopes of interest are shown in relation to date within and between each day of ablation. (note: standards were run at the start, middle and end of each otolith run additional standards were run if steady signal readings were not observed) -/ means no data.

Ablation date	N = Otoliths	N = NIST 612	Mn^{55}	Zn^{66}	As^{75}	Rb^{85}
20-Aug-08	7	39	38.4 ± 0.5	38.4 ± 8.6	37.3 ± 1.4	31.6 ± 0.4
28-Aug-08	1	6	38.4 ± 0.6	37.9 ±1.6	37.4 ± 2.0	31.6 ± 0.4
18-Sep-08	4	29	38.3 ± 0.4	38.3 ± 6.7	41.4 ± 16.3	31.5 ± 1.3
23-Sep-08	5	25	38.1 ± 2.1	37.4 ± 3.7	37.2 ± 2.7	31.5 ± 1.6
2-Oct-08	1	5	38.3 ± 0.8	38.1 ± 3.2	37.2 ± 1.3	31.6 ± 0.8
23-Oct-08	4	15	38.4 ± 0.4	37.8 ± 1.1	37.3 ± 1.3	31.6 ± 0.3
30-Oct-08	5	15	38.3 ± 0.5	37.8 ± 0.9	37.4 ± 0.8	31.6 ± 0.4
5-Nov-08	1	3	38.4 ± 0.8	37.9 ± 0.1	37.3 ± 0.6	31.6 ± 0.4
6-Nov-08	2	6	38.4 ± 0.3	38.0 ± 2.3	37.3 ± 0.8	31.6 ± 0.3
10-Nov-08	3	10	38.4 ± 0.4	38.0 ± 1.8	37.4 ± 1.6	31.6 ± 0.5
3-Dec-08	3	10	38.6 ± 2.3	38 .0 ± 1.8	37.4 ± 1.5	31.7 ± 1.0
4-Dec-08	5	15	38.4 ± 0.4	37.9 ± 0.6	37.3 ± 1.1	31.6 ± 0.3
Total	41	178	38.3 ± 1.0	38.0 ± 5.1	38.0 ± 6.8	31.6 ± 0.9
Pearce et al 1997	-	-	38.4	37.9	-	31.6
NIST 612*	-	-	37	38	37.33	32

Table 3.3 (Continued). Mean (±*SD*) analytical data of elements measured in NIST 612 standards for this study compared to Pearce et al. (1997) and NIST mean preferred values. Analytical data for isotopes of interest are shown in relation to date within and between each day of ablation. (note: standards were run at the start, middle and end of each otolith run additional standards were run if steady signal readings were not observed) -/means no data.

Ablation date	N = Otoliths	N = NIST 612	Sr	Cs	Ba
20-Aug-08	7	39	76.1 + 0.6	41.6 + 0.4	37.7 + 0.5
28-Aug-08	1	6	76.1 + 0.8	41.6 + 0.3	37.7 + 0.5
18-Sep-08	4	29	76.0 + 2.1	41.5 + 1.1	37.7 + 0.5
23-Sep-08	5	25	75.6 + 3.3	41.5 + 1.3	37.4 + 1.4
2-Oct-08	1	5	76.2 + 0.8	41.6 + 0.7	37.9 + 0.5
23-Oct-08	4	15	76.1 + 0.5	41.6 + 0.4	37.7 + 0.6
30-Oct-08	5	15	76.2 + 0.4	41.7 + 0.4	37.8 + 0.5
5-Nov-08	1	3	76.1 + 0.7	41.6 + 0.6	37.7 + 0.5
6-Nov-08	2	6	76.1 + 0.3	41.6 + 0.4	37.7 + 0.5
10-Nov-08	3	10	76.1 + 0.5	41.6 + 0.8	37.7 + 0.9
3-Dec-08	3	10	76.2 + 2.8	41.8 + 1.9	37.8 + 2.1
4-Dec-08	5	15	76.1 + 0.8	41.6 + 0.3	37.7 + 0.8
Total	41	178	76.0 + 1.7	41.6 + 0.9	37.7 + 0.9
Pearce et al 1997	-	-	76.1	41.6	37.7
NIST 612	-	-	75	41.64	37

3.3.2 Otolith Sr/Ca and Ba/Ca ratio trends

Overall trends in Sr/Ca molar ratios from the core to the otolith edge were the same in torrentfish from the Mangauika (Fig 3.3.a, b) and Rangitukia Streams (Fig 3.4. a, b). Fish from both streams demonstrated consistently high Sr/Ca ratios in the otolith core which were followed by notable decreases in Sr /Ca towards the otolith edge. The range of fish sizes from the Mangauika varied with the smallest torrentfish (Fig.3.3.a) measuring 63 mm (TL) and the largest at 123 mm (Fig 3.3.b) indicating a wide range of maturity stages.

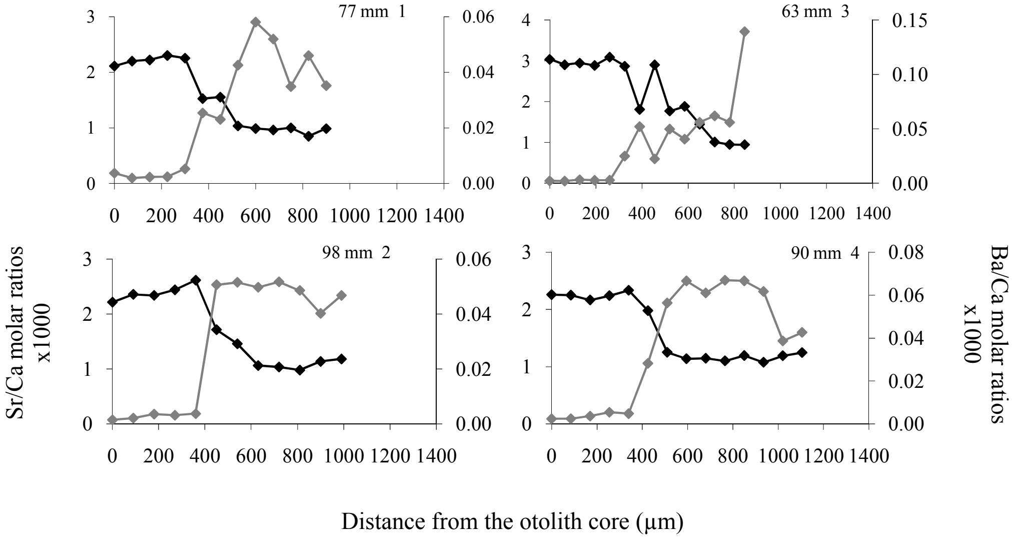


Figure 3.3 a: .Laser spot analyses of otoliths and fish size (TL) in the Mangauika Stream. Sr/Ca and Ba/Ca ratios are shown as molar ratios (x 1000) at distance from the core (µm).

However, the overall range of Sr/Ca ratios in the core of torrentfish (between 2-3) across all size ranges in the Mangauika was relatively low (Fig 3.3 a.b). Total mean Sr/Ca ratios of (all) core values (2.26 ± 0.36) of fish from the Mangauika were only slightly different to edge ratios (1.08 + 0.26). Similarly, the minimum and maximum range of Sr/Ca ratios in the otolith core (min 1.9 – max 3.0) of Mangauika torrentfish gave no indication of any large variability from mean Sr/Ca ratios (Table 3.4). This was also the case for fish from the Rangitukia which had almost the same range in mean Sr/Ca ratios at the core (2.37 + 0.21) and the edge of otoliths (1.05 + 0.11), as fish from the Mangauika (Table. 3.4).

Fish sizes in the Rangitukia also reflected a wide range of maturity stages with the smallest fish measuring 65 mm (Fig 3.4.b) with a relatively high Sr/Ca ratio (2.9) at the core and low edge ratio (1.0), (Fig 3.4. b). The largest sized fish was 141 mm with a slightly lower core Sr/Ca ratios (2.4) but similar edge ratio (1.0), (Fig 3.4. b). Minimum and maximum Sr/Ca ratios from fish in the Rangitukia were also similar in range at the core (min 2.0 - max 2.9) and had the same Sr/Ca ratios to fish in the Mangauika at the otolith edge (min 0.8 – max 1.2), (Table 3.4).

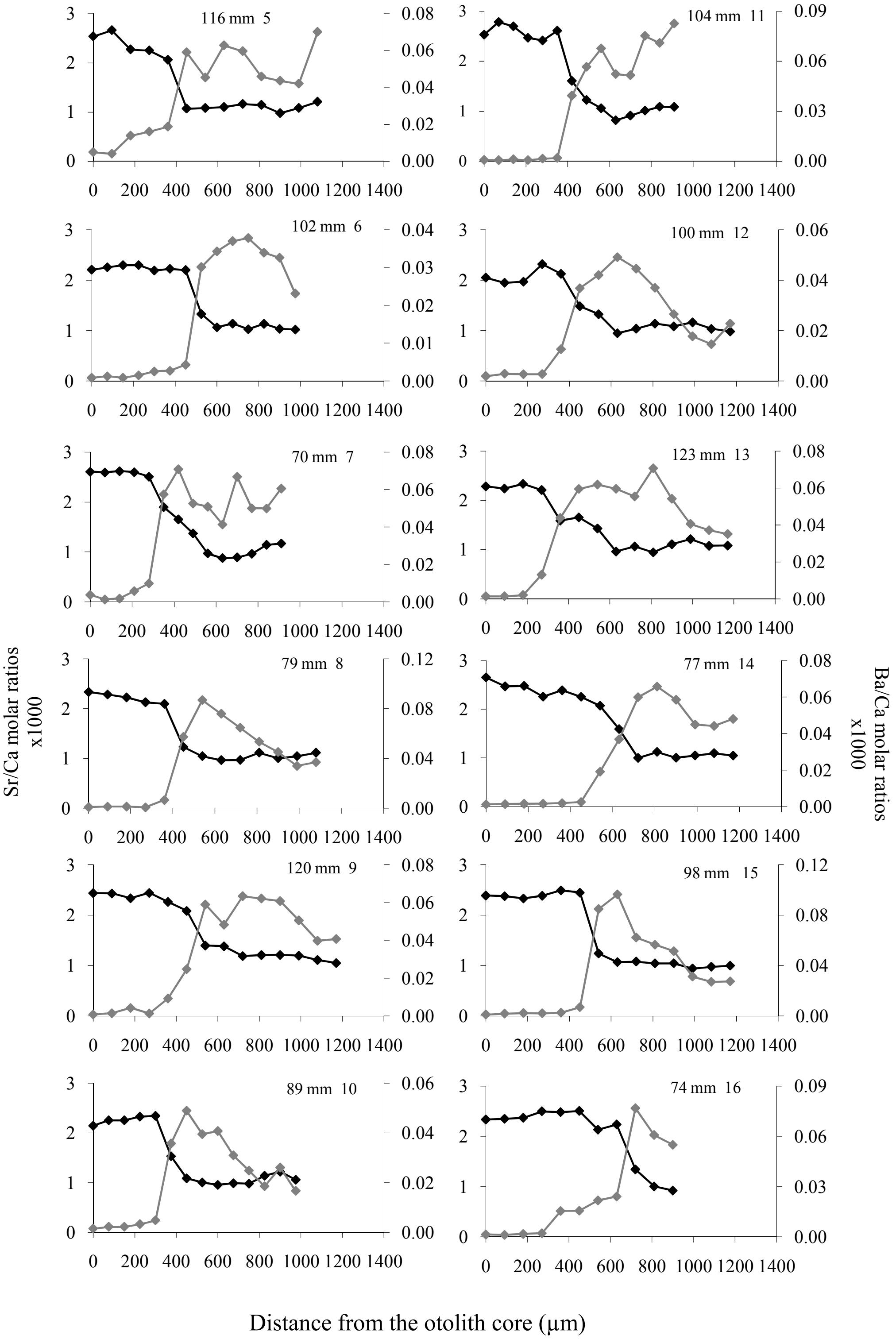


Figure 3.3 b: .Laser spot analyses of otoliths and fish size (TL) in the Mangauika Stream. Sr/Ca and Ba/Ca ratios are shown as molar ratios (x 1000) at distance from the core (µm).

Of notable interest was the distinct inverse relationship Ba/Ca ratios exhibited with Sr/Ca ratios particularly in the otolith core (Fig 3.3a,b, 3.4 a,b). At the otolith core Ba/Ca ratios were always low in relation to Sr/Ca ratios. Towards the edge however, Ba/Ca showed distinct increases which remained consistently higher than core values. However, Ba/Ca ratios at the otolith edge were considerably more variable than at the core (Fig 3.4 a,b 3.4 a, b).

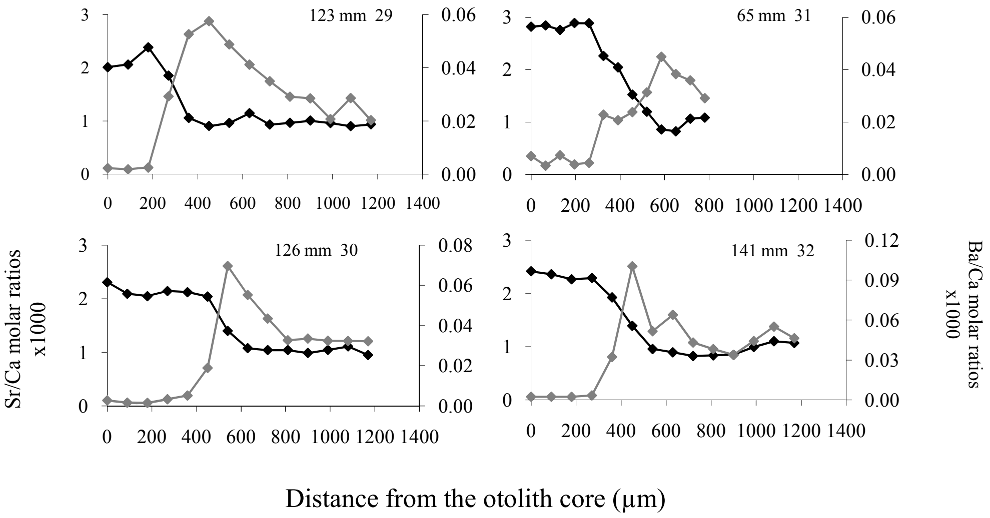


Figure 3.4 a: Laser spot analyses of otoliths and fish size (TL) in the Rangitukia Stream. Sr/Ca and Ba/Ca ratios are shown as molar ratios (x 1000) at distance from the core (µm).

Table 3.4: Total mean, minimum and maximum Sr/Ca and Ba/Ca molar ratio (x1000) values detected in the core and edge regions of sagittal otoliths from fish in the Mangauika and Rangitukia Streams.

Stream	Growth axis	N	Min-max Sr/Ca molar ratio x 1000
Rangitukia	Core	16	2.0 - 2.9
	Edge		0.8 - 1.2
Mangauika	Core	16	1.9 - 3.0
	Edge		0.8 - 1.2

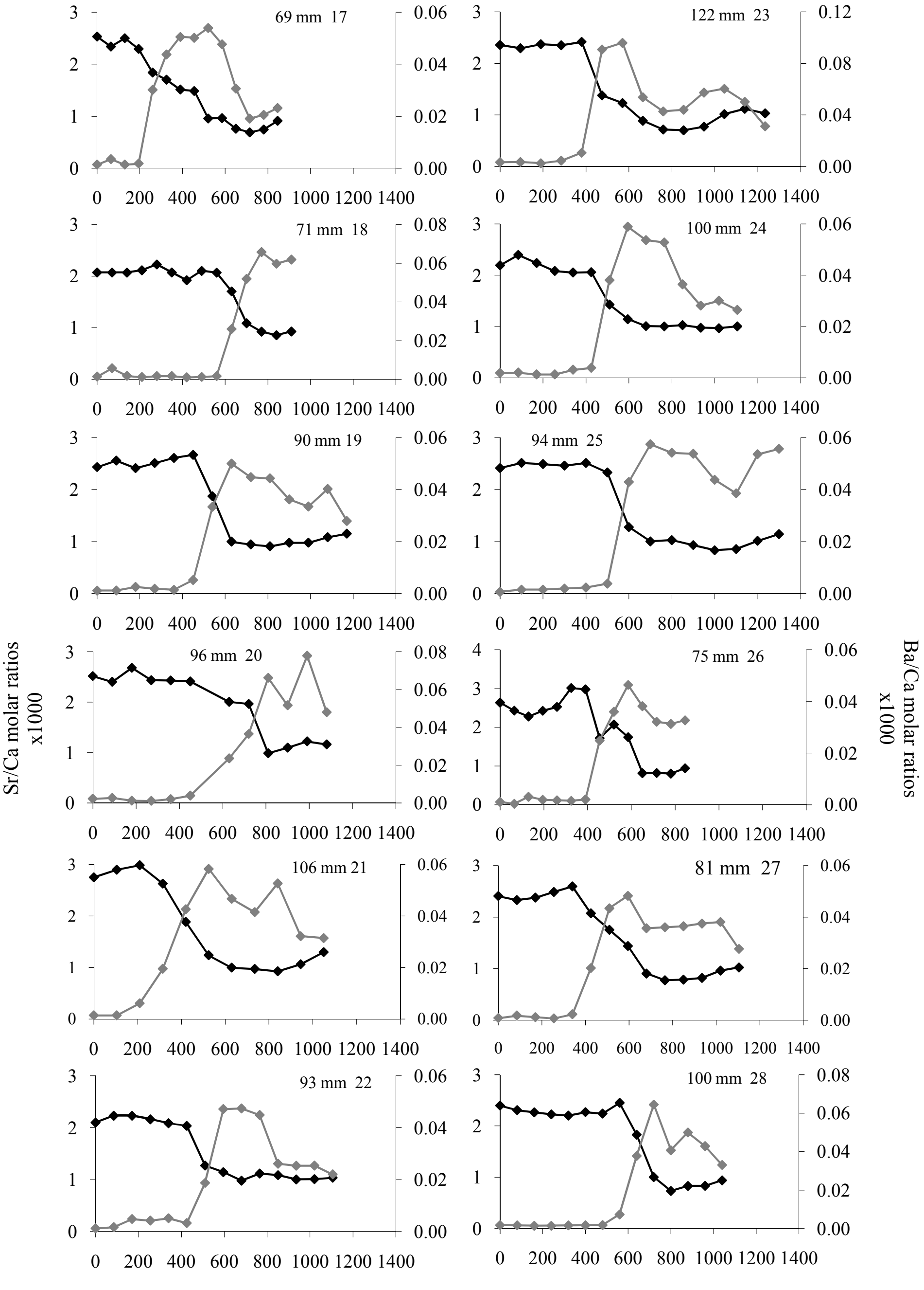


Figure 3.4 b Laser spot analyses of otoliths and fish size (TL) in the Rangitukia Stream. Sr/Ca and Ba/Ca ratios are shown as molar ratios (x 1000) at distance from the core (µm).

3.3.3 Stream water chemistry

Kruskal Wallis comparative tests of elemental concentrations (ppb) in water samples from upper and lower reach sites of the Mangauika and Rangitukia Streams are summarised in (Table. 3.5). Differences in elemental concentrations between the upper and lower reach sites of the Mangauika were only significant for Ba (6.90, *P = 0.04*), which was highest in the upper reach site (Table.3.5). However, in the Rangitukia significant differences in elemental concentrations of Sr (45.3, *P = 0.04*), Ca (3509, *P = 0.04*), and Cr (0.19, *P = 0.02*), were also evident and were highest in water samples collected from the upper reach site (Table 3.5)

Table 3.5: Kruskal Wallis comparison tests of differences in elemental concentrations (ppb) of water samples collected from upper and lower reach fishing sites of both study streams. Significant differences between sites and streams are highlighted in bold.

		Mean concentrations (ppb)					
Site	N	Sr (ppb)	Mg (ppb)	Ca (ppb)	Cr (ppb)	Mn (ppb)	Ba (ppb)
Mangauika Upper	4	36.0	2339	2981	0.333	0.149	**6.90**
Mangauika Lower	4	35.9	2637	2767	0.321	0.387	4.95
P-Value		*P = 1.02*	*P = 0.14*	*P = 0.38*	*P = 1.00*	*P = 0.41*	***P = 0.04***
Rangitukia Upper	4	**45.3**	2265	***3518***	**0.190**	0.308	7.10
Rangitukia Lower	4	39.0	2031	3004	0.066	0.126	6.13
P-Value		***P = 0.04***	*P = 0.15*	***P = 0.04***	***P = 0.02***	*P = 0.3*	*P = 0.08*
Mangauika Stream	8	35.9	**2488**	2874	**0.33**	0.27	5.93
Rangitukia Stream	8	***42.6***	2148	3256	0.13	0.22	6.62
P-Value		***P = 0.02***	***P = 0.03***	*P = 0.06*	***P = 0.006***	*P = 0.52*	*P = 0.13*

Differences in the elemental concentration of water samples from the Mangauika and Rangitukia were also evident and varied between streams (Table.3.5). In the Rangitukia Sr (42.16, *P = 0.02*), was the only element that differed significantly from water samples collected from the Mangauika stream. In the Mangauika concentrations of Mg (2488, *P = 0.03*), and Cr (0.333, *P = 0.006*), were significantly higher than in the Rangitukia (Table 3.5). There were no elemental relationships in water samples using Spearman Rank order correlations collected from both streams (Table. 3.6).

Table 3.6: Spearman rank order correlation matrix of the relationships between elemental concentrations (ppb) in water samples collected from the Mangauika (n = 8) and Rangitukia (n = 8) Streams. Significant correlations **(*P* < 0.05)** are highlighted in bold and italics.

	Mg	Cr	Mn	Sr	Ba
Mg	1.000	0.438	0.378	0.185	-0.300
Cr	0.438	1.000	0.149	-0.424	-0.065
Mn	0.378	0.149	1.000	0.197	0.066
Sr	0.185	-0.424	0.197	1.000	0.432
Ba	-0.300	-0.065	0.066	0.432	1.000

Discriminant function analysis (DFA) of Mangauika and Rangitukia water samples using Sr, Mg Cr, Ba , and Mn isotopes as predictor variables correctly classified all water samples to their stream of collection (Table. 3.7). However, DFA classification could not be carried out between upper and lower reach stream sites due to low water sample numbers between reaches (n = 4).

Table 3.7: DFA classification matrix for water samples (N = 16) collected from the Mangauika and Rangitukia Streams using Sr, Mg, Cr, Ba, and Mn (observed classifications are shown in rows, and predicted values in columns).

Stream	Percent correct	Mangauika Stream	Rangitukia Stream
Mangauika Stream	100	8	8
Rangitukia Stream	100	8	8
Total	100	16	16

3.3.4 Otolith chemistry in relation to stream water chemistry

Significant differences in the elemental concentrations of otolith edge values recorded from torrentfish from both study streams were not evident using the same predictor elements in water samples (Sr, Mg, Cr, Ba, and Mn), (Table 3.8). The only notable difference in elemental concentrations between streams was observed in Mg which had the greatest mean difference in otolith edge values of fish from the Mangauika (34.6) compared to the Rangitukia (23.4). Similarly, no significant differences in elemental concentrations were evident between fish from upper and lower reach sites of both streams (Table 3.8).

Table 3.8: Kruskal Wallis comparison tests of differences in elemental concentrations (ppm) of otolith edge values of torrentfish collected from upper and lower reach fishing sites of the Mangauika and Rangitukia Streams. (Ca excluded as an internal standard). No significant differences between sites and streams.

Stream	N	Mg	Cr	Mn	Sr	Ba	As	Rb
Lower Rangitukia	10	25.0	4.39	11.67	975	47.8	0.86	0.79
Upper Rangitukia	13	22.1	13.90	2.92	939	45.1	0.75	0.56
P-values		P > 0.1	P > 0.1	P > 0.1	P > 0.1	P > 0.1	P > 0.1	P > 0.1
Lower Mangauika	9	41.3	5.36	2.94	939	56.3	9.25	0.58
Upper Mangauika	13	30.0	6.40	3.39	934	44.1	0.48	0.73
P-values		P > 0.1	P > 0.1	P > 0.1	P > 0.1	P > 0.1	P > 0.1	P > 0.1
Rangitukia Stream	23	23.4	9.76	6.72	955	46.3	0.87	0.66
Mangauika Stream	22	34.6	5.98	3.20	936	49.1	4.07	0.64

In the upper and lower reaches of the Rangitukia mean concentrations of Ca, Sr, Mg and Ba were much the same. Noteworthy differences in mean elemental concentrations of otolith edge values were observed for Cr (13.9), in fish from the upper reach site and Mn (11.67) for lower reach sites. In the Mangauika mean differences in otolith edge values of fish from upper and lower reach sites were only slight for Sr, Mn, Cr. However, mean elemental concentration of Mg (41.35), showed the greatest discernable difference being highest in the lower reach site (Table 3.8). Spearman rank order correlations on the elemental concentrations of Sr, Mg, Cr, Ba, Rb' As and Mn in torrentfish otolith edge values were correlated for a number of isotopes (Table 3.9). This included positive correlations between Cr and Mg Mn and Mg and Ba and Mn which indicate that increases of these isotopes in otoliths is proportional (Table 3.9).

Table 3.9: Spearman rank order correlation matrix of the relationships between elements measured at the otolith edge (N = 45) of torrentfish collected from the Mangauika and Rangitukia Streams. Significant correlations **(*P* < 0.05)** are highlighted in bold.

	Mg	Cr	Mn	As	Rb	Sr	Ba
Mg	1.00	**0.53**	**0.44**	0.14	0.15	0.12	0.25
Cr	**0.53**	1.00	0.02	0.04	0.12	0.06	-0.05
Mn	**0.44**	0.02	1.00	**0.31**	-0.08	-0.07	**0.52**
As	0.14	0.04	**0.31**	1.00	-0.09	-0.02	**0.42**
Rb	0.15	0.12	-0.08	-0.09	1.00	-0.15	-0.10
Sr	0.12	0.06	-0.07	-0.02	-0.15	1.00	0.27
Ba	0.25	-0.05	**0.52**	**0.42**	-0.10	0.27	1.00

Multivariate DFA analysis of elemental concentrations of torrentfish otolith edge values varied between streams (Table 3.10). A total of six isotopes including Sr, Mg, Cr, Rb, Cs, and Mn were used as predictor variables and correctly classified 80 % of torrentfish to their stream of capture (Table. 3.10).

Table 3.10: DFA classification matrix grouping otolith edge values of torrentfish to stream of capture using Sr, Mg, Cr, Rb, Cs and Mn as predictor variables (observed classifications are shown in rows, predicted values in columns).

	Percent correct	Rangitukia Stream	Mangauika Stream
Rangitukia Steam	87	20	3
Mangauika Stream	72	6	16
Total	80	26	19

DFA was also used to classify otolith edge values of males and females to their stream fishing site using four isotopes for fish in the Rangitukia (Rb, Cr, As , and Mn) and 6 isotopes for fish in the Mangauika Stream (Rb, Ba, As, Mg, and Mn, Cs), (Table 3.11). Sex ratios were classified to their fishing reach of capture with 76% accuracy in the Rangitukia Stream. In the Mangauika males and females were classified with 86% accuracy to their fishing reach of capture (Table 3.11).

Table 3.11: DFA classification matrix grouping otolith edge values of male and females to fishing reach using Rb, Cr, As, and Mn as predictor variables for fish from the Rangitukia and Rb, Ba, As, Mg, and Mn, Cs, for fish from the Mangauika (observed classifications are shown in rows, predicted values in columns).

		Percent correct	Lower	Upper
Rangitukia Stream	Lower	56	5	4
	Upper	92	1	11
	Total	76	6	15
Mangauika Stream	Lower	75	6	2
	Upper	92	1	12
	Total	86	7	14

3.4 Discussion

3.4.1 Torrentfish migration history

Torrentfish from the Mangauika and Rangitukia streams all demonstrated the same consistent trends in otolith chemistry indicative of a shift between fresh and saltwater environments (Fig 3.3 a, b, 3.4 a,b). Elevated levels of Sr/Ca ratios in the otolith core were always followed by decreases in Sr/Ca ratios towards the edge. Similarly, Ba/Ca molar ratios demonstrated a distinct inverse relationship to Sr/Ca molar ratios being lower at the core and higher at the otolith edge. However, unexpectedly, it is clear that torrentfish Sr/Ca core ratios (3) do not reflect seawater molar ratios (8.6, Campana 1999) aligning more closely to estuarine systems (4, Radtke 1987, Tzeng, 1994).

Although the ambient water chemistry a fish may inhabit can be reflected in their otoliths (Tzeng 1996, Kawakami et al. 1998, Secor & Rooker 2000), the otoliths themselves are not in direct contact with the water (Kalish et al 1996). Therefore the concentrations of elements in otoliths may not necessarily reflect the actual concentrations of the water (Kalish et al 1996). Instead the composition of elements in otoliths is governed mainly by the trace element composition of the endolymph fluid which encompasses the otolith (Kalish 1989). For marine teleosts, elements or ions in the water are transported to the endolymph via assimilation into the blood stream through the intestines (Olsson et al. 1998) and via gills in freshwater teleosts (brachial uptake), (Campana, 1999). However, while water-bloodstream transfer mechanisms may closely reflect water chemistry, the actual composition of elements deposited may differ considerably during the crystallisation process. For diadromous fish where seawater Sr/Ca ratios may or may not reflect otolith chemistry, it is evident that Sr can be significantly discriminated against during elemental deposition along with several other elements (Campana, 1999; Stecher et al. 1996), which maybe a reflection of low Sr/Ca core ratios in torrentfish. Similarly, as low Sr/Ca ratios in the otoliths of fish may differ between the time they spend in freshwater and seawater (Secor & Rooker 2000). A shorter marine larval phase for torrentfish of a few months (Eldon and Greager 1984, McDowall 1994) may result in lower Sr uptake (Milton and Chenery, 2001). This is evident by differences in the range of core Sr/Ca molar ratios in relation to time spent at sea between several of New Zealand's diadromous fishes (Table 3.12).

Table 3.12 Otolith and water Sr/Ca molar ratios (x 1000) of core and edge values reported for New Zealand diadromous freshwater fish species including information source and river (note Lake Ellesmere has open sea access). -/means no data.

Species	River	Otolith Sr/Ca molar ratio x 1000 Core	 Edge	Source	time spent at sea
Torrentfish	Mangauika	3.0	1.2	This study	2-3 months[1,2]
-	Rangitukia	2.9	1.2	This study	
Inanga	Waikato River	8.0	1.0	Hicks et al 2005	5-7 months[1]
Koaro	Operau River	8.0-12.0	2.0	Hicks et al 2005	5-7 months[1]
Common bully	Mataura River	4.0	2.0	Closs et al 2003	3-4 months[1]
-	Clutha River Clydevale	4.0-7.0	2.0	Closs et al 2003	
-	Clutha River Balclutha	4.0	2.0	Closs et al 2003	
-	Taieri River	4.0	2.0	Closs et al 2003	
Giant kokopu	Cullen Creek	7.0	<3	David et al 2004	5-7 months[1]
-	Waituna Creek	4.5-5.0	2.0	David et al 2004	
Banded kokopu	Picnic Gully	7.0	2.0	David et al 2004	5-7 months[1]
Shortfin eel	Lake Ellesmere	16.2-20.7	2.5	Takaomi et al 2003	18 months[1]
Longfin eel	Lake Ellesmere	18.11-19.6	2.5	Takaomi et al 2003	-

*Life history source: [1]McDowall, 2000; [2]Eldon and Greager, 1984.

For example several galaxiids including the giant kokopu (*Galaxias, argenteus*), banded kokopu (*G, fasciatus*), koaro (*G, brevipinnis*) and inanga (*G, maculatus*) all have otolith core Sr/Ca ratios around (7- 8), twice that of torrentfish (Table 3.12). High core Sr/Ca ratios in galaxiids may in part be a reflection of their longer life history at sea (5-7 months), before returning to freshwater (McDowall, 2000). However, these high ratios may also be attributed to some physiological differences (Campana, 1999). For example high Sr/Ca core ratios (16-20) reported for the shortfin (*Anguilla australis*) and endemic longfin (*A Dieffenbachii*), eels (18–19) were thought to be attributed to complex biological processes (Takaomi et al 2003). Notably these ratios are more than twice that of known seawater molar ratios (8.6, Tzeng, 1994), but are thought to occur during the onset of metamorphosis (the oceanic leptocephali stage). Essentially, the production of large amounts of gelatinous extracellular matrix (Sr enriched) increase Sr in the endolymph and are absorbed onto the otolith. Once metamorphosis to the glass eel stage occurs the gelatinous matrix decreases along with Sr/Ca ratios (Otake et al 1994). Similarly an 18 month marine life history also constitutes considerably longer exposure times to the environment and higher core Sr/Ca ratios (Takaomi et al 2003) Core Sr/Ca ratios for common bully (*Gobiomorphus cotidianus*), were generally low (4) indicating an estuarine growth phase, although one individual did illustrate a close marine seawater ratios of (7), (Closs et al. 2003). Additionally, Sr/Ca ratios in bullies are marginally higher than torrentfish which reflects their slightly longer marine growth phase (Closs et al, 2003, McDowall, 1990).

The variability in Sr/Ca core ratios across the different fish species is largely evident (Table 3.5) and is most likely influenced by fish physiology, exposure time, and internal regulation processes within the endolymph (Campana, 1999). Although low core Sr/Ca ratios are not consistent with seawater ratios there is considerable evidence to suggest an early marine life history for this species. Small juveniles (23–30 mm) have been taken from the Rakaia lagoon adjacent to the sea on the South Island of New Zealand by Eldon and Greager (1983) and Scrimgeour and (Eldon 1989). Similarly, McDowall (1994) described the physical structure of juvenile torrentfish (15–20 mm) using archival specimens collected from a tidal pool in the Rakaia lagoon. In the Kakanui estuary on the South Island, Glova et al (1995) collected juveniles (19–23 mm) near the estuary entrance after dusk in May 1993. Additionally, examination of juvenile stomach contents indicated a preference for the endemic amphipod (*Paracorophium excavatum*) which typically occupies fine sediments within estuaries and harbours (Schnabel et al. 2000). In these studies the relatively small size at which juveniles (20–30 mm) enter freshwaters suggests that fish spend only several months at sea (McDowall 1994). However, for torrentfish it is important to note that Sr/Ca ratios have not previously been reported for this species and further research is necessary. Similarly a better indication of the range of Sr/Ca core ratios in torrentfish may be obtained from small juveniles collected much closer to the sea (Hicks et al, 2004). In this study overall trends in Sr/Ca ratios clearly indicate a distinct movement between fresh and saltwater environments which suggest that torrentfish from the Mangauika (170 km) and Rangitukia Streams (150 km) spent larval growth at sea prior to navigating up the Waikato and Waipa Rivers to reach there respective streams of origin 150170 km from the sea.

3.4.2 Torrentfish stream classification

The chemical composition of water samples between both streams varied. In the Rangitukia concentrations of Sr were significantly higher than in the Mangauika. However in the Mangauika Cr and Mg were significantly higher than in the Rangitukia. DFA analysis of the same elements including Ba, and Mn as predictor variables correctly classified all water samples 100 % to their stream of collection. However, elemental concentrations of otolith edge values in torrentfish from both streams demonstrated no significant differences. This was regardless of using the same significant elements identified in water samples. Similarly there were no significant differences in otolith chemistry between fishing reaches for either the Mangauika or Rangitukia Streams. There are several aspects which may explain observed indifferences in stream water chemistry with torrentfish otolith chemistry. This may have been due to time scale differences of when water samples were collected in relation to spot size and the proximity of spots to the otolith edge. Despite accurate laser spot placement (at the edge) the yield of otolith material obtained from a 50 µm spot probably incorporated otolith material from a wider timescale. This will be indifferent to when water samples were collected biasing comparisons. A smaller spot size may have narrowed the timescale differences to a more representative time frame (general time of water collection). However, as spot size decreases so does the yield of otolith material which is transported to the ICP-MS giving lower elemental counts (Steven and Ward 2005). A small ablation spot size (10-20 µm) would reduce the time scale bias closer to that of when water samples were collected. The smaller spot would also enable it to be placed closer to the otolith edge (without shattering the edge). To account for lower ablation yields (due to smaller spot size), the laser could be run using the raster mode setting (a continuous line scan run parallel to the otolith edge). The dwell time for the raster line scan can be run for 50–60 seconds which would increase the yield of otolith edge material, while maintaining the preferred timescale of a small spot size. Additionally, indifferences in water and otolith chemistry maybe attributed to fish physiology (Campana, 1999). Trace element uptake in the otoliths of freshwater teleosts occurs primarily by brachial uptake (Campana, 1999). In this regard torrentfish demonstrate a distinct preference for fast flowing environments (Glova and Duncan, 1984; Jowett and Richardson, 1996). Riverine trace elements in turbid environments may show little variability due to mixing compared to trace available elements in lentic systems. Similarly, trace element uptake via the gills may differ for torrentfish which preferentially occupy fast flowing stream environments

4. Conclusions.

It is evident in this study that the population dynamics of torrentfish in the Mangauika and Rangitukia streams are governed by distance from the sea in relation to habitat availability. Size frequency distribution patterns of torrentfish demonstrate how juveniles mature in size as they move upstream from the lower reaches of the Mangauika and Rangitukia. These patterns are supported by otolith research which indicates that torrentfish from both streams spent larval growth at sea before migrating 150–170 km up the Waipa and Waikato Rivers to their stream of origin. Spawning was a prolonged event building from February to peak periods in May for the Mangauika and from January to peak periods in April for the Rangitukia. Based on the general location of ripe and spent male and female torrentfish (relative to spawning period) between upper and lower reach sites of both streams spawning evidently occurs throughout the entirety of streams..

This research demonstrated the importance of clear river passage to and from the sea in relation to habitat availability by studying two torrentfish populations located at large distances from the sea, with limited habitat availability. These aspects also influenced the population structure and some reproductive aspects of torrentfish.. However, there was no indication of spawning behaviour or spawning habitats of this fish which to date still remains a mystery.

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