# Larval fish of Tauranga Harbour

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by

**Nathania Brooke**


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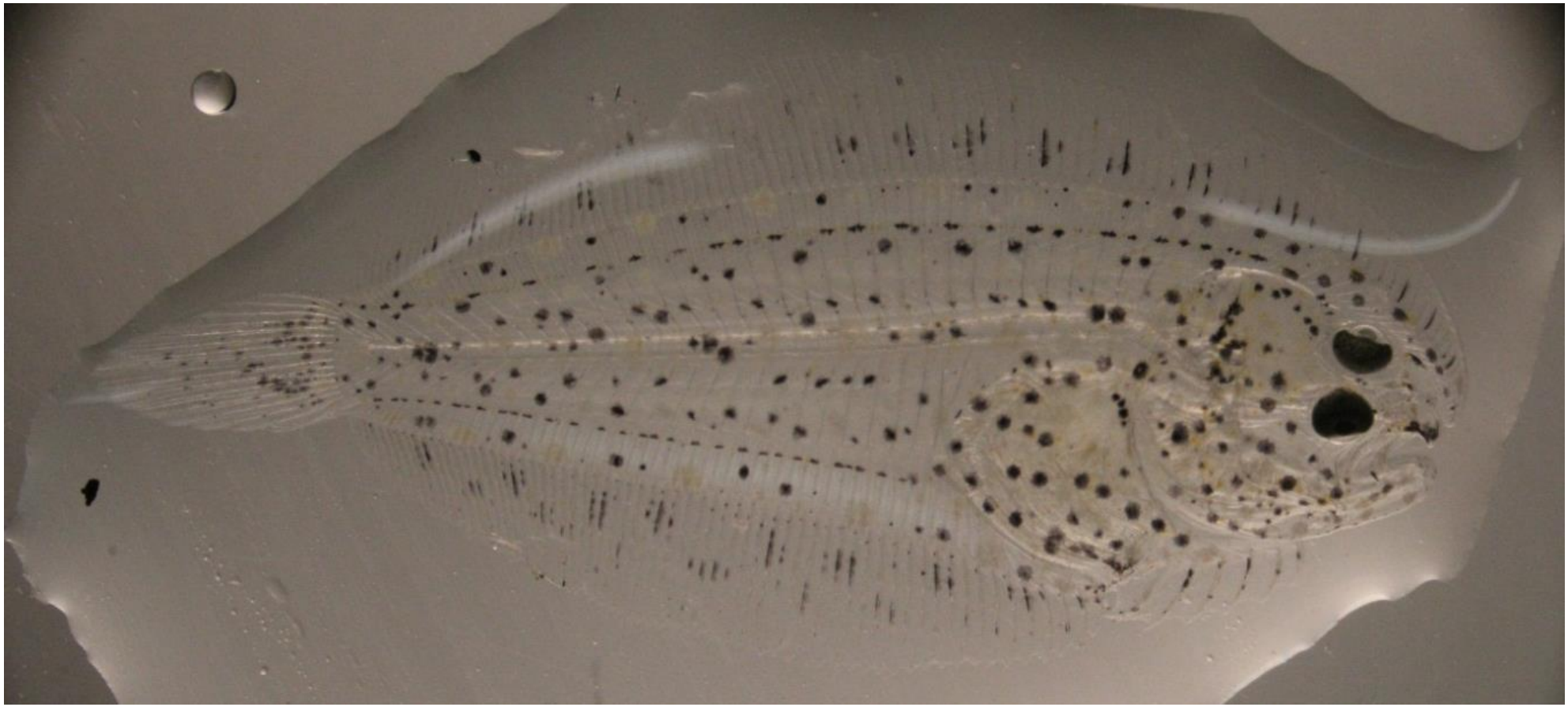

Frontispiece: Larval flatfish

# Abstract

Estuaries are important nursery habitats for many fish species, both in New Zealand and worldwide, characterised by high levels of primary production, shallow warmer waters, and affording relative protection from predators. Many estuaries are under constant threat from anthropogenic stressors due to the vicinity of industries that can cause contamination. It is necessary to first understand how larval fish use estuaries in order to understand the potential effects of anthropogenic impacts on their life history stages. Few studies in New Zealand have examined the use of estuaries by pre-settlement larvae. The majority of research undertaken in New Zealand on larval fish has been completed in coastal waters, examining the effects of seasonality, distribution patters, and growth of larvae. The objectives of this research were to increase understanding as to how larval fish use Tauranga Harbour. The study used a stationary channel net at Bridge Marina to intensively sample over one summer, and fortnightly over the ensuing 16 months, in an effort to discover which species of larval fish are found within the harbour; if they were more abundant on the flood or ebb tides; if they were more abundant during the day or night; if any patterns of seasonality were present; and if the abundance was affected by environmental variables such as water temperature or current speed. A choice chamber experiment was conducted to assess if larval kingfish (a species not found in the estuarine sampling programme), were able to differentiate between two different water types - estuarine and oceanic, in an effort to assess if larvae may use olfactory cues when choosing a habitat.

The larvae of at least 19 species from 18 families were caught during the intensive summer sampling, and at least 13 species from 11 families during the fortnightly sampling, with no new species found during the fortnightly sampling. Three taxa (anchovy *Engraulis australis*, Tripterygiidae and Gobiidae) were the most abundant over the entire sampling period, making up the majority of all catches. Larvae were found in higher abundances at night compared to the day, and no significant difference was found between abundances on the flood and ebb tides. Seasonality had an effect on larval fish abundance, with higher abundances caught

during spring and summer. The kingfish larvae in the choice chamber experiment appeared to display a preference for the oceanic water over the estuarine water.

The findings of this study indicate that larval fish of a range of species use Tauranga Harbour potentially as a nursery. Not surprisingly perhaps, estuarine species were found in the highest abundances. Larval abundance in the estuarine water column is affected primarily by the diel cycle, with larvae displaying behaviours of diel vertical migration and possibly selective tidal stream transport. Abundances of larvae peaked during spring and summer when the water temperature begins to warm after winter, coinciding with the spawning seasons of many fish species. Larval kingfish displayed an attraction towards oceanic water, or perhaps an avoidance of the estuarine water. This suggests that olfactory stimuli are important when choosing potential habitats, signifying that larval fish of estuarine species may actively seek out refuge within an estuary using olfactory cues. This study provides a good benchmark for future studies on larval fish within Tauranga Harbour and other estuarine systems.

# Acknowledgements

There are many people who have guided and helped me to make this thesis possible. Firstly, thanks to my supervisors, Dr Phil Ross, Prof Chris Battershill, Dr Tom Trnski and Dr Keith Gregor. Phil, the long hours spent on the pontoon of A-pier, the ideas and the support over the past two years were greatly appreciated. Chris, it was always enlightening to talk to you, I left our meetings given a new perspective and a fresh way to think about what I was doing. Tom, without your enthusiasm about the project, I think I wouldn't have embarked on the journey to write this thesis, your knowledge of all things larval fish was highly helpful, and saved me many hours peering through a microscope trying to identify what species I had found. Keith, thanks for introducing me to Phil in the first place, allowing me the chance to do a special topic instead of coastal geomorphology, and ultimately leading me on my path to undertaking this research.

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# Chapter 1 – General Introduction

## 1.1 Estuaries

Estuaries are valuable and highly productive ecosystems (Ramos *et al*., 2006; Vasconcelos *et al*., 2010) which provide significant ecosystem services such as nutrient cycling, disturbance regulation and food production (Costanza *et al*., 1997a). They differ from the adjacent oceans as they act as a transition from land to sea, and freshwater to salt water (Marques *et al*., 2005). They are protected from the forces of the ocean (wind, waves, storms) by barrier islands, reefs, deltas and headlands (Potter, 2013). Estuaries have high levels of primary and secondary productivity and are able to support a diverse range of fish and invertebrates (Beck *et al*., 2001). Estuarine sediments can support large numbers of animals through high production of food, while salinity gradients and muddy substrate may prevent many species from entering the estuary (McLusky & Elliott, 2004).

Estuaries are highly important ecosystems, nurseries and refuges (Costanza *et al*., 1997b) and offer a range of habitats including mangroves/tidal marsh, mudflats and seagrass beds. Estuaries are often referred to as nurseries due to the heightened productivity within them and the consequent high macrofaunal diversity that is usually supported (Beck *et al*., 2001). In recent studies, however, specific vegetative habitats such as seagrass meadows and mangroves have been a focus, as evidence suggests they support a higher biodiversity than unvegetated habitats (such as mudflats or open water) (Beck *et al*., 2001). Mangrove stands are utilised by many species of fish as a nursery as they provide protection from predators and have an increased availability of food compared to seagrass beds (Laegdsgaard & Johnson, 2001).

The value of estuaries as a nursery habitat for juvenile fish is well demonstrated in New Zealand (Francis *et al*., 2005) and worldwide (Beck *et al*., 2001; Martinho *et al*., 2007). However, what is less certain is the role that estuaries play in early larval life history stages. Developmental larvae are known to enter estuaries to make use of the shelter and food resources. For some species, moving into an estuary is vital for completing the life cycle (Pattrick & Strydom, 2014a). Marsh

vegetation and submerged plants provide cover for early life-history stages which are prone to heavy predation (Moyle & Cech, 2004). Rapid growth due to high food availability and warmer water temperatures allow larval fish to grow faster, becoming less vulnerable to predation, thereby increasing survivorship (Moyle & Cech, 2004; Ramos *et al*., 2006). Accordingly, juvenile stages of many fish spend the first parts of their lives within the shallow, warmer environment (Morrison *et al*., 2002), before moving upstream into freshwater or out into to the less sheltered open coast or oceanic marine environment (Vasconcelos *et al*., 2011).

## 1.2 Human impacts

Unfortunately, the ecological value of estuaries may be threatened by anthropogenic stressors, such as pollution, habitat loss and overfishing (Kennish 2002; Dolbeth *et al*., 2008). Agricultural, industrial and transportation industries are often situated in the vicinity of estuaries or rivers, and can often be the cause of contamination of the estuary (Ramos *et al*., 2006; Jordan, 2012). Little attention has been given to the effects of this degradation on the capacity of estuaries to provide habitat for larval fish. It is necessary to understand the influence of anthropogenic impacts or the external environment on the production of fish within estuaries (Dolbeth *et al*., 2008). To better understand potential anthropogenic impacts on larval life stages, it is first important to understand the significance of the estuary as a nursery, migratory route or feeding ground for larval fish (França *et al*., 2012).

## 1.3 Fish in estuaries

Ramos *et al*. (2006) mentions there are three general categories of fish that are found in estuaries: temporary estuarine residents, residents, and occasionally found species. Potter and Hyndes (1999) divided the categories further, as shown in Figure 1.1. Resident species are solely estuarine, completing their lifecycle within the estuary (Ramos *et al*., 2006; Dolbeth, *et al*., 2008). Temporary estuarine residents use the estuary seasonally (Ramos *et al*., 2006). Those found on rare occasions or in low numbers are in the occasional category (Ramos *et al*., 2006), which corresponds to the category Potter and Hyndes (1999) calls the ‘marine stragglers’. The categories of species that are the focus of this study are:

the marine estuarine-opportunists; estuarine and marine; semi-anadromous; and the solely estuarine species; henceforth known as a collective of *estuarine dependent species*.

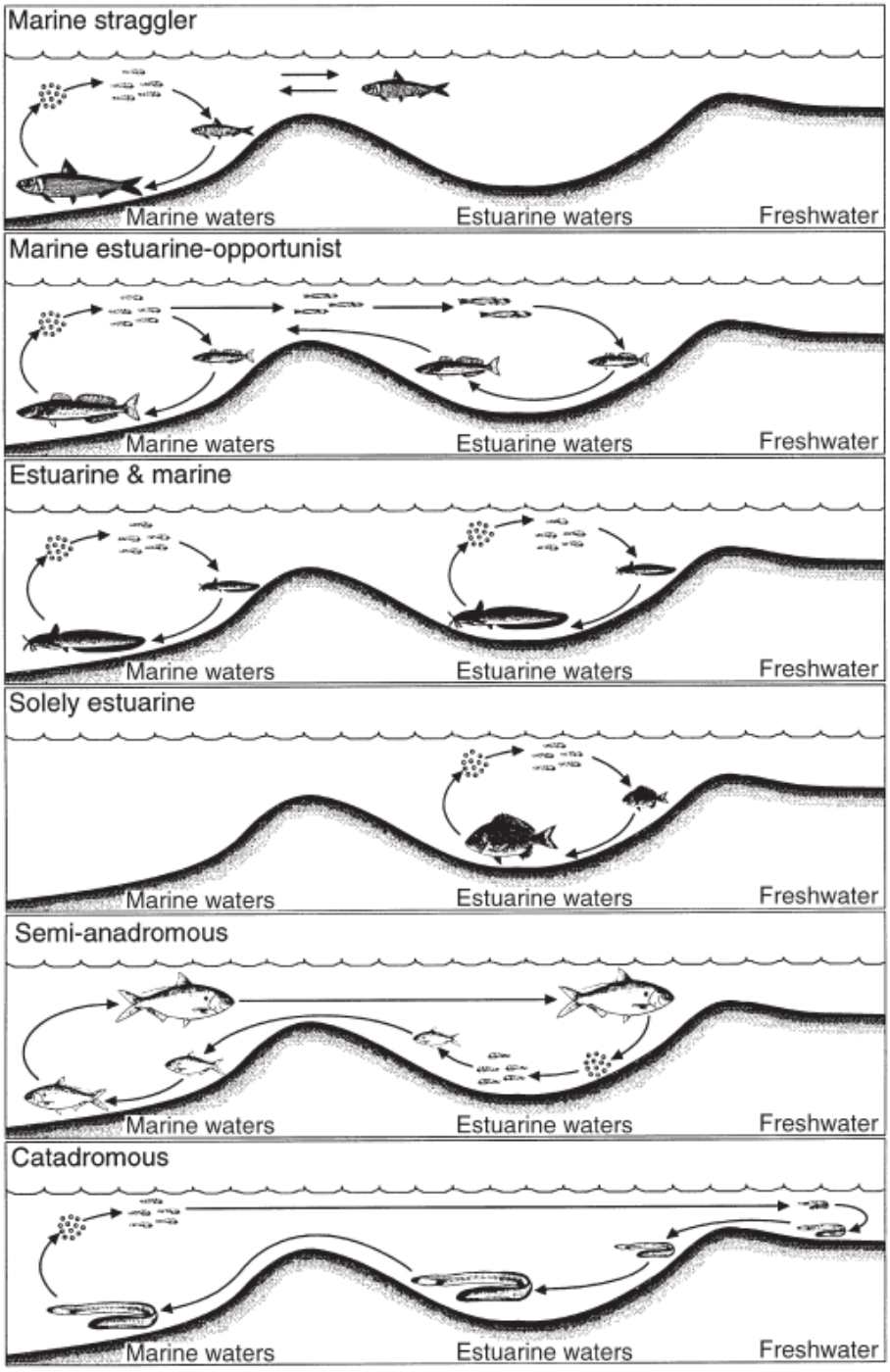



Figure 1.1: Diagram of the various ways fish use estuaries and the different lifecycle categories. From Potter and Hyndes (1999).

## 1.4 Larval fish

The study of larval fish can be useful for several reasons. The presence of larval and juvenile fish can be an indicator of ecosystem health (Ramos *et al*., 2012). Important nursery habitats may be recognised by surveying the presence of juvenile fish (Beck *et al*., 2001) while spawning grounds are indicated by the presence of larval fish (Suthers, 2009). Larval fish information can be used to estimate the yield from fisheries. This can be done using the eggs and larvae to estimate spawning biomass, or projecting forward to older life stages that are more useful in estimates of recruitment (Hancock, 1992). Changes in larval fish assemblages over time can be used as an early indicator of environmental shifts related to climate change, due to the survival of larval fish being closely tied with primary and secondary production (Hernandez *et al*., 2010).

Knowing how larval fish use biotic structures in an estuarine environment can help to understand the importance of these structures as deterrents for predators and in the redistribution of food for larvae (Kingsford, 1993). Biotic structures such as jellyfish, marine snow and flotsam can provide shelter that may influence the survival and distribution of larval fish (Kingsford, 1993). A positive correlation between drift algae, and fish and invertebrates has been shown in estuaries and in oceanic waters (Kingsford & Choat, 1985). Pelagic species of algae (such as some *Sargassum*) create a dynamic habitat that is able to support a diverse assemblage of marine related taxa, including early life stages of fish (Casazza & Ross, 2008).

The species composition and distribution patterns of larval fish within estuaries varies due to environmental fluctuations and reproductive seasons (Ramos *et al*., 2006). Larval fish abundance in estuaries is variable during summer months but generally greater than abundances found in winter (McLusky & Elliott, 2004; Suthers, 2009), and peaks in abundances seem to occur during spring and summer (Ramos *et al*., 2006). As distance increases upstream from the mouth of the estuary, species diversity decreases (Suthers, 2009).

The behaviour of larval fish is often different to that of the adult fish. Larval fish are frequently found in higher abundances at night compared to during the day

(Beckley, 1985; Roper, 1986; Neira & Potter, 1992; Trnski, 2001). Reebs (2002) states that there are a few theories on why activity of early life stages of fish differs from that of the adults; the first being that they show low activity levels when predators are most active; the second being that as they develop, their food choice changes, leading to a change in behaviour; and the third is that of competition between fish of different ages, and separation temporarily might avoid this.

## 1.5 Worldwide

The number of larval fish species described around the world is relatively low, with only 10% of species' larva having been identified (Kendall & Matarese, 1994). If larvae are unable to be identified to species level, then research undertaken on larval fish abundance and distribution patterns is inadequate. The identification of larvae has mainly come from commercially important fisheries. The species are generally coastal, as fewer oceanic species have been described (Dolphin, 1997). The percentage of fish species that are described as larvae is displayed in Figure 1.2.

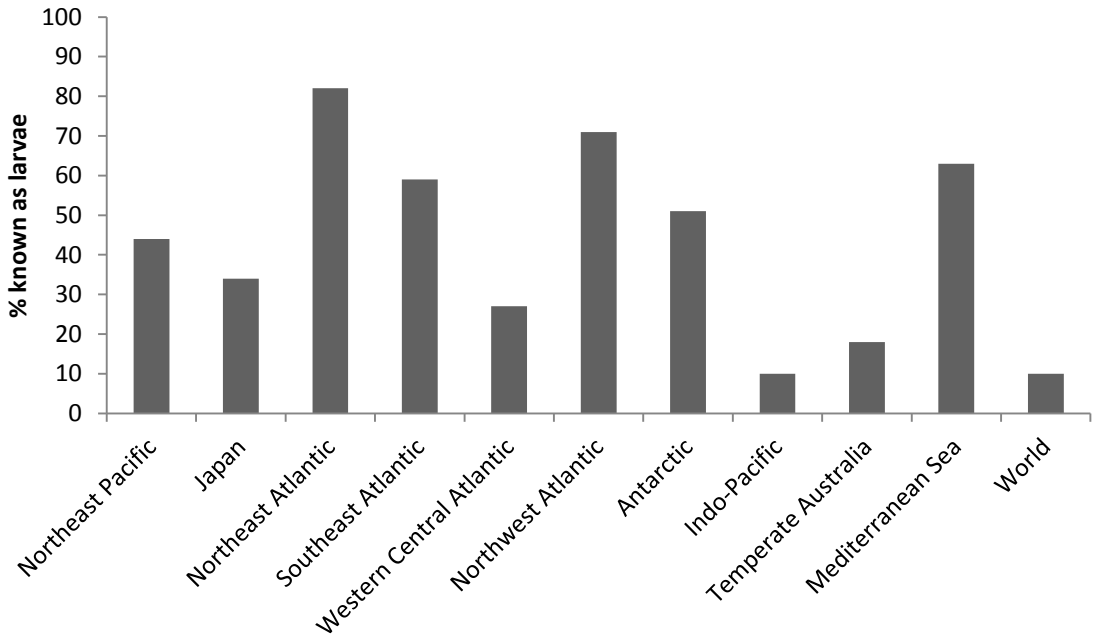



Figure 1.2: By geographic region, percentage of fish species described as larvae. From Kendall & Matarese (1994).

Moser *et al*. (1984) seems to be the most important publication on larval fish: the work provides information on over 20,423 fish species, with 1,932 known as larvae. Areas that are lacking information of larval fish are the Atlantic coast of Northern Africa, the Pacific and Atlantic coasts of South America, southern Australia and New Zealand. Areas where more than half of the fish species have been described as larvae include the Mediterranean, the Northeast Atlantic and the Antarctic (Dolphin, 1997).

Listed below are some of the identification guides that exist for larvae by geographic region:

- Temperate Australia (Neira *et al*., 1998)
- Japan (Okiyama, 1988)
- Indo-Pacific (Leis & Carson-Ewart, 2004; Leis & Trnski, 1989)
- Northeast Pacific (Matarese *et al*., 1989)
- Western North Atlantic (Fahay, 2007)
- Worldwide (Moser, *et al*., 1984)
- California (Moser, 1996)
- Antarctica (Kellermann, 1989)

Larval fish have been the focus of many studies worldwide in marine, estuarine and freshwater habitats. Some studies on marine larvae in the past 15 years relevant to this study have included investigations into:

- distribution between different habitats (Able *et al*., 2006; Ooi & Chong, 2011),
- abundance and composition in relation to seasonality, diel cycle or tidal cycle (Hickford, 2000; Barletta-Bergan *et al*., 2002a; Hernández-Miranda *et al*., 2003; Strydom & Wooldridge, 2005; Ramos, *et al*., 2006; Bonecker *et al*., 2009; Moyano *et al*., 2009; Hanel *et al*., 2010; Álvarez *et al*., 2012; Chen *et al*., 2014; Ricardo *et al*., 2014),
- detecting habitats for settlement (Atema *et al*., 2002; Lecchini *et al*., 2005; Gerlach *et al*., 2007; Radford *et al*., 2012),
- factors of recruitment into estuaries and estuarine use (Strydom, 2003a; Comerford & Brophy, 2012; Primo *et al*., 2013; Pattrick & Strydom, 2014b),

- trialling sampling methods (Strydom, 2003b, 2006; Gyekis *et al*., 2006; Neal *et al*., 2012;),
- light sensitivity and vertical zonation (Job & Bellwood, 2000; Mueller & Neuhauss, 2010), and
- foraging ecology (Nunn *et al*., 2011).

Most larval fish studies have been focused on tropical regions. Studies on temperate ecosystems such as waters around New Zealand are less abundant. A workshop proceedings presenting studies performed in temperate Australia (largely in Southern Queensland and New South Wales (Hancock, 1992)) was very useful as a rare source of information. These studies looked at spatial and temporal distribution, tidal and diel distribution, species composition, seasonal variation, growth rates, age and diet of larvae (Hancock, 1992).

## 1.6 New Zealand

A number of studies have examined aspects of larval fish ecology and biology in New Zealand. The effects of seasonality, the vertical and horizontal distribution patterns, and age and growth of larval fish are relatively well studied in coastal waters (Hickford, 2000). In contrast, few studies have examined pre-settlement larvae and how they use estuaries (Hickford, 2000).

Only 99 of the approximately 1000 species of fish in New Zealand waters are known in their larval form (Dolphin, 1997). The majority of the studies on larval fish in New Zealand have taken place around the northeastern North Island, Wellington Harbour or around Kaikoura and the Otago Peninsula in the South Island (Table 1.1). A number of unpublished Theses that provide information on the identification of larval fish in New Zealand are also listed in Table 1.1. Table 1.2 gives a summary of the spawning times of species that are thought to be found in Tauranga Harbour as adults or larvae. The majority of species in Table 1.2 spawn in the spring and summer months.

Table 1.1: List of studies on larval fish undertaken in New Zealand

| Region | Type of study | Reference(s) |
|---|---|---|
| Northeastern North Island | Seasonality | Thompson (1983)<br>Kingsford (1986)<br>Roper (1986) |
| | Vertical distribution patterns | Kingsford (1986)<br>Kingsford and Choat (1986)<br>Kingsford and Milicich (1987) |
| | Horizontal distributions | Crossland (1980, 1981, 1982)<br>Kingsford (1986)<br>Cole (1987)<br>Kingsford and Choat (1989)<br>Tricklebank *et al*. (1992) |
| | Age & growth | Kingsford (1980)<br>Park (1984)<br>Milicich (1986)<br>Atkinson (1987)<br>Kingsford and Milicich (1987) |
| | Descriptive | Thompson (1983)<br>Kingsford (1986) |
| | Onshore transport | Kingsford (1986)<br>Kingsford and Choat (1986) |
| North Island – Hauraki Gulf | Distribution & seasonality | Crossland (1981, 1982) |
| North Island – Wellington Harbour | Descriptive | Elder (1966)<br>Frentzos (1980)<br>Keith (2000) |
| South Island – Otago Peninsula | Descriptive | Anderton (1906)<br>Graham (1939, 1956) |
| | Seasonality | Robertson & Raj (1971)<br>Robertson (1973, 1975a, 1975b, 1976, 1978, 1980, 1981) |

| | | |
|---|---|---|
| South Island – Kaikoura Peninsula | Horizontal and vertical distribution | Hickford (2000) |
| | Descriptive | Dolphin (1997) |
| South Island – Chatham Rise | Seasonality | Robertson (1976, 1978)<br>Robertson *et al*. (1978)<br>Robertson & Mito (1979) |

Table 1.2: Spawning calendar of species that may be found as adults or larvae in Tauranga Harbour. Modified from Crossland (1981); Neira, *et al*. (1998).

| Species | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Anchovy *Engraulis australis* | ■ | ■ | ■ | | | | | | ■ | ■ | ■ | ■ |
| Pilchard *Sardinops sagax* | | | | | | | | | | ■ | ■ | ■ |
| Gurnard *Chelidonichthys kumu* | ■ | | | | | | | | | ■ | ■ | ■ |
| Jack mackerel *Trachurus novaezelandiae* | ■ | ■ | | | | | | | | ■ | ■ | ■ |
| Jack mackerel *Trachurus declivis* | ■ | ■ | | | | | | | | | ■ | ■ |
| Bigbelly seahorse *Hippocampus abdominalis* | ■ | ■ | | | | | | | | | ■ | ■ |
| Parore *Girella tricuspidata* | ■ | ■ | ■ | | | | | ■ | ■ | ■ | ■ | ■ |
| Snapper *Pagrus auratus* | ■ | | | | | | | | | ■ | ■ | ■ |
| Spotted stargazer *Genyagnus monopterygius* | | | | | | | | | | ■ | ■ | |
| Flounder *Rhombosolea plebeian* | | | | | | | | | | ■ | ■ | ■ |
| Leatherjacket *Meuschenia scaber* | | | | | | | | | | ■ | ■ | ■ |
| Kingfish *Seriola lalandi* | ■ | | | | | | | | | | ■ | ■ |
| Blue warehou *Seriolella brama* | | | | | | | ■ | ■ | ■ | ■ | | |

## 1.7 Research gaps

In New Zealand and in particular, the Bay of Plenty, there is a distinct lack of information on the composition of larval fish communities and how different species use estuaries as a habitat. Further research would be useful in determining how larval fish use estuaries in New Zealand. Knowing how larval fish use different habitats that are found within estuaries (e.g. mangroves and seagrass) can provide knowledge on areas that are important nursery habitats, outlining possible areas that could need protection. More in-depth research on the temporal and spatial distribution of larvae could prove useful for managing fish stocks. The information on larval fish for both estuarine and oceanic species is inadequate for the majority of the New Zealand coastline. Using other methods such as light traps or plankton tow nets to capture larval fish could show different results, with some methods possibly suited better to catching different species. It would also be useful to know how different man-made structures are used by larvae at varying times of the year and in different locations.

New Zealand is lacking a comprehensive identification guide that covers all of the larval species known in New Zealand waters. A guide covering the identification of 15 species from nine orders was written as part of a special topic paper in 2014 by the author (see Appendix I). The guide also outlines resources that can be used for the identification of species not included in the guide.

## 1.8 Purpose of research

A pilot study completed in 2013 trialled different methods of catching larval fish, and developed the skills needed for identification of the larvae caught. The purpose of the research in this thesis is to further understand how larval fish use Tauranga Harbour.

This question will be addressed through three components of the study:

**Part 1** is to investigate at the movement of larval fish over tidal and diel cycles. Trnski (2001) found that for most fish species there was no difference in the

abundance of larval fish between the flood or ebb tides, irrespective of whether they were of marine or estuarine origins.

This part of the research will investigate:

- What species of larval fish are found within Tauranga Harbour,
- If larval fish are found in higher abundances at day or at night,
- If larvae are found in higher abundances on the flood or ebb tides, and
- If larvae are found in higher abundances in a particular part of the tide (start, middle, end).

This research will test the hypotheses that a range of species will be found, and that larvae will be found in higher abundances during the flood tides and at night.

**Part 2** examines the temporal distribution of larval fish over the course of a year. Hickford (2000) found that there was a seasonal variation in the abundance and distribution of fish larvae off the Kaikoura coast.

This part of the research will investigate:

- Which larval fish species are present in Tauranga Harbour,
- Does seasonality have an effect on the abundance of larval fish, and
- Is the abundance of larvae affected by environmental variables.

It is hypothesised that a range of species would be found, that larvae would be found in higher abundances over summer when the water temperature is warmer.

**Part 3** examines the use of olfaction in larval fish to assess if a preference for a certain water type exists. Larvae are known to use environmental cues to select suitable settlement habitats (Kingsford *et al*., 2002; Huijbers *et al*., 2008), and it is thought that olfaction is the sense primarily responsible for locating settlement habitats (James *et al*., 2008; Coppock *et al*., 2013).

This part of the research will investigate:

- If larval fish are able to differentiate between water from different origins (oceanic or estuarine), and
- If the larvae show a preference for/avoidance of a particular water type.

It is hypothesised that the larvae would not be attracted to the estuarine water.

## 1.9 Sampling site – Tauranga harbour

Tauranga Harbour (37°38'0"S 176°05'0"E) is situated on the northeast coast of the North Island in the Bay of Plenty. It is one of New Zealand's largest natural harbours covering 218 $km^2$ (Figure 1.3 & 1.4). The harbour is largely shallow (< 10 m deep) (Ellis *et al*., 2013) and during low tide over 60% of the harbour is very shallow or dry (Britton *et al*., 2008). The southern entrance is 36 m deep, and the deepest part within the harbour is 15.5 m. The catchment for the harbour is about 1,300 $km^2$ and home to over 100,000 people (Lawrie, 2006). The majority of the catchment is pasture (39%) and indigenous forest (38%), with only 1% of the catchment as wetlands. The harbour receives freshwater inflows that originate in the Kaimai-Mamaku ranges (Sinner *et al*., 2011). Tauranga Harbour is home to many habitats including saltmarsh, mangroves, mudflats, seagrass, tidal channels and rocky reefs (Bay of Plenty Regional Council, 2014). Sedimentation in Tauranga Harbour has increased over the years due to land use changes, population growth and soil disturbance during development (Bay of Plenty Regional Council, 2015). The water temperature ranges from 15 – 21.2 °C.

The harbour has two entrances, the northern entrance at Otawhiwhi (Bowentown) and the southern at Mauao (Mt Maunganui). The harbour contains two marinas with a total of 1050 berths, along with 380 swing moorings, and 25 boat ramps. It is home to the Port of Tauranga, New Zealand's largest export port by shipping volume (Environment Bay Of Plenty, 2009). The tidal flow through the southern entrance to the harbour reaches four knots, while at the northern entrance it reaches up to seven knots (Sinner, *et al*., 2011). The tidal range of the harbour is 1.59 m at spring tide (Environment Bay of Plenty, 2007).

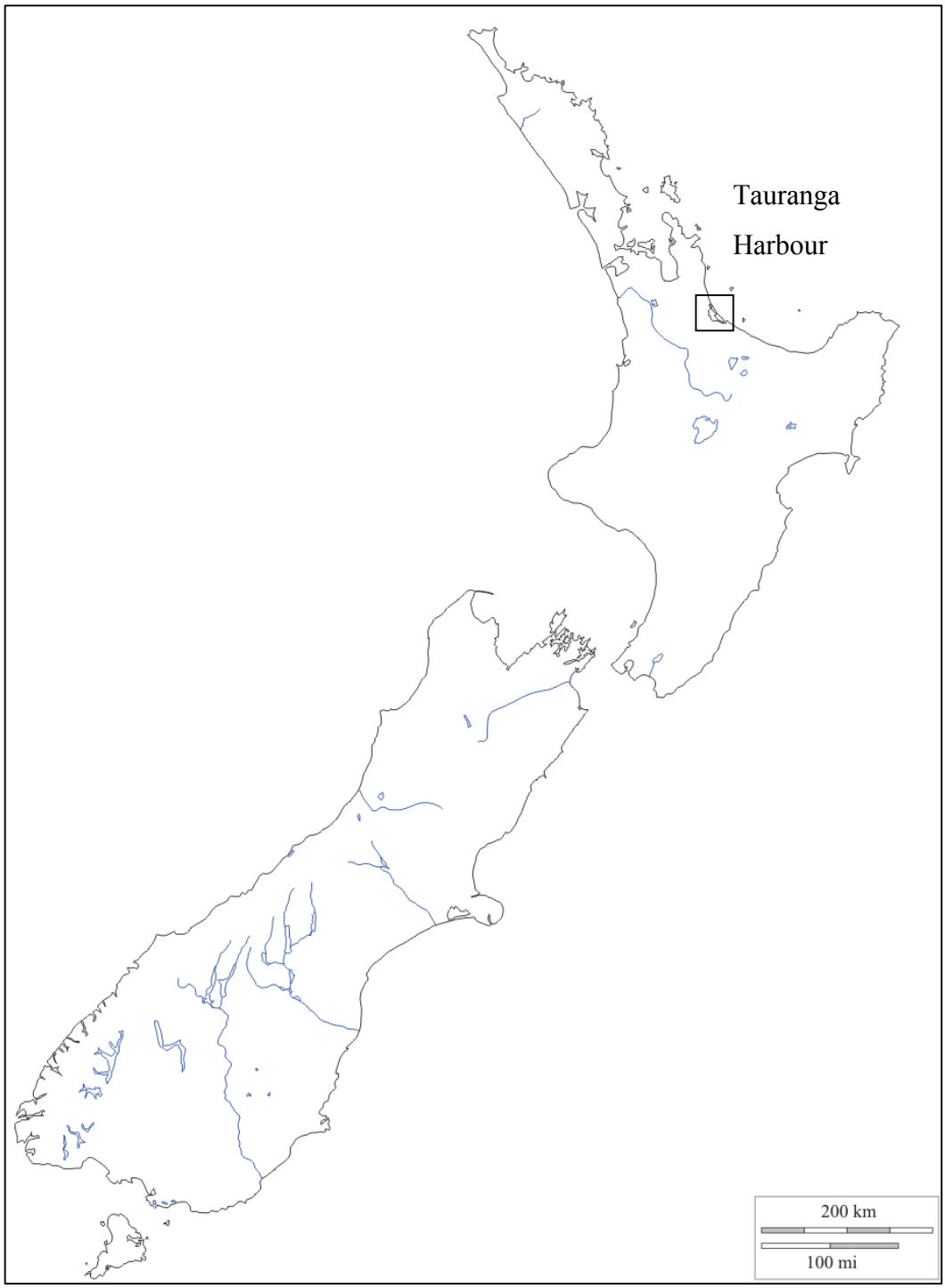



Figure 1.3: Map showing the location of Tauranga Harbour (black box) in New Zealand.

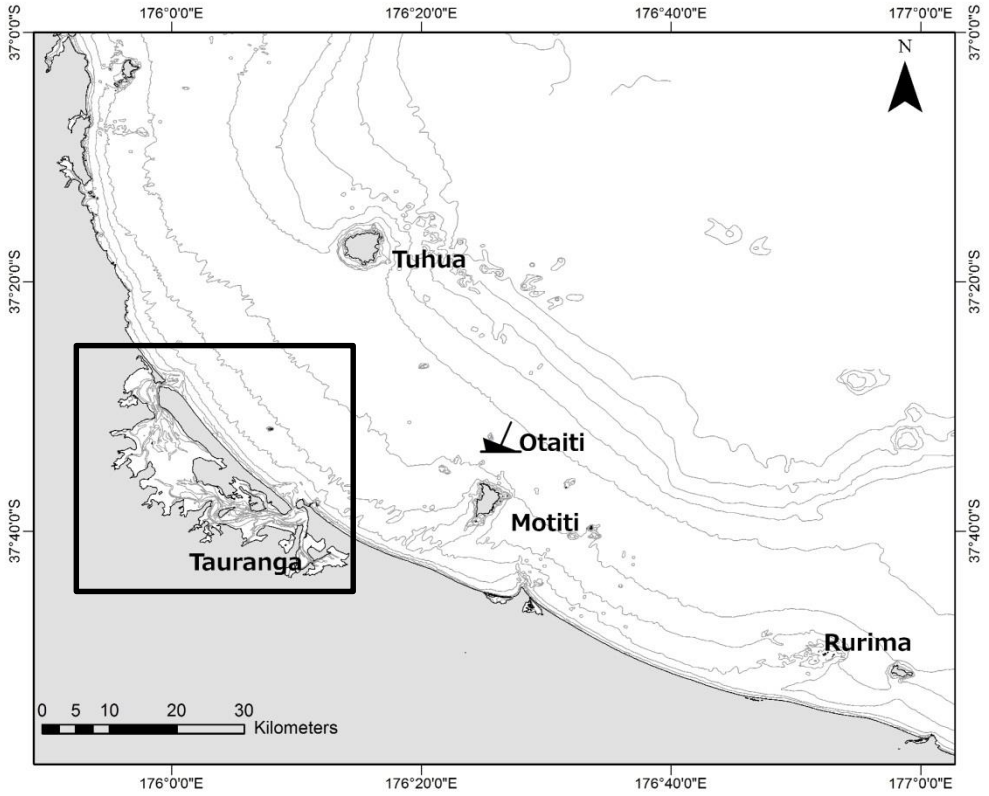



Figure 1.4: Map of the Bay of Plenty, with Tauranga Harbour shown in the box.

The Tauranga Bridge Marina (known henceforth as Bridge Marina) is situated close to the channel entrance of the southeastern estuarine network (Figure 1.5) of the harbour. The channel is 600 m wide and 4.4 m deep in the centre. The flow through the channel is tidally driven; semi-diurnal with a tidal range of -0.1 – 2.1 m. To the north of the Bridge Marina is Stella Passage which is dredged to 12.9 m to allow ships into the Port of Tauranga. To the south is Town Reach which not dredged and is 5.2 m in depth. The Bridge Marina is built with floating pontoons and is not enclosed by sea walls meaning that water is tidal and is able to flow through the channel largely unhindered.

Figure 1.5: Photo showing Tauranga Bridge Marina (bottom right), and the southern entrance to the harbour between Matakana Island and Mauao (top left). From Sunlive (2015).

## 1.10 Permits and ethics

Larval fish are collected under the Ministry for Primary Industries Special Permit 560 for the University of Waikato Client number 8770024.

Larval kingfish were transported under a transfer permit from NIWA.

Under section 3.1 (4) (ii) in the Code of Ethical Conduct for the Use of Animals for Research, Testing and Teaching, approval from the animal ethics committee was not required as the animals used for experimentation were larval, and not considered “animals” for the purposes of research.

# Chapter 2 –Tidal and diel abundance of larval fish in an estuary channel in Tauranga Harbour, New Zealand

## 2.1 Introduction

Estuaries are known to act as important nursery areas for fish, both in New Zealand (Francis *et al*., 2005) and internationally (Beck *et al*., 2001; Martinho *et al*., 2007; Pattrick & Strydom, 2014a), on account of their high food availability and relative protection from predators (Martinho *et al*., 2007). Despite these qualities, fish biodiversity in estuarine systems is generally low, possibly due to the unpredictable nature of estuarine environments which makes them best suited to species that function as generalists (Costanza *et al*., 1997b). Estuaries in New Zealand provide a wide range of habitats including mangroves forests, mudflats, seagrass beds and open water. Mangroves are utilised by many species of fish as a nursery in tropical (Barletta-Bergan *et al*., 2002b; Dorenbosch *et al*., 2004) and subtropical regions (Bloomfield & Gillanders, 2005; Ricardo *et al*., 2014), as they provide protection from predators and have an increased availability of food compared to seagrass beds and other estuarine habitats (Laegdsgaard & Johnson, 2001). This range of available habitats, coupled with the ready availability of food and protection from predators, contribute to making estuaries ideal nursery grounds for fish. Most species of marine fish spawn in coastal waters (Beckley, 1985), even those that occupy estuaries as adults. For these species, to complete their lifecycle, their larvae must move from coastal or off-shore spawning grounds to estuarine nursery grounds (Islam *et al*., 2007; Pattrick & Strydom, 2014a).

Transport of larval life stages is determined by a range of physical and biological processes. Physical processes include the oceanography and climate of an area, for instance, tides, currents, eddies, frontal systems, gyres and jets, wind driven currents and other parameters such as water temperature and chemistry (Norcross & Shaw, 1984; Hernández-Miranda, *et al*., 2003; Pattrick & Strydom, 2014b). Important biological factors include environmental preferences, seasonal suitability, spawning behaviour, behaviour of adults and larvae, larval duration, food availability and predator effects (Norcross & Shaw, 1984; Leis, 2009;

Pattrick & Strydom, 2014b). For larvae within an estuary factors that affect the dynamics of circulation, and therefore distribution of larval fish, also include river flow, tide, wind, coastal ocean non-tidal forcing and circulation induced by the topography of the estuary (Norcross & Shaw, 1984).

The larvae can be carried by active or passive transport (Norcross & Shaw, 1984; Neira & Potter, 1992; Trnski, 2001), active transport via swimming or passive transport with currents (Beckley, 1985). Larval fish may use various strategies to control their position within or around estuaries. As the current speed of the water moving out of the estuary generally exceeds the swimming speed of larvae, the larvae from outside the estuary must use a variety of strategies to gain access to the nursery grounds (Forward *et al*., 1999; Islam *et al*., 2007), while larvae already in the estuary utilise alternative techniques to remain within the nursery grounds (Boehlert & Mundy, 1988). These strategies can include; selective tidal stream transport; displacement by major currents (Pattrick & Strydom, 2014a), vertical migration, moving between incoming and outgoing currents, or remaining in an area with no net water movement (Kunze *et al*., 2013). Moving between different currents can assist their move upstream or downstream (Trnski, 2001). The term 'selective tidal stream transport' is given to the process where during the flood tide, the larvae ascend in the water column, and during the ebb tide they descend to the bottom (Islam *et al*., 2007; Pattrick & Strydom, 2014a). By using these strategies, the larvae can maintain their position within the estuary, or can move in or out of the estuary.

It is reported that the estuarine-dependent larvae of the marine-spawned species are more abundant on flood tides as they enter the estuary, while larvae that are spawned within the estuary are found in higher abundances on the ebb tide (Trnski, 2001; Pattrick & Strydom, 2014a). In order to reduce export from the estuary for the early life stages of resident estuarine species, the eggs are often large and demersal, and the larval stage brief (Boehlert & Mundy, 1988). Species with pelagic eggs generally spawn in the upper reaches of the estuary with the aim of preventing the larvae being swept out to sea on an ebb tide (Suthers, 2009).

Tidal and diel cycles are the main environmental cycles that affect activity in fish (Strydom & Wooldridge, 2005). Larval fish are known to perform diel vertical migration (Haldorson *et al*., 1993) and vertical migrations based on tidal phase, such as selective tidal stream transport (Boehlert & Mundy, 1988; Pattrick & Strydom, 2014a). The typical diel vertical migration behavioural pattern shows organisms at depth during the day to avoid predation and in surface waters at night for feeding (Ospina-Alvarez *et al*., 2012) or until the light levels become too low for feeding to be successful (Haldorson *et al*., 1993). These behaviours can also control the depth to which larvae migrate (Job & Bellwood, 2000). Diel vertical migrations are exhibited by larval fish, which are often known to be more abundant at night (Pattrick & Strydom, 2014a; Trnski, 2001). Tidally timed vertical migrations can be used to move upstream or downstream, depending on the larval stage and the species (Queiroga, 1998). Jager (1999) states that larvae sink in the water column when the water is moving at a low velocity and, when the water velocity increases, are redispersed in the water column, a form of advective tidal transport. Other factors can influence vertical migrations, such as stratification of the estuary, oxygen, temperature or predator/prey distributions (Norcross & Shaw, 1984), but these are less studied in comparison to diel vertical migration and selective tidal stream transport. Strategies involving tidal and diel cycles often influence a greater success of recruitment and enhance the ability of larval and juvenile fish to remain within an estuary (Pattrick & Strydom, 2014a).

Tauranga Harbour is the largest estuary in the Bay of Plenty, and one of the largest estuaries in New Zealand (Lawrie, 2006). Although we know it is occupied by a range of recreationally and commercially important fish species there is little information available about the value of Tauranga Harbour as a nursery habitat for larval life stages. The aims of this study are to investigate what species use the harbour in the larval stage of their life cycle, whether these larvae exhibit tidal related distributions that facilitate their export or retention within the estuary, and whether their diel patterns are similar those exhibited by fish elsewhere. It was hypothesised that a range of species would be found within the harbour, that larvae would be found in the water column during flood tides to enhance retention within the estuary, and that larvae would be found in higher abundances in the surface waters at night.

## 2.2 Methods

### 2.2.1 Study site

The Bridge Marina (37°40'08.3"S 176°10'36.2"E) (Figure 2.1) was selected as the sampling location for this research as it provided access to mid-channel waters without requiring the use of a boat.

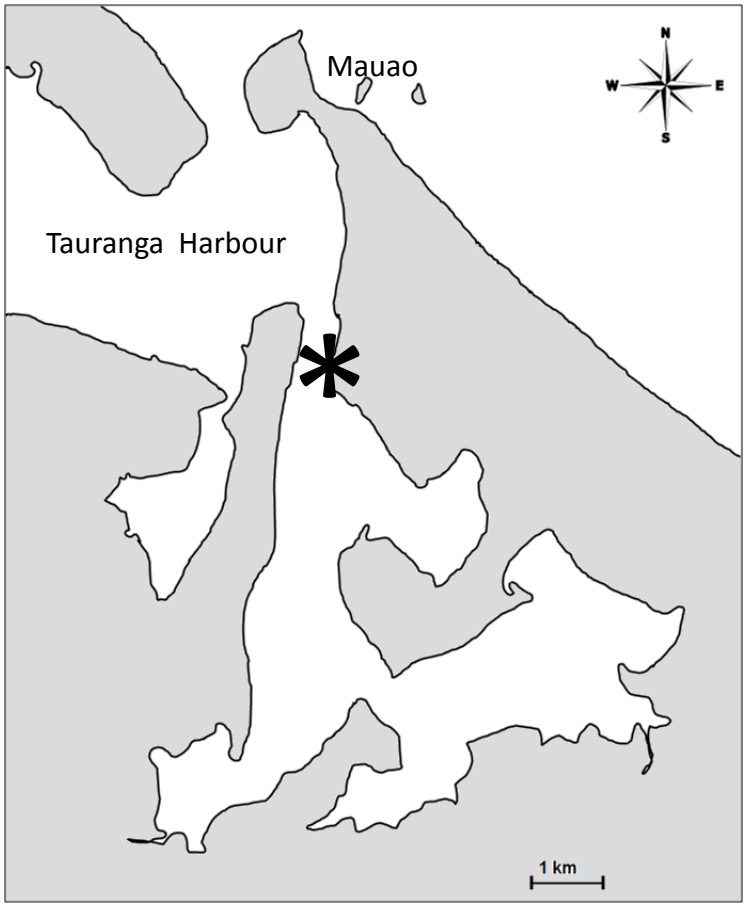



Figure 2.1: Location of the sampling site (shown by the asterix) in Tauranga Harbour.

### 2.2.2 Sampling

To assess the tidal and diel variability of larval fish abundance within the entrance channel to the southeastern estuary network, intensive plankton sampling was conducted using a stationary channel net. The dimensions of the net mouth were 1 m by 2 m. The net was 5 m long with a mesh size of 0.8 mm (Figures 2.2 and 2.3). The net was deployed from a mast and boom system that was strapped to a pontoon pile of 33 cm diameter. This configuration allowed the net to be positioned approximately 1 m from the edge of the pontoon (Figure 2.4). The

mast was attached to a pile on the end of A-pier at high tide. The boom allowed the net to be raised and lowered over both incoming and outgoing tides. Two orange floats were attached to the top of the net to keep the top of the net level with the surface of the water. The end of the net was a PVC tube of 17 cm diameter. A removable canvas and mesh cod-end piece was attached to the PVC tube with hose clamps. The net was able to be rotated 180 degrees allowing for sampling of both the incoming and outgoing tides.

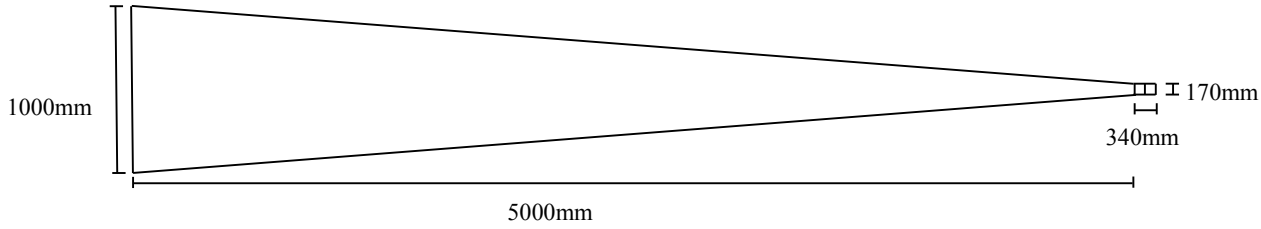



Figure 2.2: Diagram showing the dimensions of the channel net and cod end piece (side view).

Figure 2.3: Channel net in the water.

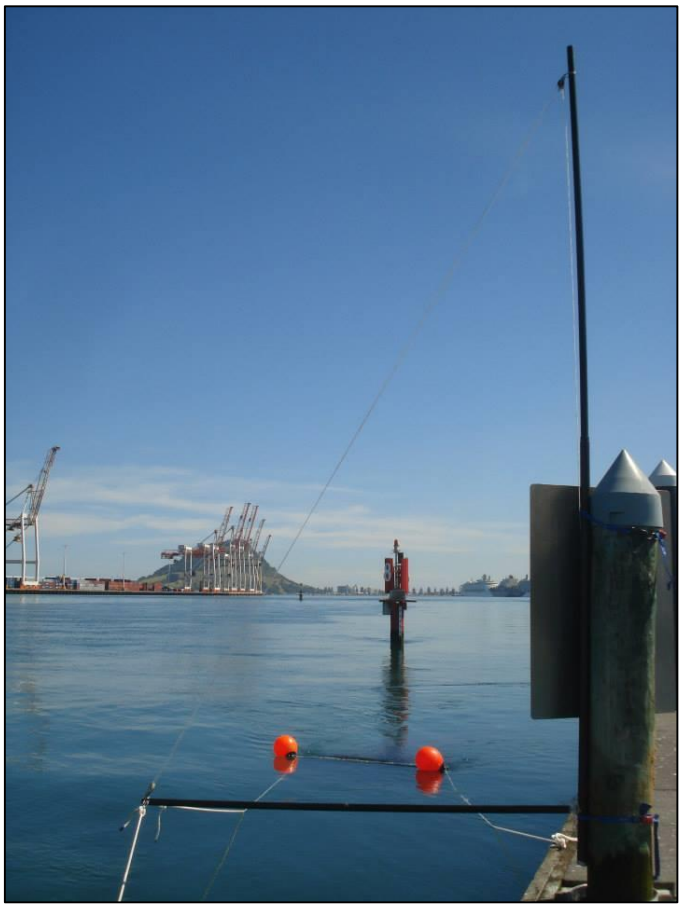


Figure 2.4: Photo showing the mast and boom set up with the net sampling the outgoing tide.

A flow meter (General Oceanics, Inc., mechanical flowmeter model 2030 series) was positioned across the mouth of the net so it sat in the centre (Figure 2.5). A reading was taken from the flowmeter before the net was placed in the water, and when the net was pulled out. The difference in the readings was recorded as 'distance in counts' and used in the following calculations to work out the speed and volume of water that passed through the net.

A. DISTANCE in metres = $\frac{Distance\ in\ COUNTS \times Rotor\ constant\ (26837)}{999{,}999}$

B. SPEED in m/sec = $\frac{Distance\ in\ metres}{Time\ in\ seconds}$

C. VOLUME in cubic metres = $Net\ mouth\ area\ \times distance\ in\ metres$

Figure 2.5: Photo showing the position of the flowmeter in the mouth of the net.

Four 48-hour time periods (48-h series) were chosen in December 2013 and January 2014 for larval fish sampling. The dates were 9-11 and 16-18 December and 7-9 and 14-16 January. Sampling days were selected aiming to have individual tides falling either entirely during the day or night, however due to the low hours of darkness in this peak summer period; this was not always possible. Four full tidal cycles were sampled during each of the four 48-h series.

Over the course of each of the flood or ebb tides, one to seven plankton samples were taken, with an average of 4.58 samples. Efforts were made to sample the water column during early, middle and late periods of each ebb or flood tide. The objective was to sample a target volume of 1000 $m^3$ per sample by altering the soak time of the net in accordance with water flows following the methods of Trnski (2001), who had a target volume of 500 $m^3$. The sampling times were estimated with longer fishing times at the start and end of the tide when the current speed was lower, and shorter fishing times during the peak of the tide, in an attempt to fish the target volume of water for each sample. The two 48-h series in December ran with minimal problems, and had mean volumes of close to the target of 1000 $m^3$.

Unfortunately, a number of unanticipated challenges meant the mean volumes during January were not close to the target volume. During early January, large amounts of sea lettuce and salps present in the water column would quickly fill the net, meaning it was no longer fishing effectively. This meant that the net could not be left down for the allocated times due to the net clogging. These effects were most apparent at the beginning of the outgoing tide, and the middle to end of the incoming tide, as this is when sea lettuce and salps were most highly represented in the water column. Shorter sampling times were adopted in an attempt to remedy this problem. The early samples were taken at least one hour after the slack tide. The middle samples were taken during the peak flow of the tide. The end samples were timed so the net was removed from the water before slack tide. Sampling times ranged from 3 minutes to 60 minutes, with an average sampling time of 23.65 minutes. Table 2.1 shows a summary of the sample volumes over the four 48-h series. Across all samples, the mean volume was 819.8 $m^3$ which was not significantly different to the target of 1000 $m^3$. However, the actual sample volumes ranged greatly, from 20.83 $m^3$ to 6115.3 $m^3$. An average of 37.75 samples were taken in each 48-h series (min 22, max 44), with an overall total of 151 samples. The third series also had the highest tidal and largest current range of those sampled, which could account for the high mean volume sampled. A total of 22 samples were taken during this series compared to the other three series which ranged from 41-44 samples. The final series had the shortest sampling times (3-36 minutes), resulting in the lower mean volume. Water temperature ranged from 16.3°C to 25.88°C over the sampling period.

Table 2.1**:** Summary of sampling date, time, volume filtered, current speed and tidal range. 'Start time' is the beginning of the first sample, 'End time' is the end of the last sample within each 48-h period.

| 48-h series | Date | Start time | End time | Volume, $m^3$ mean (s.d.) | Current range (cm $s^{-1}$) | Tidal range (m) |
|---|---|---|---|---|---|---|
| 1 | 9-11 Dec | 0743 | 0815 | 1391 (744.9) | 7.5-82.5 | 0.1-1.9 |
| 2 | 16-18 Dec | 0815 | 0820 | 1178 (400.5) | 2.3-48.5 | 0.3-1.8 |
| 3 | 7-9 Jan | 0725 | 1120 | 1521 (1372.4) | 0.4-169.9 | 0.1-2.0 |
| 4 | 14-16 Jan | 0823 | 0810 | 428 (220.9) | 2.8-61.6 | 0.3-1.7 |

Following each sampling time, the cod end was emptied into a 20L bucket, and the contents transferred to 1L plastic jars. Samples were sorted on the pier during the day, and night samples were refrigerated and then sorted the next day in the lab at the University of Waikato Coastal Marine Field Station. Samples were sorted by spreading out the contents of each jar on blue trays; larval fish were removed with forceps and transferred to 50 mL pottles containing 70% ethanol. Each pottle was labelled externally with the corresponding sample code and also had a waterproof label placed inside. Pottles were placed in a cardboard box as protection from sunlight and stored for subsequent identification.

After the 48-h series were completed, the larval fish from each sample were identified under a stereomicroscope using key meristic characteristics of body shape, relative position of fins, counts of fin rays and myomeres and pigmentation. Identification was completed by the aid of both unpublished and published identification guides including those by Neira *et al*. (1998) and Leis & Trnski (1989).

### 2.2.3 Data analysis

The larval fish density for each sample was standardised to the number of larvae per 500 $m^3$. The integrated concentration of larvae for each tide was represented by the mean of the within tide samples (1-7 samples per tide). This was used as the unit of replication. A multidimensional scaling (MDS) and cluster analysis was performed using STATISTICA 12 on the integrated concentrations of all species of the four tide types (day ebb, day flood, night ebb, night flood).

Further analysis was undertaken for the most common taxa. Taxa were considered common if they made up more than 10% of the total catch, or were found in each of the 48-h series and had at least one integrated concentration value greater than 1.0 per 500 $m^3$. Two-way ANOVAs were used to test the statistical significance of the tidal and diel variables on the density of common taxa. Data were tested for homogeneity of variances using Cochran's test prior to ANOVA, however not all data met the assumptions of the ANOVAs, and a variety of transformations were not able to make some data sets homogenous due to the low numbers of larvae caught. Using Microsoft Excel the densities of all species and seven common taxa

were plotted against the flood and ebb tides for the day and night. Densities of larvae per 500 $m^3$ for common taxa were plotted against tidal cycles to show when larvae were present during the tide.

## 2.3 Results

A total of ~154,300 $m^3$ of water was filtered, which collected 2337 larvae of at least 19 species of fish in 18 families. Of these, 11 taxa were assigned to identifiable species, two to genus and six to family (Table 2.2).

The anchovy *Engraulis australis* was the most abundant and common species, representing 45.48% of the 2337 larvae collected, with 29 occurrences out of a possible 33 tides. Other abundant taxa were the families Gobiidae (23.65%, 22 tidal occurrences), Tripterygiidae (10.16% 9 occurrences), and pipefish *Stigmatopora macropterygia* (5.76%, 24 occurrences). The remaining identified taxa represent 9.13% of the total catch, with 2.91% remaining unidentified.

None of the identified taxa were present in every tide sampled. The closest was *E. australis*, which was absent from only four random daytime tides of the 33 sampled. The Clupeids, smelt *Retropinna retropinna,* Gobiesocids, piper *Hyporhamphus ihi*, and *Trachurus* sp. were found in low abundances (<5% of the total larvae caught) over a quarter or more of the tides. Six taxa were rarely found, with only one specimen each of stargazer *Leptoscopus macropygus,* leatherjacket *Meuschenia scaber* and a Congrid, and two specimens of snapper *Pagrus auratus*, oyster blenny *Omobranchus anolius*, and gurnard *Chelidonichthys kumu,* found over the entire sampling period.

Table 2.2: Summary of larval fish collected from Bridge Marina during four 48-h series of sampling. The *Max* is the highest integrated concentration recorded within a tide. The number of occurrences out of a total of 33 possible tides is in the right column.

| Family | Taxon | % of total | *Max* | Occurrences |
|---|---|---|---|---|
| Unidentified | | 2.91 | 5.56 | 14 |
| Syngnathidae | *Stigmatopora macropterygia* Pipefish | 5.76 | 3.17 | 24 |
| | *Lissocampus filum* Sea horse | 0.18 | 0.73 | 4 |
| Clupeidae | | 2.8 | 3.04 | 10 |
| Engraulidae | *Engraulis australis* Anchovy | 45.48 | 51.36 | 29 |
| Retropinnidae | *Retropinna retropinna* Smelt | 4.04 | 12.63 | 12 |
| Gobiesocidae | Clingfish | 0.86 | 2.01 | 13 |
| Hemiramphidae | *Hyporhamphus ihi* Piper | 0.68 | 1.11 | 9 |
| Tripterygiidae | Triplefin | 10.26 | 11.00 | 9 |
| Creediidae | *Limnichthys* sp. | 0.23 | 0.62 | 3 |
| Carangidae | *Trachurus* sp. Mackerel | 1.13 | 1.37 | 9 |
| Kyphosidae | *Girella tricuspidata* Parore | 0.95 | 18.70 | 3 |
| Sparidae | *Pagrus auratus* Snapper | 0.09 | 2.18 | 2 |
| Labridae | | 0.64 | 1.00 | 5 |
| Gobiidae | | 23.65 | 48.13 | 22 |
| Blenniidae | *Omobranchus anolius* Oyster blenny | 0.09 | 4.96 | 2 |
| Leptoscopidae | *Leptoscopus macropygus* Stargazer | 0.05 | 0.31 | 1 |
| Triglidae | *Chelidonichthys kumu* Gurnard | 0.09 | 0.88 | 2 |
| Monacanthidae | *Meuschenia scaber* Leatherjacket | 0.05 | 0.43 | 1 |
| Congridae | | 0.05 | 0.66 | 1 |

Higher densities of larval fish (P=0.012) were present in the water column at night compared to the densities of larval fish present during the day (Figure 2.6, Table 2.3). No statistical difference was found between the densities found on the flood and ebb tides, however, a significant difference (P=0.028) was found for the densities of larval fish during the day and night on the ebb tide.

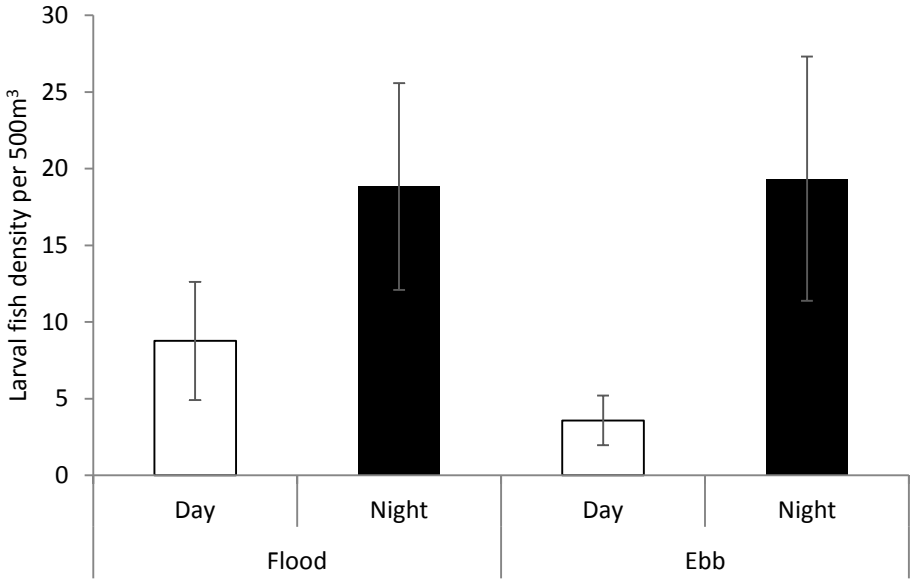



Figure 2.6: Mean larval fish density (±SE) over the flood and ebb tides during the day and night. Higher densities were present at night compared to the day.

Table 2.3: Summary of ANOVA p-values for the densities of larval fish of all species. Tide refers to the flood and ebb tides, diel refers to day and night. Statistically significant values are in bold.

| Tide (T) | Diel (D) | Flood × D | Ebb × D | Day × T | Night × T |
|---|---|---|---|---|---|
| 0.464 | **0.012** | 0.202 | **0.028** | 0.226 | 0.962 |

Figure 2.7 shows the densities of larval fish in relation to the tidal phase over the four 48-h series. A pattern is visible indicating a higher density of larval fish during the slack low tide. Higher numbers of larvae were found during the January sampling.

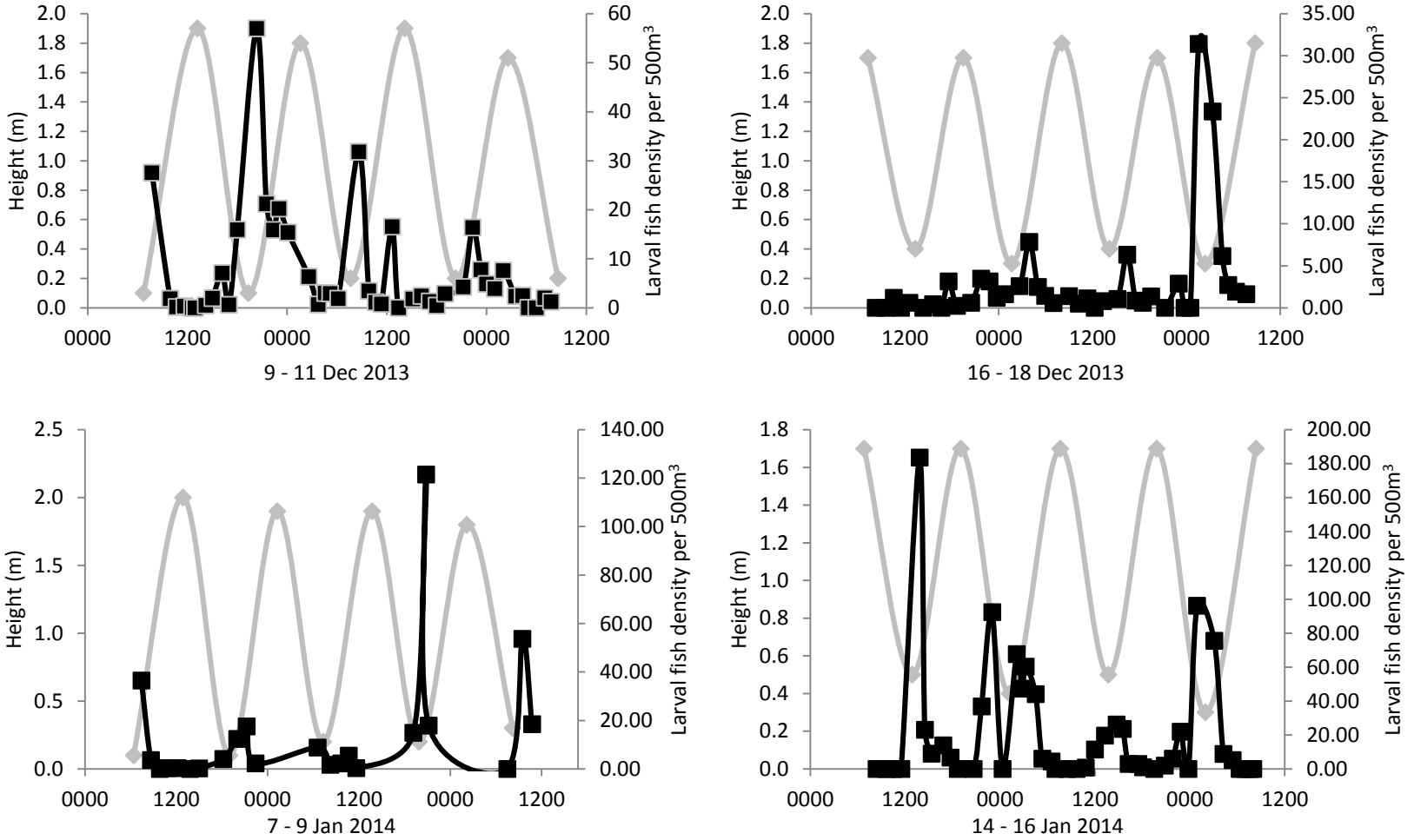
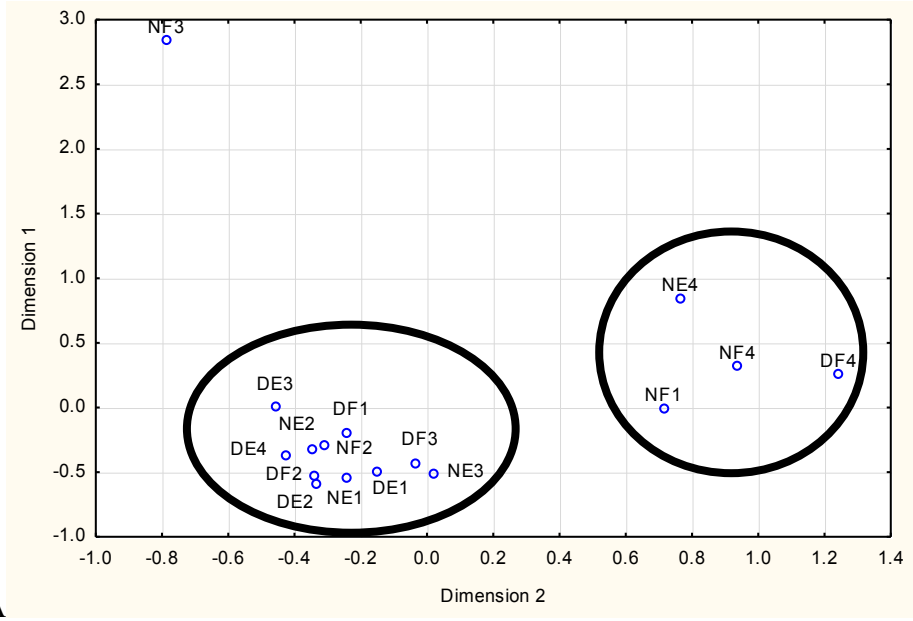
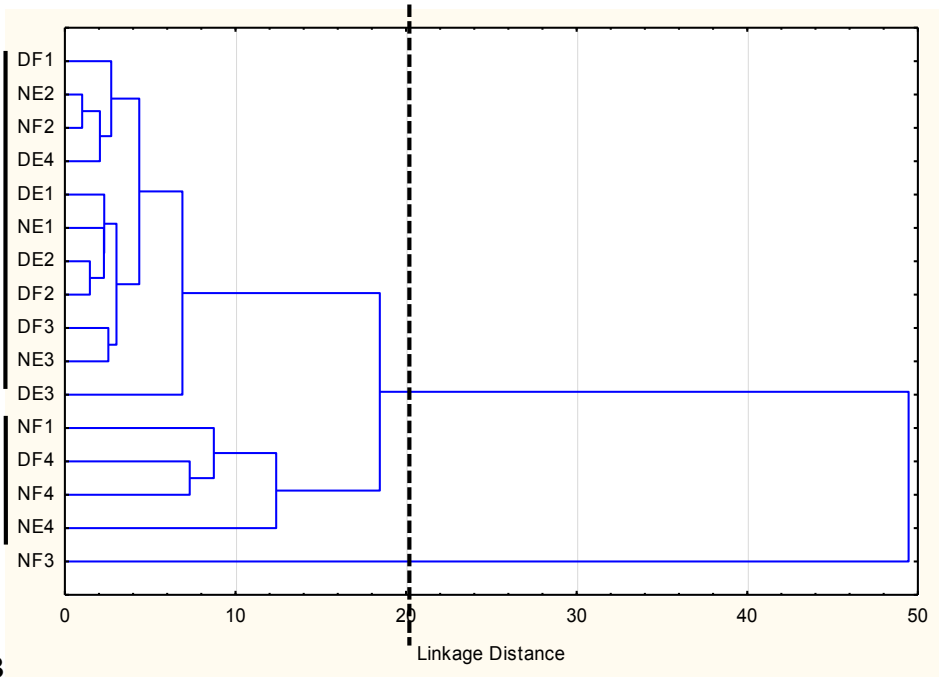



Figure 2.7: Tidal phases of the four 48-h series showing the density of larval fish. Grey represents the tidal phase, while black is the density of larvae per 500 $m^3$.

The integrated concentrations of all larvae across the 33 tides were used to create an MDS and cluster analysis (Figure 2.8). Two groups were formed. Group I consisted mainly of samples from the first three 48-h series, and group II was predominantly made of samples from the fourth 48-h series. The sample NF3 was dissimilar to the other samples and not closely linked to either of the two groups due to having much higher concentrations of larvae present in each of the tides.




A




B

I

II

Figure 2.8: Integrated concentrations of fish larvae from Tauranga Harbour during 33 tides in four 48-h series. A) shows the results of a two-dimensional ordination (stress = 0.0000046) and B) a cluster analysis. The codes represent time of day (D, day; N, night), tidal phase (E, ebb; F, flood) and series number (1-4).

### 2.3.1 Abundance of common taxa

The seven most common taxa found were *E. australis*, Gobiidae, Tripterygiidae, *R. retropinna*, *H. ihi*, *S. macropterygia* and Gobiesocidae. The *E. australis*, Gobiidae and Tripterygiidae each formed more than 10% of the total catch, while *E. australis*, Gobiidae, *R. retropinna*, *H. ihi*, *S. macropterygia* and Gobiesocidae were found in each of the 48-h series and had at least one integrated concentration value greater than 1.0 per 500 $m^3$. Figures 2.9 – 2.15 show the mean density of the common taxa over the day and night on the flood and ebb tides.

While most of the common taxa appeared to be found in higher densities on the tides at night compared to the tides during the day, only two of the seven common taxa, *E. australis* (Figure 2.9) and *H. ihi* (Figure 2.14) had significantly different densities between day and night (Table 2.4), with higher abundances found at night (P=0.047 and 0.002, respectively). None of the common taxa differed with tide phase, and no interactions were found between the tide and diel factors (Table 2.4).

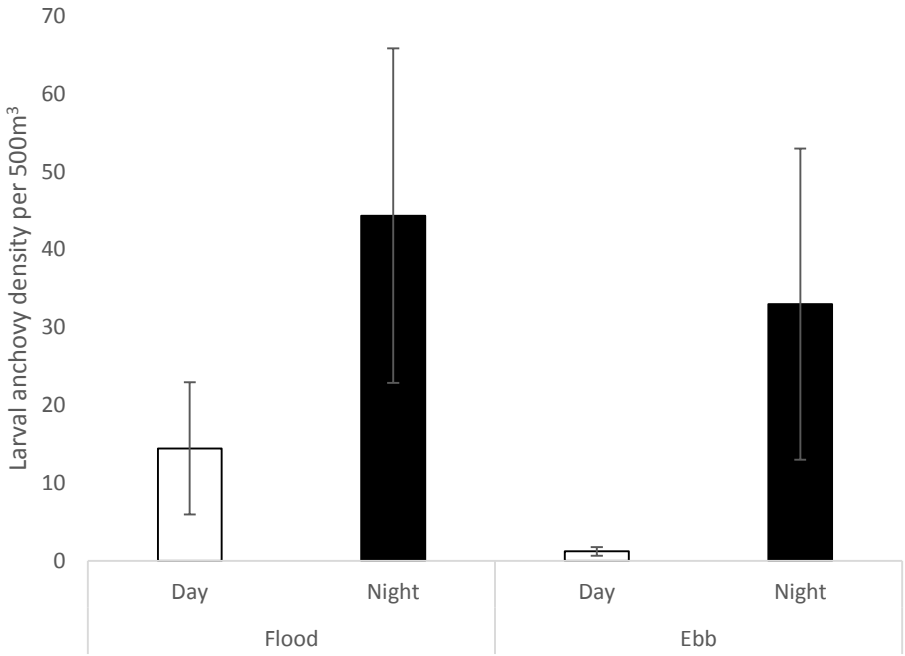



Figure 2.9: Mean density of larval anchovies *Engraulis australis* (±SE) during the day and night on the flood and ebb tides. The differences in densities during the day and night were statistically significant (p=0.047).

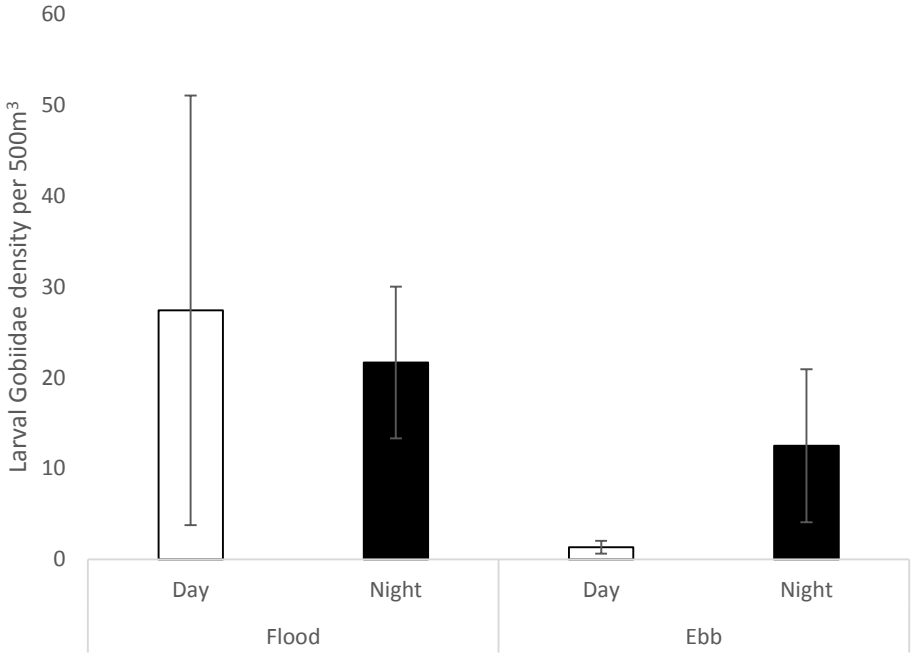



Figure 2.10: Mean density of larval gobies (family Gobiidae) (±SE) during the day and night on the flood and ebb tides. The difference in densities between the day and night, and flood and ebb tides were not statistically significant ($p>0.05$).

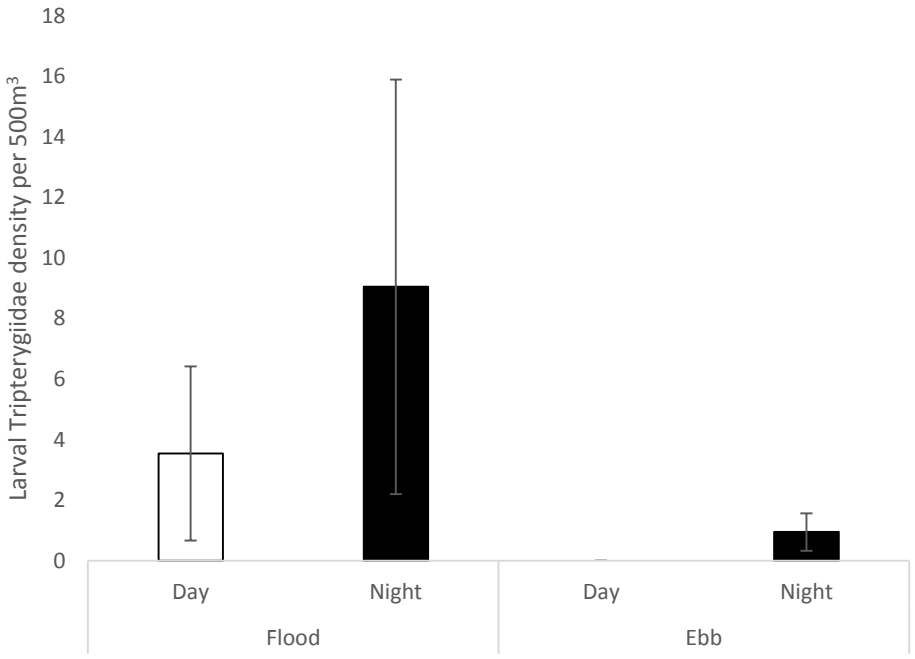



Figure 2.11: Mean density of larval triplefins (family Tripterygiidae) (±SE) during the day and night on the flood and ebb tides. The difference in densities between the day and night, and flood and ebb tides were not statistically significant ($p>0.05$).

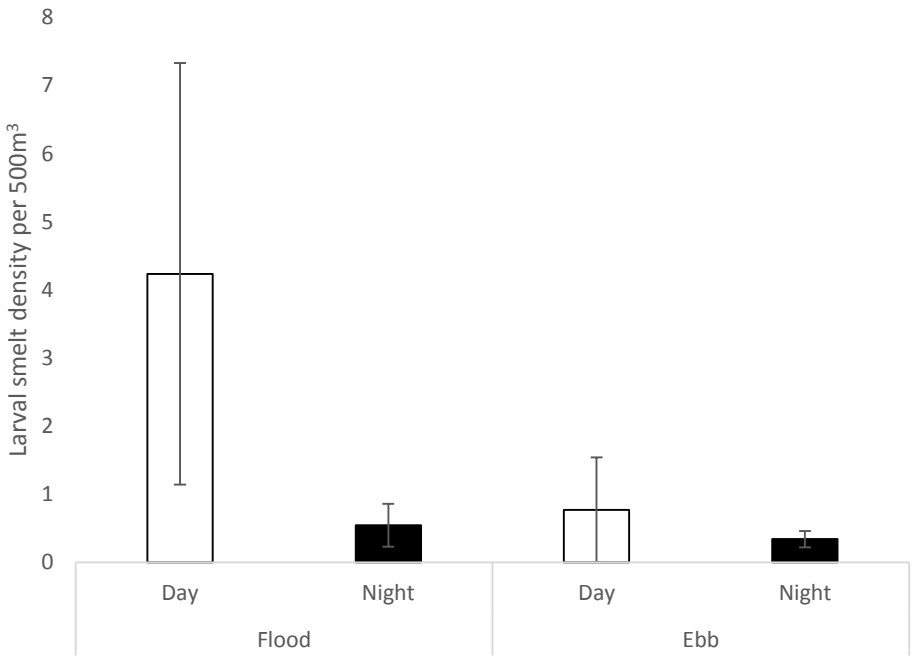



Figure 2.12: Mean density of larval smelt *Retropinna retropinna* (±SE) during the day and night on the flood and ebb tides. The difference in densities between the day and night, and flood and ebb tides were not statistically significant ($p>0.05$).

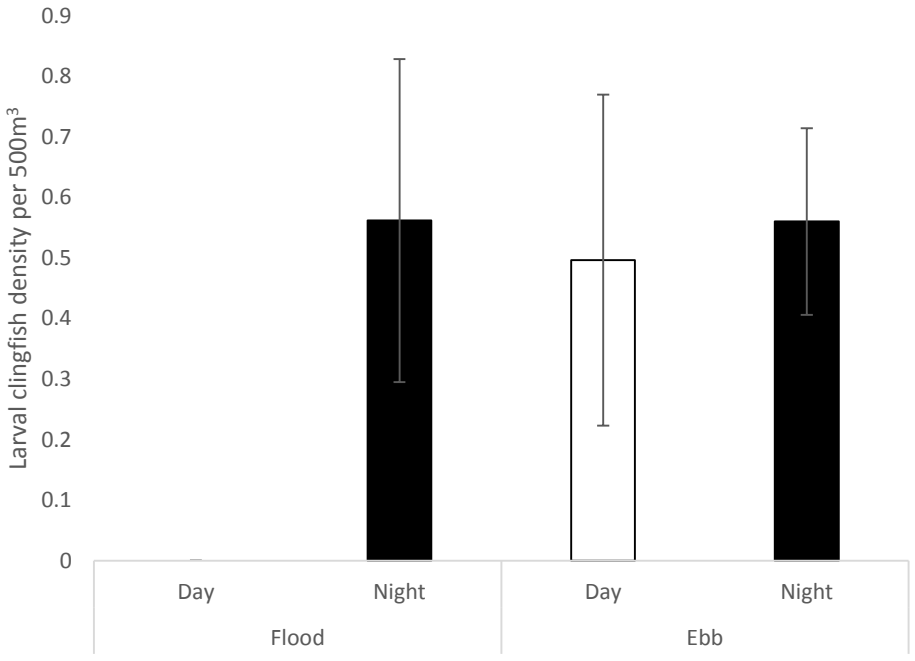



Figure 2.13: Mean density of larval clingfish (family Gobiesocidae) (±SE) during the day and night on the flood and ebb tides. The difference in densities between the day and night, and flood and ebb tides were not statistically significant ($p>0.05$).

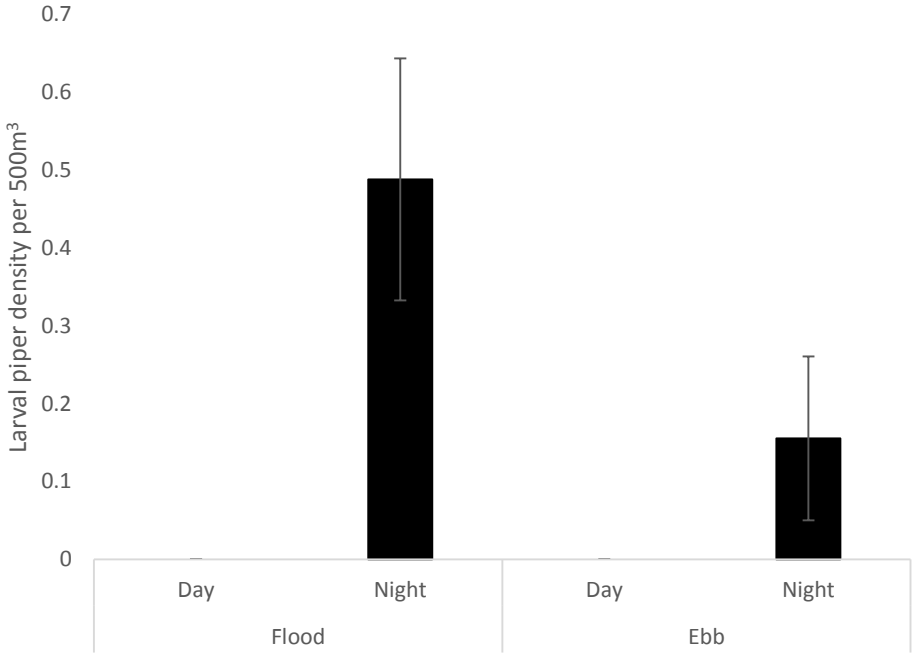



Figure 2.14: Mean density of larval piper *Hyporhamphus ihi* (±SE) during the day and night on the flood and ebb tides. The differences in densities during the day and night were statistically significant (p=0.002).

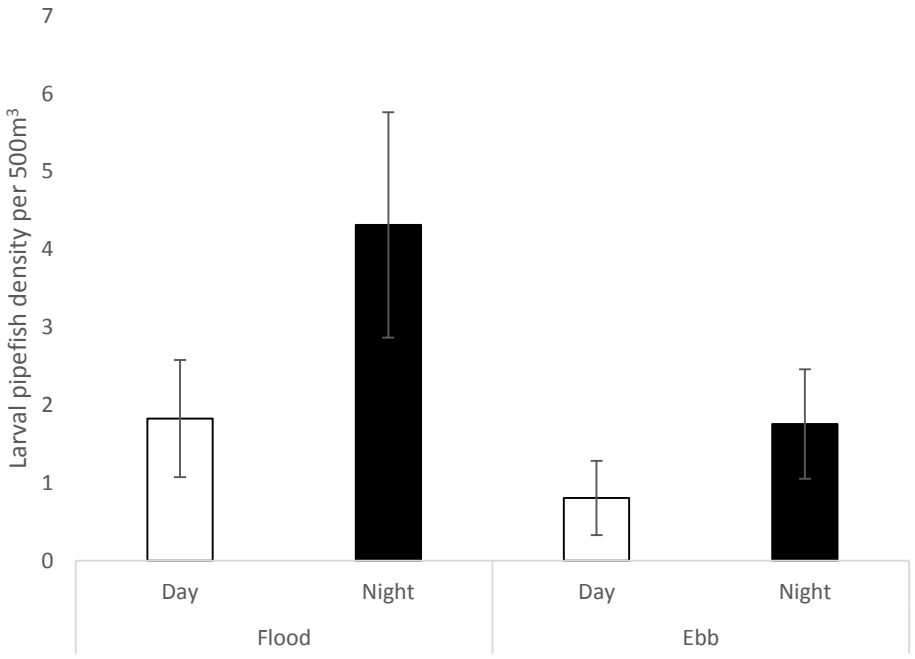



Figure 2.15: Mean density of larval pipefish (family Syngnathidae) (±SE) during the day and night on the flood and ebb tides. The difference in densities between the day and night, and flood and ebb tides were not statistically significant (p>0.05).

Table 2.4: Summary of ANOVA results for the densities of common larval taxa over the four 48-h series. Statistically significant values are in bold.

| Taxon | Diel (D) | Tide (T) | D × T |
|---|---|---|---|
| *Engraulis australis* | **F 4.350** | F 0.692 | F 0.004 |
| | **P <0.05** | P = 0.413 | P = 0.950 |
| Gobiidae | F 0.038 | F 1.595 | F 0.367 |
| | P = 0.847 | P = 0.218 | P = 0.550 |
| Tripterygiidae | F 0.646 | F 2.099 | F 0.322 |
| | P = 0.429 | P = 0.159 | P = 0.575 |
| *Retropinna retropinna* | F 1.416 | F 1.121 | F 0.888 |
| | P = 0.245 | P = 0.299 | P = 0.355 |
| Gobiesocidae | F 2.116 | F 1.323 | F 0.458 |
| | P = 0.158 | P = 0.261 | 0.258 |
| *Hyporhamphus ihi* | **F 11.78** | F 3.15 | F 3.15 |
| | **P <0.01** | P = 0.088 | P = 0.088 |
| *Stigmatopora macropterygia* | F 3.216 | F 3.484 | F 0.644 |
| | P = 0.085 | P = 0.073 | P = 0.429 |

### 2.3.2 Tidal variation in abundance

The density of the seven common taxa per 500 $m^3$ was plotted against the tidal phases for each of the four 48-h series. Figures 2.16, 2.17, 2.19, 2.20 and 2.21 show the density of *E. australis*, Gobiidae, *R. retropinna*, Gobiesocidae and *H. ihi* respectively. All show a pattern of peaks in density slightly before, during or after slack low tide.

Figure 2.18 (Tripterygiidae) and 2.22 (*S. macropterygia*) show no obvious patterns with peaks occurring at various times of the flood and ebb tides. The Tripterygiidae were only found in December.

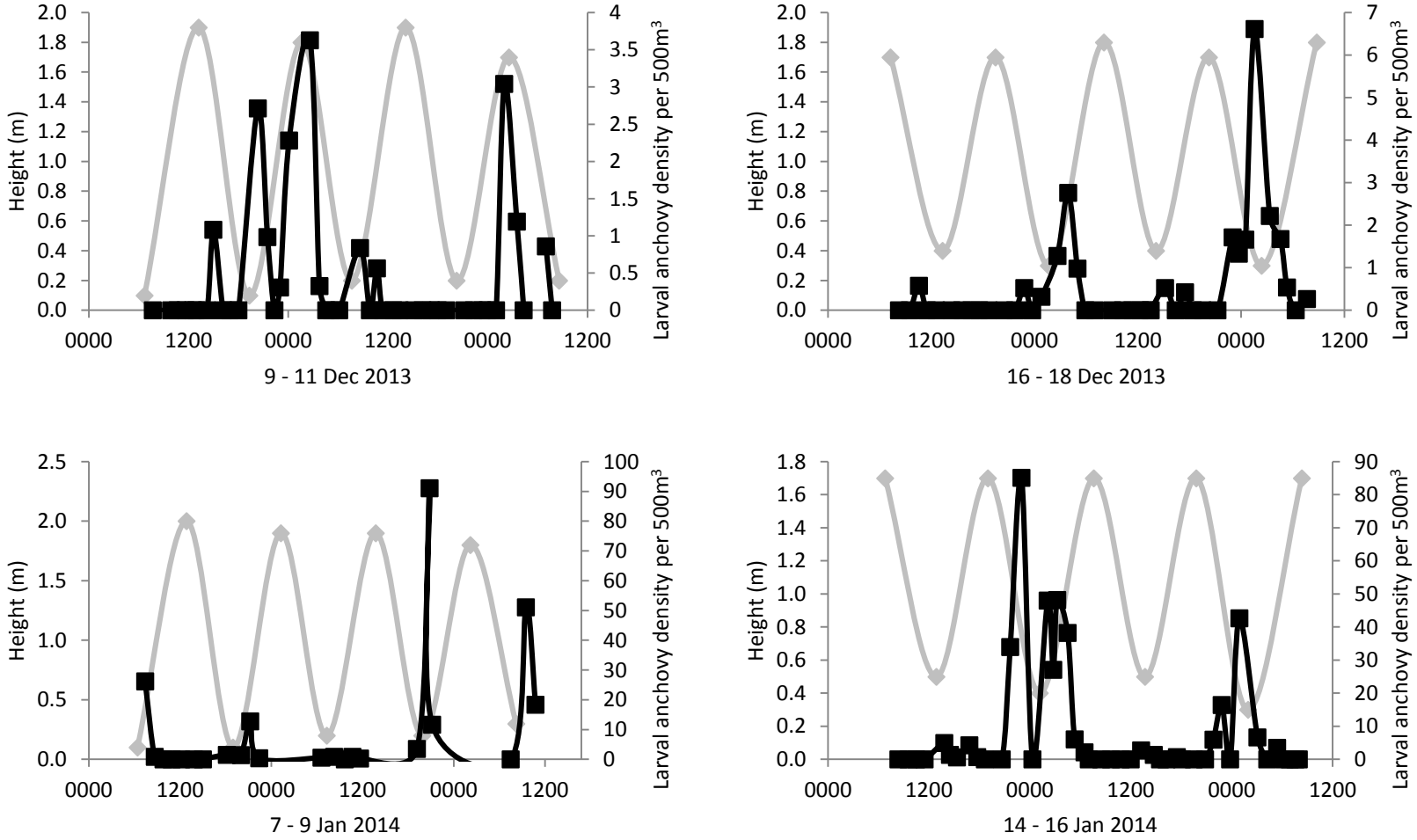



Figure 2.16: Tidal phases of the four 48-h series showing the density of *E. australis*. Grey represents the tidal phase, black is the density of larval *E. australis*.

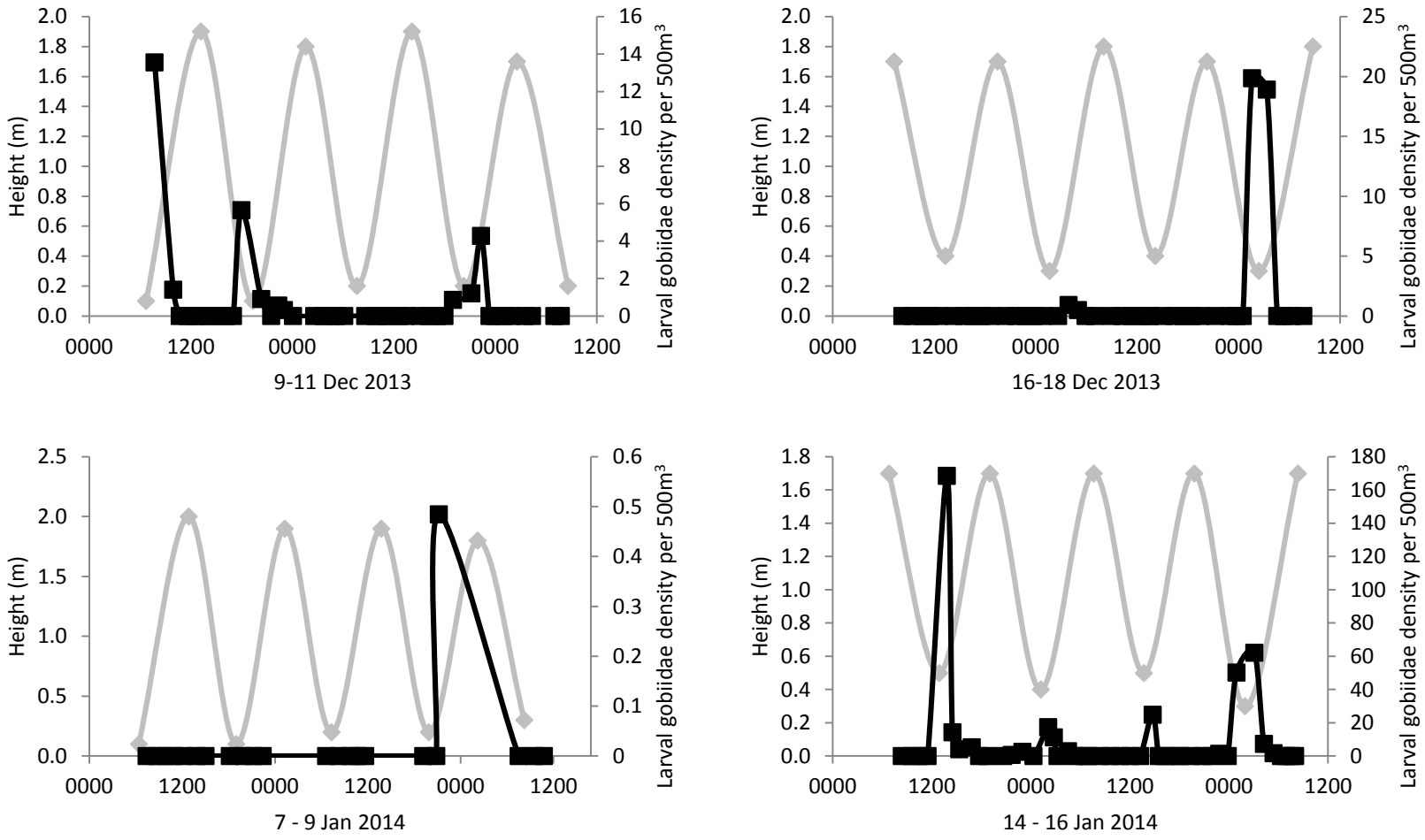



Figure 2.17: Tidal phases of the four 48-h series showing the density of Gobiidae. Grey represents the tidal phase, black is the density of larval Gobiidae.

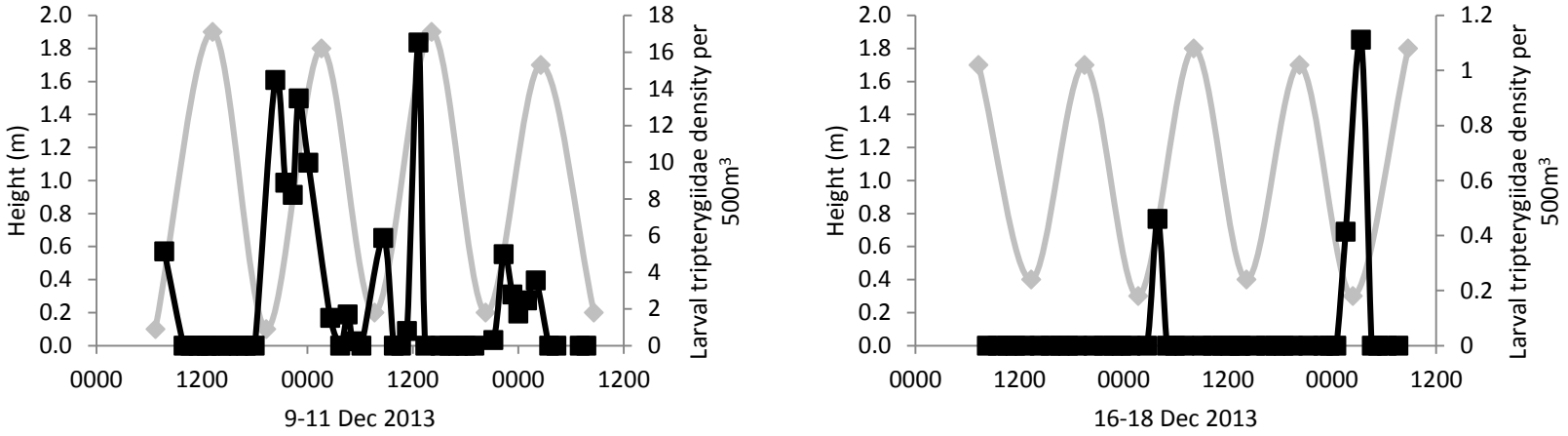



Figure 2.18: Tidal phases of the four 48-h series showing the density of Tripterygiidae. Grey represents the tidal phase, black is the density of larval Tripterygiidae.

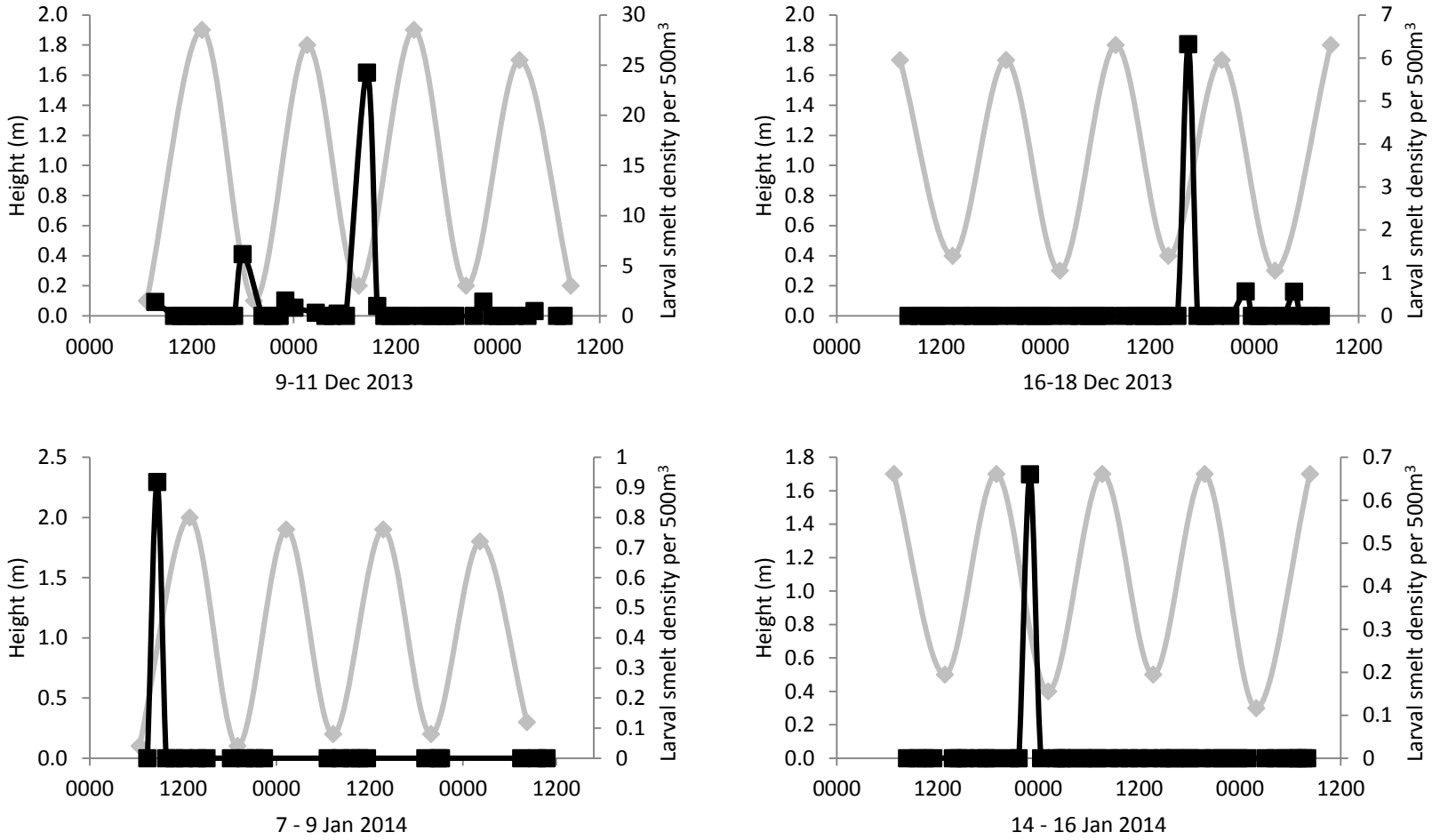



Figure 2.19: Tidal phases of the four 48-h series showing the density of *R.retropinna*. Grey represents the tidal phase, black is the density of larval *R. retropinna*.

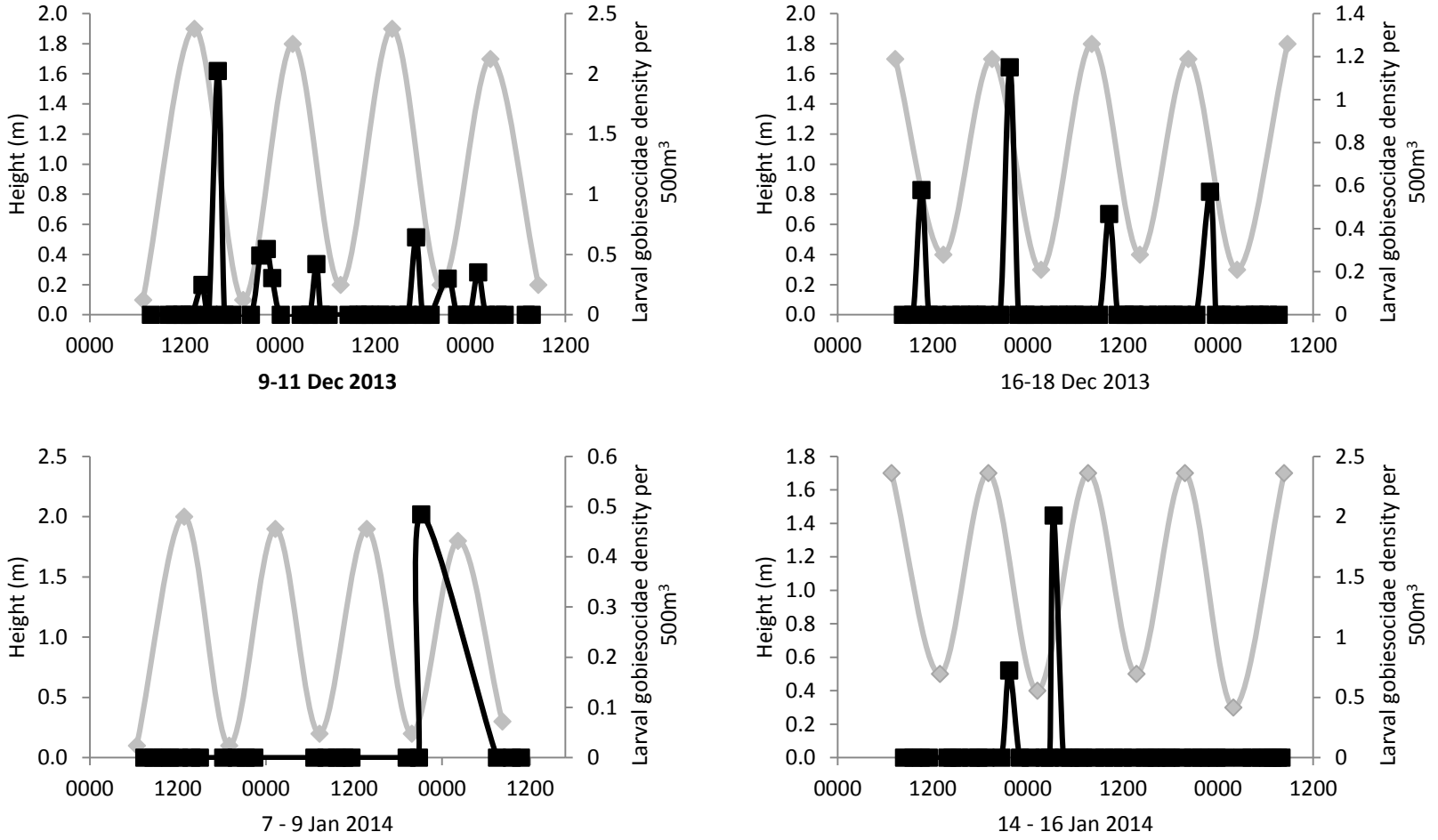



Figure 2.20: Tidal phases of the four 48-h series showing the density of Gobiesocidae. Grey represents the tidal phase, black is the density of larval Gobiesocidae.

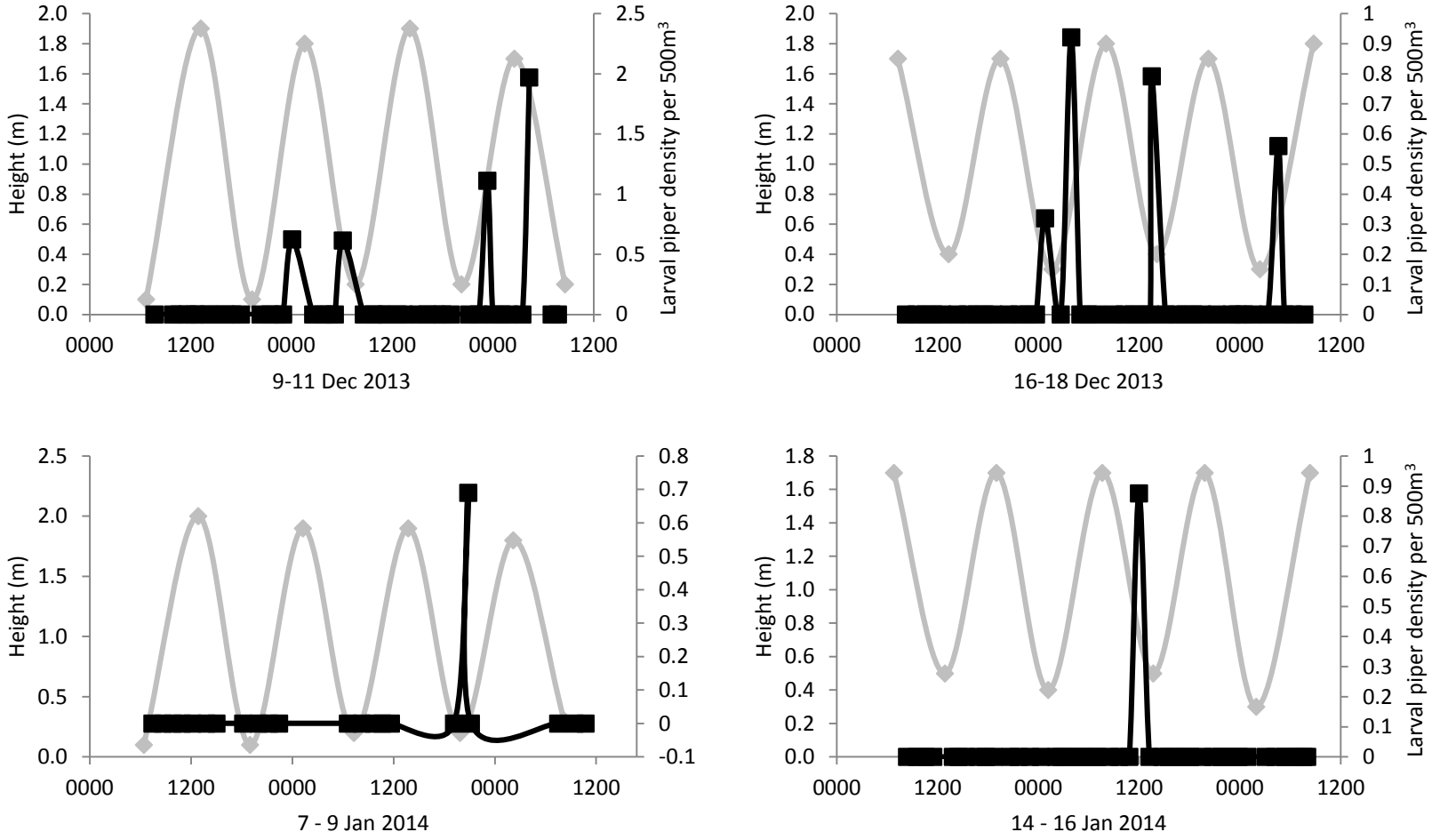



Figure 2.21: Tidal phases of the four 48-h series showing the density of *H. ihi*. Grey represents the tidal phase, black is the density of larval *H. ihi*.

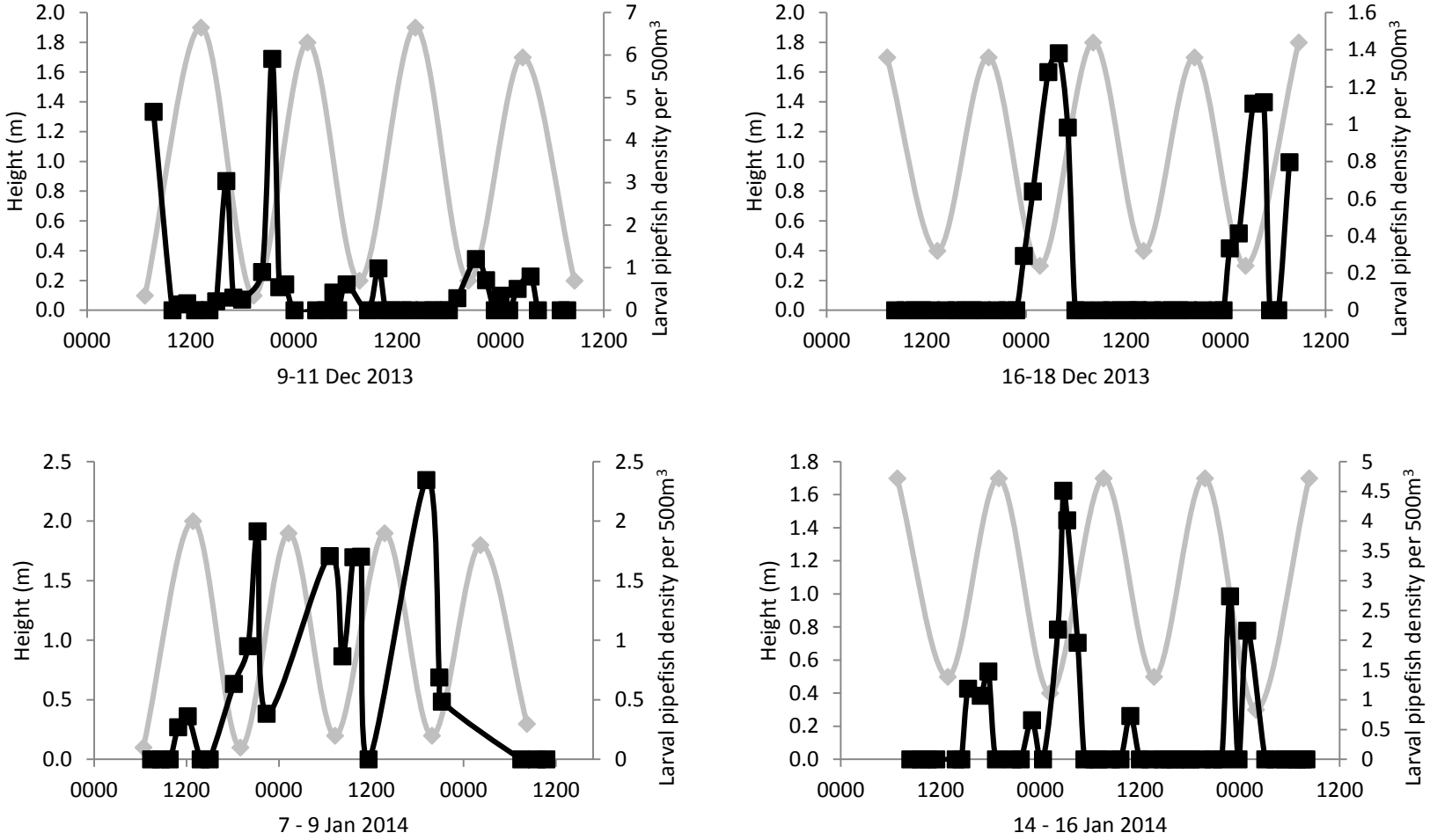



Figure 2.22: Tidal phases of the four 48-h series showing the density of *S*. *macropterygia*. Grey shows the tidal phase, black is the density of larval *S*. *macropterygia*.

## 2.4 Discussion

Estuaries are utilised as nurseries by juveniles of many fish species, however, not much is known about how larval fish use estuaries as a nursery habitat in New Zealand. Tidal and diel cycles are deemed to be the most important environmental variables affecting activity in fish (Strydom & Wooldridge, 2005), so these variables were selected for testing in regards to larval fish within Tauranga Harbour, as no previous studies have investigated larval fish abundance or identity within the harbour.

New Zealand waters hold over 1200 bony and cartilaginous fishes (Paul, 2000), with only 99 known as larvae (Dolphin, 1997). Over the two months sampled for this study, the larvae of 19 species from 18 families were collected. In studies performed in estuaries in New Zealand, Crossland (1981) found 27 species from 26 families, Roper (1986) found larvae of 31 taxa from 23 families, while Sutherland & Closs (2001) caught only seven species of larval fish. These studies indicate the range of species that are found in estuaries across New Zealand. The species caught during this study were similar to those found by Roper (1986) in Whangateau Harbour and Crossland (1981) in the Hauraki Gulf. Sutherland & Closs (2001) compared the number of species caught in their study to other studies, and concluded that the limited sampling methods used may have caused the lower number of species caught, which could also be the case for this study. When comparing studies of larval fish assemblages within estuaries, it is important to consider the methods and sampling effort used, and the environmental conditions encountered (Bonecker *et al*., 2009).

Costanza *et al*. (1997b) states that biodiversity within estuarine systems is generally low, with a high abundance of a few species and a large number of rare species (Ramos *et al*., 2006). This study reports a similar trend, with a high abundance (79.29% of the total catch) of three common taxa (anchovy, gobies and triplefins), and a number of taxa that were caught in very low densities, just one or two specimens over the whole sampling period. The low abundances of the uncommon species made it difficult to complete statistical analyses and draw firm conclusions about those species. The common species found in this study are typical of larval fish assemblages in temperate estuaries. Ramos *et al*. (2006)

found that larval Gobiidae (resident species), or Clupeidae and Engraulidae (estuarine spawners) generally dominate estuaries in temperate regions. The Engraulid, *Engrauilis australis* was the most abundant species found in this study, followed by the Gobiidae and Tripterygiidae. A range of species (stargazer *L. macropygus*, leatherjacket *M. scaber*, conger eel (Family Congridae), oyster blenny *O. anolius*, gurnard *C. kumu* and snapper *P. auratus*) were found in very low abundances (one or two larvae), although they cannot be considered rare as the adults of the species are considered common in this geographic region.

The results of this study indicated that there was no difference in abundance of larval fish due to the tidal phase, but rather the diel phase showed a strong influence on the abundance of the certain larvae (Table 2.3), similar to the findings of Trnski (2001) who found that tidal phase was a secondary variable, after diel phase. Islam *et al*. (2007) stated that larvae are more abundant at night, but reported higher abundances on the flood tides rather than the ebb. Churchill *et al*. (1999) also found higher abundances of larvae during flood tides over ebb tides, and attributed it to the behavioural response of selective tidal stream transport. The results of this study had higher abundances of larvae found at night, and on the ebb tides at night, similar to Strydom & Wooldridge (2005). Hettler & Barker (1993) found higher abundances of larvae at night, and made no reference to the influence of tidal cycle on abundance.

For the common species, differences between the diel and tidal variables (Figures 2.9 – 2.15), and patterns of abundance during the tidal phases (Figures 2.16 – 2.22) were apparent when the data were plotted but these were not statistically significant, possibly due to number of replicates completed or the low densities of larvae that were caught. The patterns showed that larvae appeared to be more active just before, during or after the slack low tide. To my knowledge, no previous studies have looked at which part of the tidal cycle, (e.g. start, middle, end) larvae are most active, most focused on if larvae were more abundant on either the flood or ebb tides.

The pattern of diel vertical migration (DVM) explains the higher abundance of larval fish caught at night over the sampling period (Trnski, 2001; Pattrick &

Strydom, 2014a). Although all the larval fish species together showed higher abundance due to the influence of the diel phase, only two of the common species showed a significant difference due to diel phase. The piper *H. ihi* was only found at night, and the anchovy *E. australis* was found in higher abundances at night.

The numbers of larval fish caught across each of the tides was not homogenous. The amount of larvae were not consistent for each tide. Trnski (2001) found a high variation of larval fish concentrations temporally and within tides in a similar study in Swansea Channel, NSW. Often high numbers of the same species were caught at the same time, suggesting that schooling occurs with some species of larval fish. Leis (2006) states that the larvae of some benthic species are known to school, thought to be a defensive mechanism against predation.

A few problems arose while sampling that made the sampling and sorting time consuming and difficult. Tauranga Harbour has a high amount of the sea lettuce *Ulva lactuca*, and often upon emptying the cod end, the sample would be full of sea lettuce, making it difficult to sort. On occasion, the flowmeter would also have sea lettuce wrapped around it when the net came in, making the reading for that sample void and impossible to work out the volume of water sampled. High amounts of sea lettuce were found at the start of the incoming tides, and the end of the outgoing tides. Sampling during year/s where the amount of *U. lactuca* was lower than usual could be a way of a combating this problem, and would be interesting to compare to my initial findings.

In December there were high numbers of jellyfish in the water. If jellyfish entered the net they would clog the cod end, and need to be removed carefully before the sample was sorted. A whitebait net was modified, with chicken mesh put in place of the netting, to make a jellyfish scoop. During the day, the jellyfish scoop was used to scoop jellyfish out of the water before they entered the net, and they were put into the water behind the net. At night it was difficult to see the jellyfish before the entered the net, so the scoop was not used.

In January there were large amounts of salps in the water. The salps clogged the net, making it very heavy to pull in, and causing the cod ends to split open on two

occasions, and on one occasion to come off. Sampling times in January were shortened in an effort to continue sampling. At the peak of the salps, the net could be in the water for 5 minutes and be pulled up with 100 L of salps. These samples were poured into 20 L buckets and placed into a cool room at the Coastal Marine Field Station until they were able to be sorted. Generally, samples that had large amounts of salps did not have high numbers of larval fish. This could possibly be due to the drag created by the salps clogging the net, which the larvae sensed and were able to avoid, or that the larvae were avoiding the salps themselves, and were not in the surface waters while the salps were.

Larvae are not planktonic, and are able to control their position in the water column (Leis, 2006). During the first 48-h series, a small school of larvae was observed avoiding the net/ropes. Trnski (2001) suggests a change in behaviour of larvae between night and day; in that during the day larvae with developed swimming and sensory abilities are able to avoid the net, while less developed larvae are unable to. At night, larvae are unable to see the net, so higher abundances of larvae are caught. Net avoidance could be a factor in the higher abundance of larvae caught at night in this present study.

If it was logistically viable, it would have been ideal to complete more 48-h series to enable more robust statistical analyses and to provide a more informative data set on the larval fish found within Tauranga Harbour. As the sampling was completed during one summer, there was no way of knowing if the data collected was representative of the normal abundance of larvae. If further sampling could have taken place, it would have been interesting to sample during different phases of the moon so the lunar cycle could be included as another variable. Sampling through more months of the year, and the same months on a yearly basis would provide interesting comparisons and deliver further information on how larval fish use Tauranga Harbour as a nursery. As a personal observation, the samples that had high amounts of seagrass also had higher numbers of fish. This could be the subject of future research: to assess if floating seagrass mats are an important habitat for larval fish, similar to studies by Casazza & Ross (2008) and Kingsford & Choat (1985).

The densities of larvae caught over the summer period appears to show that diel phase has a strong influence on the activity of larvae within Tauranga Harbour. Tidal phase did not appear to have a strong influence on the majority of taxa caught.

# Chapter 3 – Temporal distribution of larval fish in a channel estuary, Tauranga Harbour, New Zealand

## 3.1 Introduction

It is well known that estuaries are important nursery habitats for many fish species (Able, 2005; Vasconcelos *et al*., 2010; Primo *et al*., 2013). Food availability and a decrease in predation pressure make estuaries suitable nursery habitats (Álvarez *et al*., 2012). Early life stages of estuarine-dependent species move into estuaries and remain for varying amounts of time during development (Nordlie, 2003). It is important to determine the abundance and species composition of larvae that use the estuary, in an effort to establish if annual cycles exist and to learn how and when these early life stages use the estuary. Studies on larval fish in the estuarine environment are generally aimed towards identifying active and passive mechanisms of transport, and determining the different strategies larval fish use to control their position within the estuary Islam *et al*., 2007; Primo *et al*., 2012; (Bruno & Acha, 2014). Seasonal effects on abundance of larval fish have been less studied, has and have often been linked with oceanographic or meteorological factors (Azeiteiro *et al*., 2006).

The assemblages of larval fish undergo changes in abundance and composition on a seasonal basis (Álvarez *et al*., 2012). These changes in abundance and composition are influenced by biological mechanisms such as reproductive strategies and availability of food (Hernández-Miranda *et al*., 2003), or physical mechanisms such as environmental fluctuations (Ramos *et al*., 2006). It is thought that the assemblages of larval fish are the result of spawning strategies by the adult fish during conditions that are favourable for the survival of larval fish (Hernandez *et al*., 2010). Larval fish abundance in estuaries is variable during summer months but generally greater than abundances found in winter (McLusky & Elliott, 2004; Suthers, 2009). It is not unusual for activity patterns to change between seasons: possible reasons for this could be due to lower water temperatures in winter which can cause certain species to become sluggish; or due to seasonal fluctuations in the availability of food (Reebs, 2002). Larvae are known to be more active at night, which is believed to be driven by predator

avoidance during the day (Ospina-Alvarez *et al*., 2012), or the behavioural cue related to light levels (Pattrick & Strydom, 2014a). Luo (1993) found that larvae of the bay anchovy *Anchoa mithchilli* ceased schooling during the hours of darkness and swam at a lower rate, becoming more likely to be transported by currents. The seasonal patterns of abundance and diversity of species can also show annual variability (Nordlie, 2003), with Kingsford (1986) finding seasonal peaks in the densities of larvae caught as well as variability in the timing of the peaks between years.

Oceanographic drivers such as the velocity and direction of winds, tides and currents can affect seasonal larval fish abundance and distribution in estuaries (Hernández-Miranda *et al*., 2003; Bruno & Acha, 2014), as can environmental factors such as salinity, temperature (Marques *et al*., 2005), light intensity, food availability (Reebs, 2002) and precipitation (Bonecker *et al*., 2009). Food availability is seasonally linked with blooms of phytoplankton and elevated levels of zooplankton which occur in spring when water temperatures begin to rise (Haldorson *et al*., 1993). Salinity gradients can also have an effect on the species that are found within estuaries. Estuarine species are generally euryhaline, and more adapted than marine species to the range of salinities that can be found in estuaries over the course of a year (Veale *et al*., 2014). Light intensity is important for the behaviour of vertical migrations as larvae are visual feeders, thus the depth they descend to is limited by the available light which depends on the light intensity (Job & Bellwood, 2000). The light availability can vary across seasons due to the number of daylight hours and conditions that cause the water to be more or less turbid, which can affect the abundance and distribution of larval fish.

The patterns in seasonal abundance of larval fish imply a connection between the effects of abiotic and biotic factors. Larval fish are found in higher abundances during spring and summer, when the water temperature begins to warm after winter (Neira & Potter, 1994; Strydom, 2003a; Able *et al*., 2006; Primo *et al*., 2012). The reproductive strategies of adults are associated with environmental features such as water temperature which, in turn, affects the abundance of larvae seasonally (Azeiteiro *et al*., 2006). It is also thought that adults may reproduce at a time when oceanographic features are present that will aid the larvae in reaching

estuarine nursery areas; as the fate of the eggs and larvae are largely determined by the environmental factors present during spawning (Pattrick & Strydom, 2014b). The marine environment is incredibly dynamic, therefore it is important to monitor environmental conditions so changes that may affect the biological mechanisms of larval fish are able to be assessed or predicted.

The aims of this study were to determine which larval fish species were present in Tauranga Harbour, if larval fish abundance was affected by seasonality and if a coupling between larval fish and environmental factors was present, using biological and environmental data. The larval fish abundance of the harbour would be compared with the seasonality, water temperature, water currents and wind speed monitored at the sampling site within the harbour. It was hypothesised that a range of species would be found in the harbour; that larvae would be found in higher abundances over summer months; and that water temperature would have an effect on the abundance of larvae present.

## 3.2 Methods

### 3.2.1 Study site

Samples were taken from Bridge Marina in Tauranga Harbour (Figure 3.1), exclusively from one site near the fuelling berth (37°40'09.9"S 176°10'44.1"E) (Figure 3.2). The water depth is 2.7 m at low tide. This location was selected for sampling as the net could be set without needing the mast and boom system, used in the previous chapter, and also because the footbridge connecting the pier, where the net was deployed, received an uninterrupted flow of water into the marina on the incoming tide.

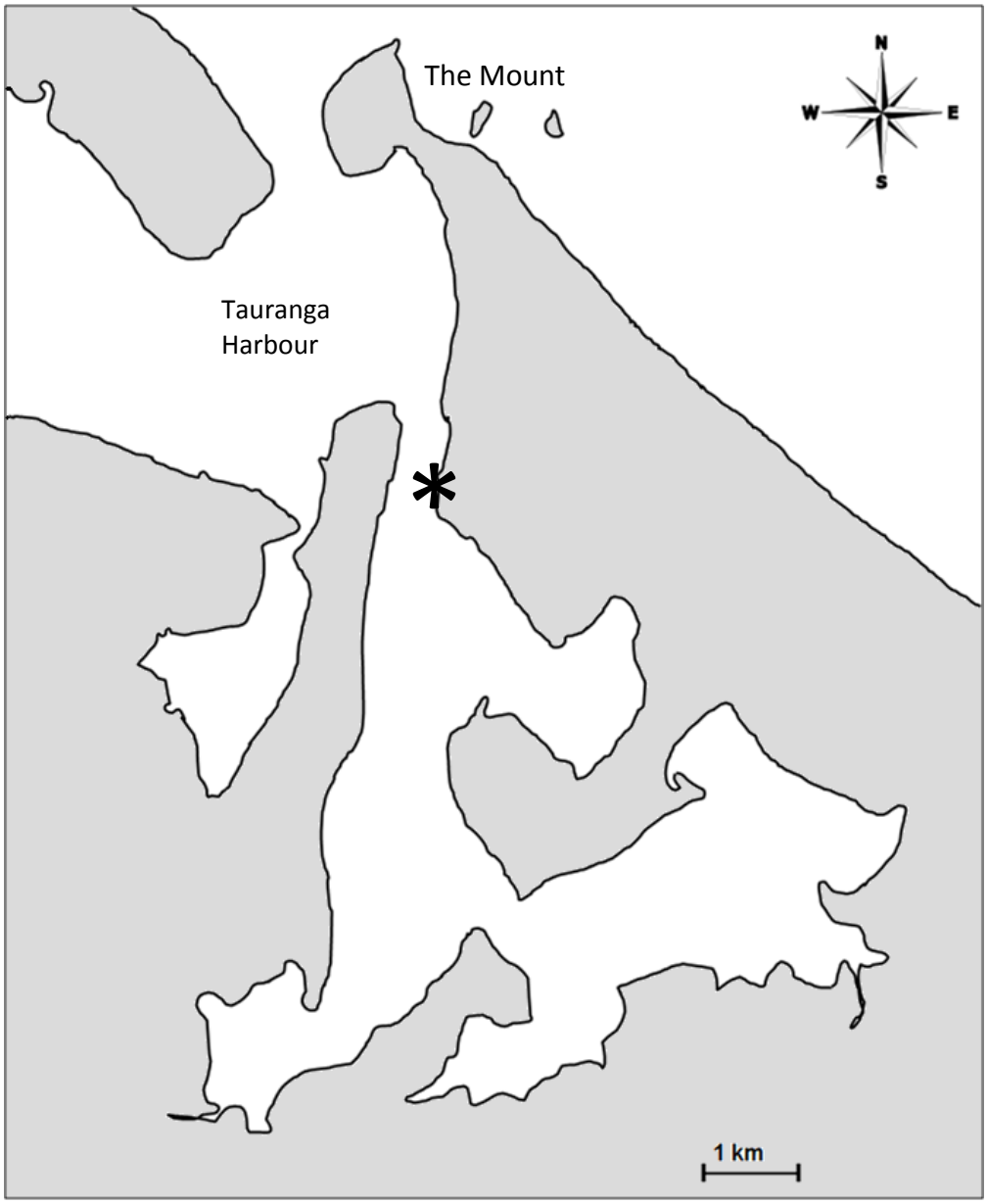



Figure 3.1: Location of the sampling site in Tauranga Harbour.

Figure 3.2: Position of the net with the fuelling berth shown in the upper left corner.

### 3.2.2 Sampling

To assess the temporal variability of larval fish and establish which species are present in the harbour, plankton sampling was conducted using a set net from December 2013 till March 2015. The 1 m by 2 m channel net used in the previous chapter was used to sample the incoming tide (Figure 2.3). The flow meter (General Oceanics, Inc., mechanical flowmeter model 2030 series), used in the previous chapter, was positioned across the mouth of the net in the centre (Figure 2.5). A reading was taken from the flowmeter before the net was placed in the water, and when the net was pulled out. The difference in the readings was recorded as the 'distance in counts', and used in the below calculations to work out the speed and volume of water that passed through the net:

$$\text{DISTANCE in metres} = \frac{Distance\ in\ COUNTS \times Rotor\ constant\ (26837)}{999{,}999}$$

$$\text{SPEED in m/sec} = \frac{Distance\ in\ metres}{Time\ in\ seconds}$$

$$\text{VOLUME in cubic metres} = Net\ mouth\ area\ \times distance\ in\ metres$$

Sampling was conducted approximately fortnightly, with the exception of June and August 2014 when no sampling took place due to adverse weather conditions (Table 3.1). Sampling occurred in pairs within a 48 hour period, with one sample taken during the hours of darkness and one during the hours of light. The net was set after low tide for at least an hour and no longer than two hours. After 15-100 minutes the net was lifted, with an average sampling time of 49 minutes. The target duration for the net was an hour, as from the intensive study discussed in the previous chapter, it was difficult to assess the volume of water sampled and there was great variability due to current speed and tides. The mean volume of water sampled was 952 $m^3$ with a standard deviation of 554 $m^3$.

Table 3.1: Summary of the water volume sampled and the current range over the total sampling period.

| Series | Date | Season | Volume, $m^3$ mean (s.d.) | Current range (cm $s^{-1}$) |
|---|---|---|---|---|
| 1 | 9-10 Dec 13 | Summer | 958.99 (354.33) | 12-44 |
| 2 | 16-18 Dec 13 | Summer | 911.80 (229.23) | 9-33 |
| 3 | 7-9 Jan 14 | Summer | 1046.16 (321.17) | 12-44 |
| 4 | 14-16 Jan 14 | Summer | 377.73 (213.28) | 3-23 |
| 5 | 5-6 Feb 14 | Summer | 1316.30 (131.77) | 16-19 |
| 6 | 12 Feb 14 | Summer | 682.41 (170.79) | 8-11 |
| 7 | 19-20 Feb 14 | Summer | 1095.14 (32.91) | 15-16 |
| 8 | 11-12 Mar 14 | Autumn | 690.79 (93.90) | 9-11 |
| 9 | 25-26 Mar 14 | Autumn | 980.20 (285.48) | 11-16 |
| 10 | 19-20 Apr 14 | Autumn | 2968.28 (1527.16) | 26-34 |
| 11 | 6-7 May 14 | Autumn | 1308.09 (84.41) | 17-23 |
| 12 | 20-21 May 14 | Autumn | 1547.48 (326.25) | 18-25 |
| 13 | 3-4 Jul 14 | Winter | 1223.93 (4.48) | 17-18 |
| 14 | 17-18 Jul 14 | Winter | 877.81 (80.35) | 11-13 |
| 15 | 30-31 Jul 14 | Winter | 831.17 (29.03) | 9-11 |
| 16 | 1-2 Sept 14 | Spring | 2238.43 (202.14) | 14-18 |
| 17 | 26 Sept 14 | Spring | 1130.00 | 18 |
| 18 | 30 Sept-1 Oct 14 | Spring | 1036.55 (75.30) | 14-15 |
| 19 | 15-16 Oct 14 | Spring | 567.63 (358.17) | 4-11 |
| 20 | 30-31 Oct 14 | Spring | 993.16 (238.54) | 11-16 |
| 21 | 13-14 Nov 14 | Spring | 691.72 (233.15) | 7-12 |
| 22 | 27 Nov 14 | Spring | 1205.71 (760.85) | 9-24 |
| 23 | 11-12 Dec 14 | Summer | 797.33 (71.20) | 10-12 |
| 24 | 26-27 Dec 14 | Summer | 1123.16 (24.25) | 15-16 |
| 25 | 8-9 Jan 15 | Summer | 1246.88 (203.54) | 15-19 |
| 26 | 26-27 Jan 15 | Summer | 585.96 (262.03) | 7-13 |
| 27 | 10-11 Feb 15 | Summer | 511.30 (276.38) | 4-10 |
| 28 | 24-25 Feb 15 | Summer | 728.66 (185.90) | 9-13 |
| 29 | 11 Mar 15 | Autumn | 813.00 | 11 |

The contents of the cod end were emptied into 1 L plastic jars and refrigerated overnight (for night sampling), and sorted in the morning, or sorted straight away for daylight samples. The larval fish samples were processed and stored in the same manner as outlined in the previous chapter.

### 3.2.3 Oceanographic and environmental factors

A range of oceanographic and environmental factors, including water temperature, current speed, and wind speed and direction, were recorded from the Port of Tauranga Harbour Conditions Monitoring System (Port of Tauranga Limited, 2015), for each sample that was taken.

### 3.2.4 Data analysis

The density of larval fish for each sample were standardised to number of larvae per 500 $m^3$. If multiple samples were taken during the same diel phase on the same day (in the case of the earlier samples when there was a high number of salps in the water), standardised densities were added to facilitate analysis. The catch per unit effort (CPUE) of individuals per 500 $m^3$ was calculated for each species identified, and also the number of occurrences over the whole sampling period. The months in which each species were found were summarised in Table 3.3. Using Statistica 12, Sign and Wilcoxon matched paired tests were performed to identify the differences in abundances for the different seasons (winter, spring, summer and autumn), and for the different phases of the diel cycle (day and night). Data were tested for homogeneity of variances using Levene's test prior to analyses. After a variety of transformations were conducted, the data sets were still not homogenous, therefore non parametric tests were conducted instead of ANOVAs. Plots were created to visualise the density of larvae caught during each season and during the diel cycle. ANOVA's were performed to test the density of larvae compared to each of the oceanographic and environmental variables, as non-parametric tests were unable to be performed. The data did not meet the assumptions of the ANOVA; even after variations transformations had been performed. Using Microsoft Excel, larval fish density was plotted against the seasons, against day/night, and against the physical variables (water temperature, wind speed, entrance current).

## 3.3 Results

### 3.3.1 Community composition

A total of ~78,030 $m^3$ of water was filtered, from which 2501 larvae of at least 13 species of fish in 11 families were collected. Of these, seven taxa were assigned to identifiable species, two to genus and four to family (Table 3.2). The catch per unit effort (CPUE) standardised to the number of individuals per 500 $m^3$ shows the very low numbers of larvae caught compared to the volume of water sampled. Only the Gobiidae larvae and anchovy *Engraulis australis* were caught in high enough numbers to produce CPUE indices above 1.0.

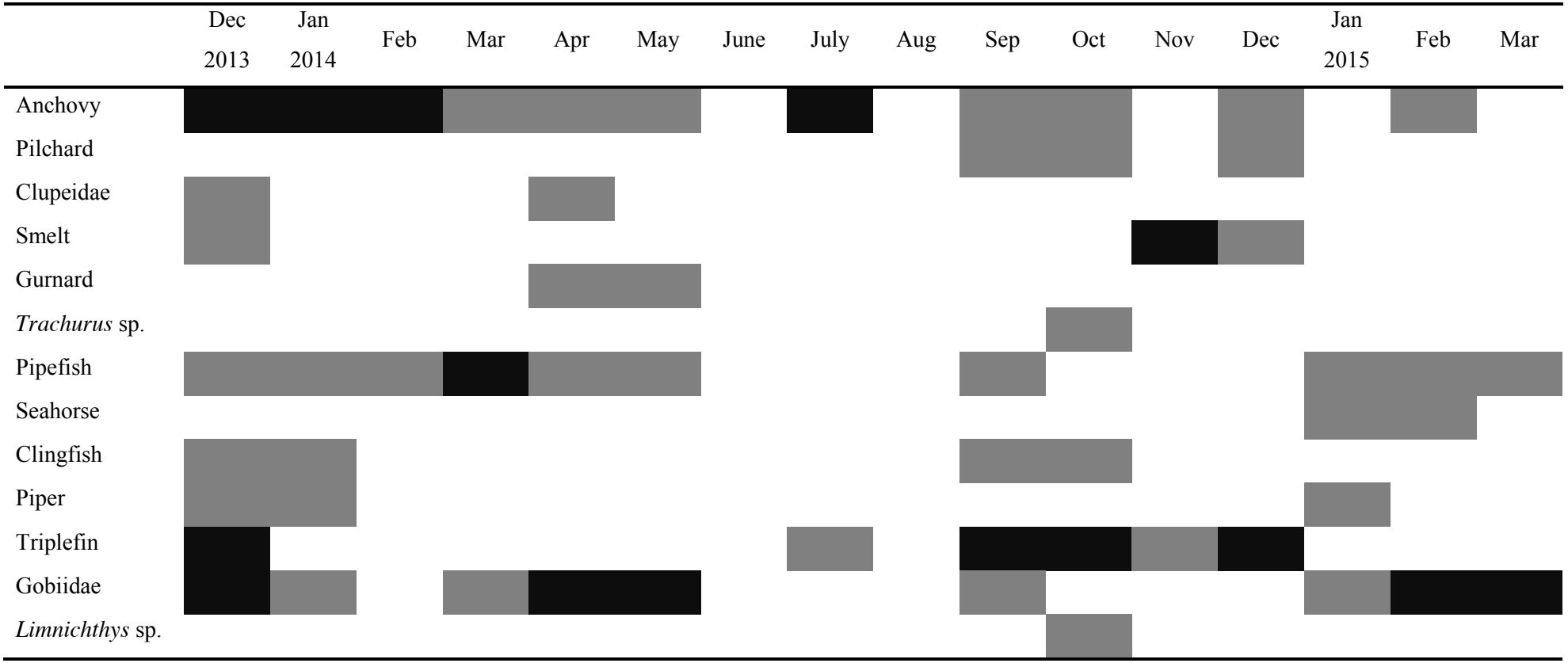
The family Gobiidae was the most abundant taxa found over the 16 months sampled, representing 62.97% of the larvae collected, and occurring in 31 of the possible 82 samples taken. The second most abundant taxa were the anchovy at 21.64% of the total larvae collected. *Engraulis australis* was present in 45 out of 82 samples, and was the taxa found in the most samples over the 16 months. The remaining identified taxa equated to 12.71% of the total larvae, with 2.68% remaining unidentified. None of the identified taxa were present in every tide sampled. Nine taxa were found in less than ten of the 82 samples, with four taxa present in more than ten samples. Three taxa were rarely found, with only one specimen of *Limnichthys* sp., and two specimens of mackerel *Trachurus* sp. and gurnard *Chelidonichthys kumu* found over the entire sampling period.

Pipefish, anchovy and Gobiidae were the taxa present during the most months of the year (Table 3.3). Anchovy was only absent from samples for three months, while pipefish were absent for four months, and Gobiidae were absent for five months. *Limnichthys* sp. and *Trachurus* sp. were only found during October, while gurnard, Cluepidae and seahorses were only found during two months of the sampling period (gurnard in April and May, Clupeidae in April and December, and seahorses in January and February).

Table 3.2: Summary of larval fish collected from Bridge Marina over the sampling that took place from December 2013 to March 2015. The CPUE represents the number of individuals per 500m$^3$. The number of occurrences out of a total of 82 possible samples is in the column on the far right.

| Family | Taxon | CPUE | % of total | Occurrences |
|---|---|---|---|---|
| Unidentified | | 0.43 | 2.68 | 13 |
| Syngnathidae | *Stigmatopora macropterygia* Pipefish | 0.54 | 3.39 | 32 |
| | *Lissocampus filum* Sea horse | 0.02 | 0.12 | 3 |
| Clupeidae | | 0.05 | 0.32 | 5 |
| | *Sardinops sagax* Pilchard | 0.05 | 0.32 | 4 |
| Engraulidae | *Engraulis australis* Anchovy | 3.47 | 21.63 | 45 |
| Retropinnidae | *Retropinna retropinna* Smelt | 0.37 | 2.32 | 8 |
| Gobiesocidae | Clingfish | 0.03 | 0.20 | 5 |
| Hemiramphidae | *Hyporhamphus ihi* Piper | 0.04 | 0.24 | 5 |
| Tripterygiidae | Triplefin | 0.90 | 5.60 | 18 |
| Creediidae | *Limnichthys* sp. | 0.006 | 0.04 | 1 |
| Carangidae | *Trachurus* sp. Mackerel | 0.01 | 0.08 | 2 |
| Gobiidae | | 10.09 | 62.97 | 31 |
| Triglidae | *Chelidonichthys kumu* Gurnard | 0.01 | 0.08 | 2 |

Table 3.3: Summary of the taxa caught during the sampling period and which months they were found in. The shaded boxes indicate the most abundant species for each month. No sampling took place during June and August.



### 3.3.2 Temporal distribution

The density of larval fish per 500m$^3$ during the day and night is shown in Figure 3.3. Similar peaks are present during the day and night in January 2014, and a peak in density occurred during the night during February 2015. Throughout the rest of the sampling period, the density of the larvae remains fairly low and similar for both the day and night. Figure 3.4 shows the mean density of larval fish per 500m$^3$ over the diel cycle. A higher density is shown for the samples taken at night, found to be statistically significant (Table 3.4).

The density of larval fish per 500m$^3$ during the five seasons sampled (2x summer, autumn, winter and spring) is shown in Figure 3.5, and the mean density excluding larvae from the family Gobiidae is shown in Figure 3.6. The mean density across the four seasons is shown in Figure 3.7. Summer had higher densities of larval fish while autumn to spring have lower densities, with winter having the lowest density of the four seasons. Table 3.5 shows there is a significant difference ($P < 0.05$) between the density of the larval fish during winter and summer (Sign test), and winter and the other seasons (Wilcoxon test).

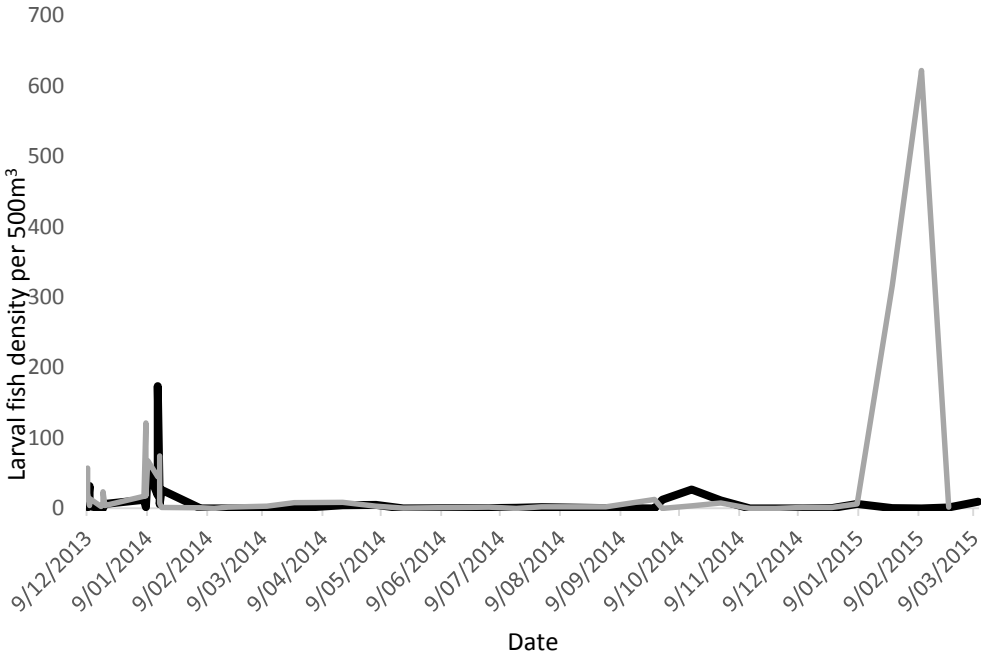



Figure 3.3: Larval fish density per 500m$^3$ between December 2013 and March 2015. Black represents density caught during the day; grey represents density caught during the night.

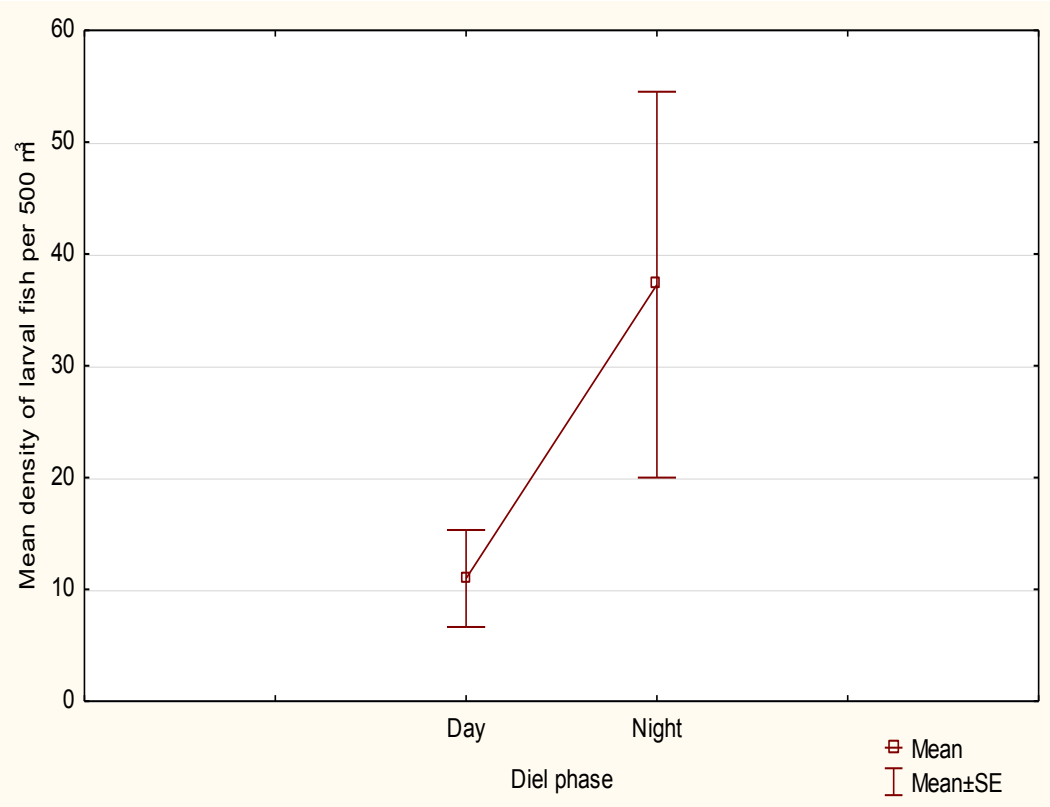



Figure 3.4: Mean density (± SE) of larval fish per 500m$^3$ over the diel cycle (day and night).

Table 3.4: Non parametric test results of the density of larval fish during the day and night. Statistically significant variables are in bold.

| *Sign test* | *Wilcoxon test* |
|---|---|
| **P = 0.001** | **P = 0.005** |
| **F = 3.288** | **Z = 2.829** |

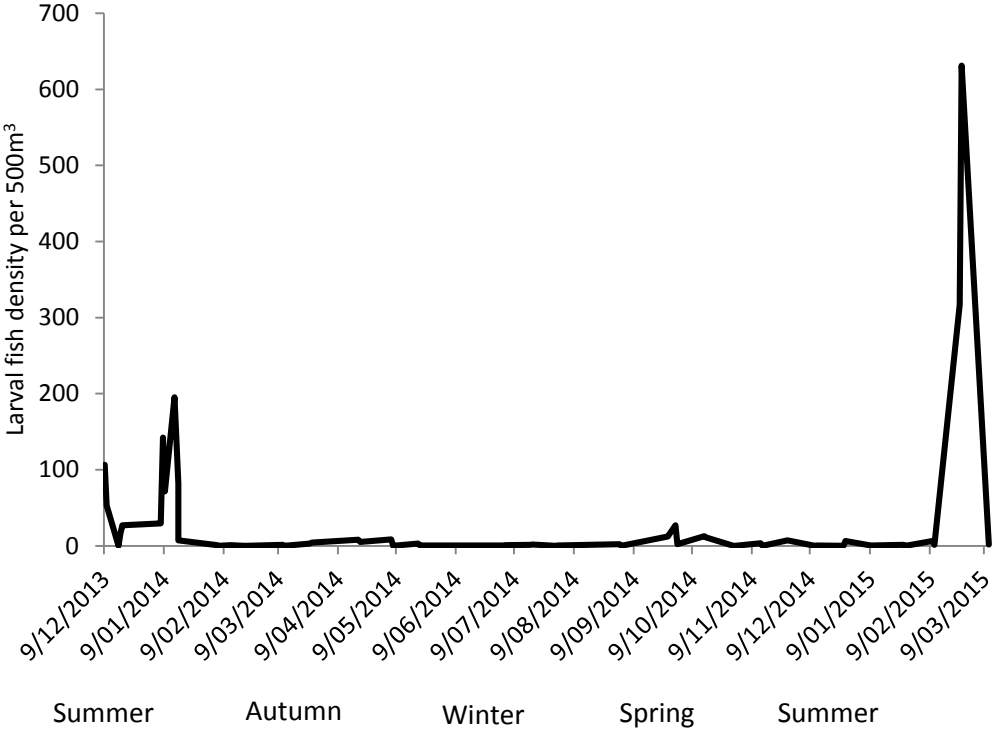



Figure 3.5: Larval fish density per 500m$^3$ between December 2013 and March 2015 showing the different seasons sampled.

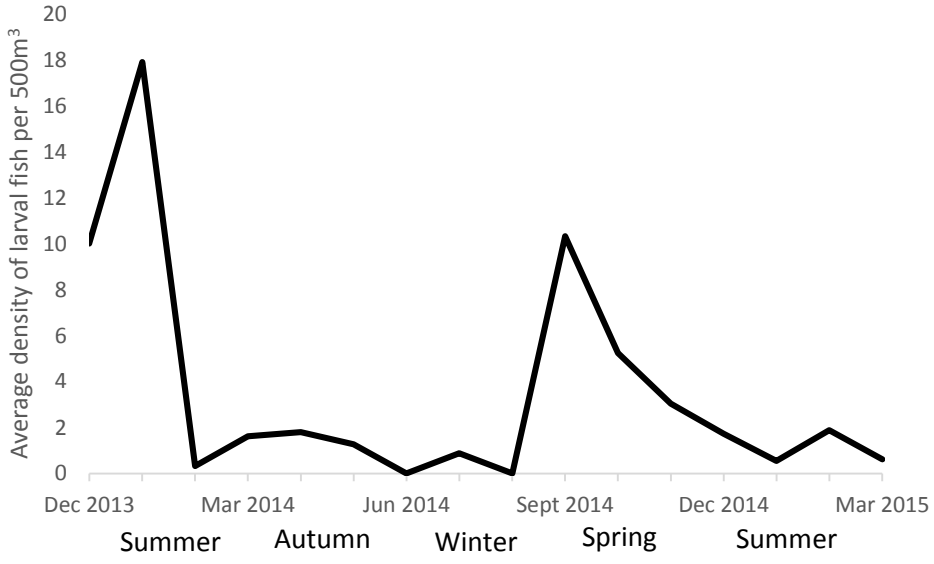



Figure 3.6: Density of the larvae, excluding the larvae from the family Gobiidae, over Dec 2013 – Mar 2015 showing the different seasons.

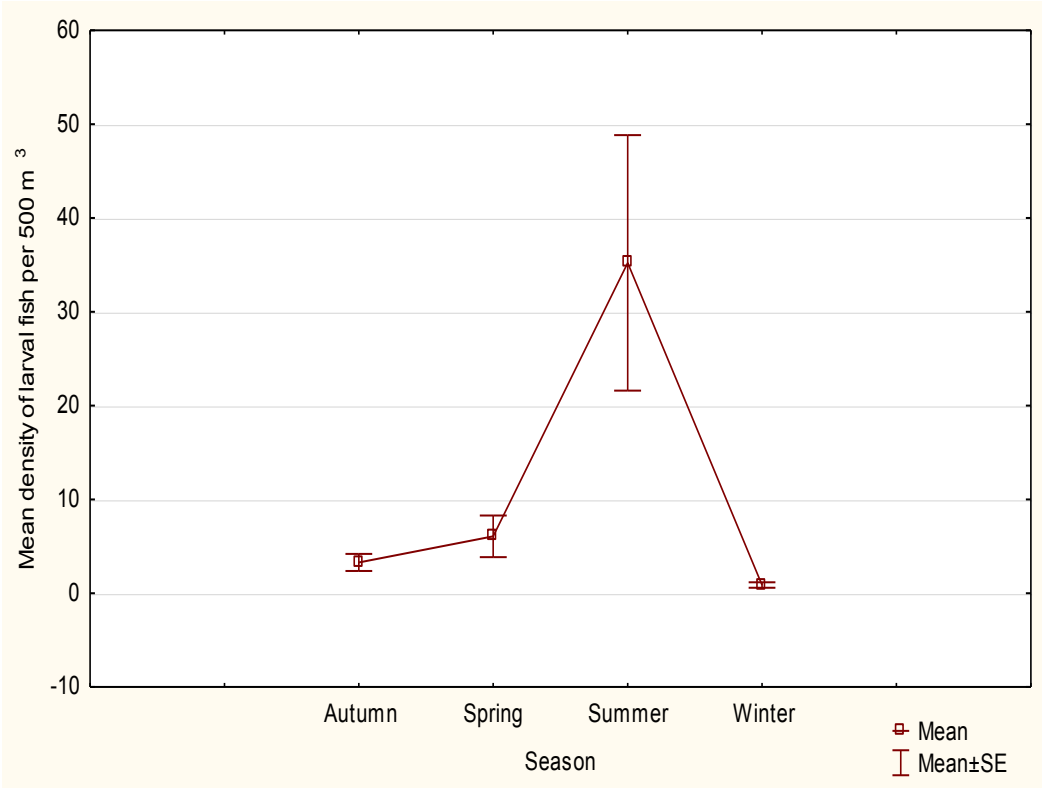



Figure 3.7: Mean density (±S.E.) of larval fish per 500m$^3$ across the four seasons of a year.

Table 3.5: Non parametric test p-value results of the density of larval fish during the different seasons. Statistically significant variables are in bold.

| *Sign test* | Summer | Autumn | Winter | Spring |
|---|---|---|---|---|
| Summer | | 0.546 | **0.041** | 0.773 |
| Autumn | 0.546 | | 0.221 | 0.505 |
| Winter | **0.041** | 0.221 | | 0.221 |
| Spring | 0.773 | 0.505 | 0.221 | |
| *Wilcoxon* | Summer | Autumn | Winter | Spring |
| Summer | | 0.131 | **0.028** | 0.388 |
| Autumn | 0.131 | | **0.046** | 0.260 |
| Winter | **0.028** | **0.046** | | **0.046** |
| Spring | 0.388 | 0.260 | **0.046** | |

### 3.3.3 Oceanographic and environmental factors

The results from the density of larvae compared to the oceanographic and environmental variables are shown in Table 3.6. The only variable linked to a statistically significant difference in larval density was wind speed. Figure 3.8 shows the mean density of larval fish per 500 $m^3$ in relation to the wind speed. A small peak is shown at 5 knots, and a larger peak at 11 knots. The remainder of the wind speeds display similar densities of larvae.

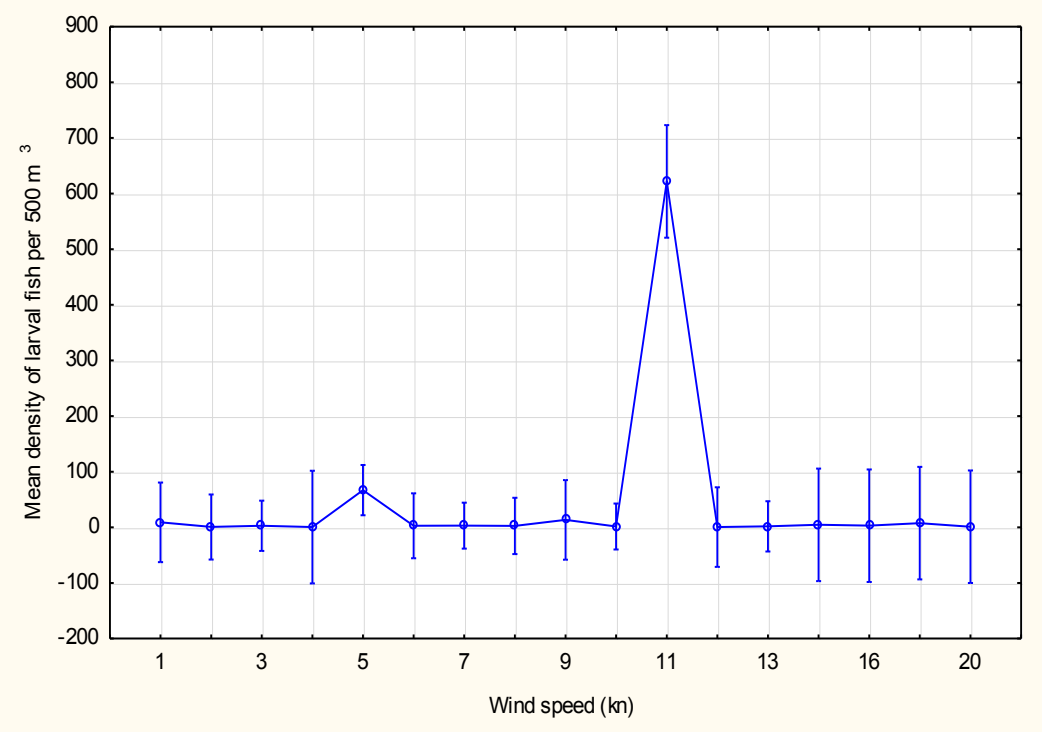



Figure 3.8: Mean density (with 95% confidence intervals) of larval fish per 500 $m^3$ against the wind speed (knots).

Water temperature (Figure 3.9) displayed peaks during the summer months and was the lowest during the winter months. The density of larval fish was near zero throughout the majority of the year, with peaks occurring during summer, with a smaller peak during spring when the water began to get warmer. Wind speed (Figure 3.10) appeared to show a downward trend over the course of the sampling, while entrance current (Figure 3.11) appeared to show an upward trend over the course of the sampling; however, neither appeared to show a relationship with the density of larval fish.

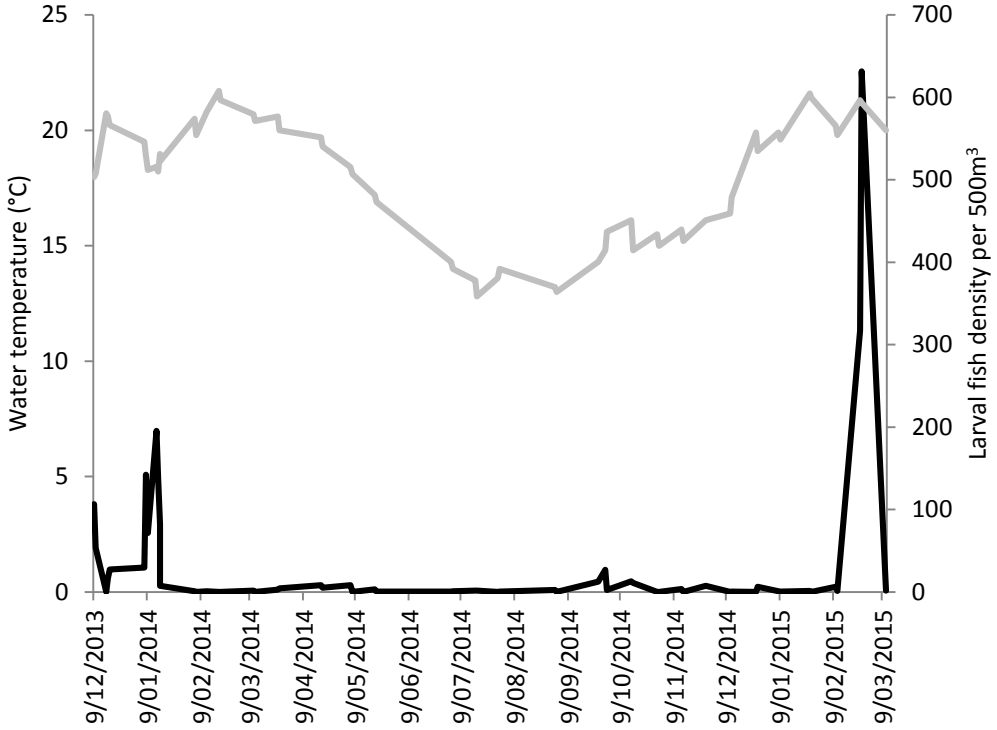



Figure 3.9: Density of larval fish per 500m$^3$ (black line) and water temperature (°C) (grey line) over the sampling period December 2013 to March 2015.

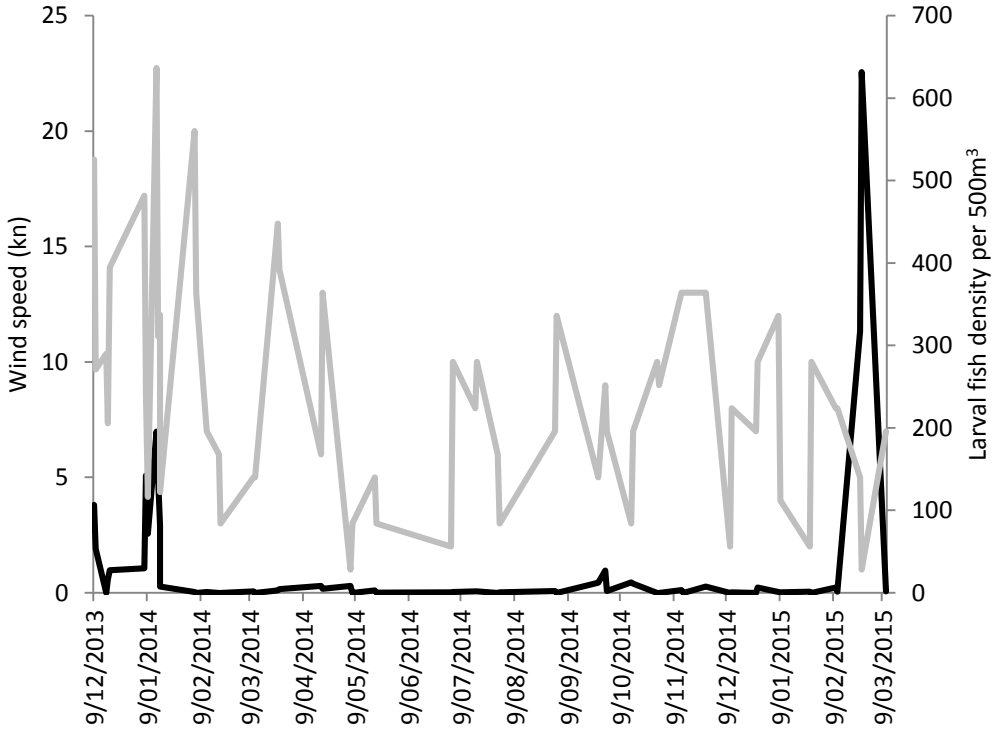



Figure 3.10: Density of larval fish per 500m$^3$ (black line) and wind speed (kn) (grey line) over the sampling period December 2013 to March 2015.

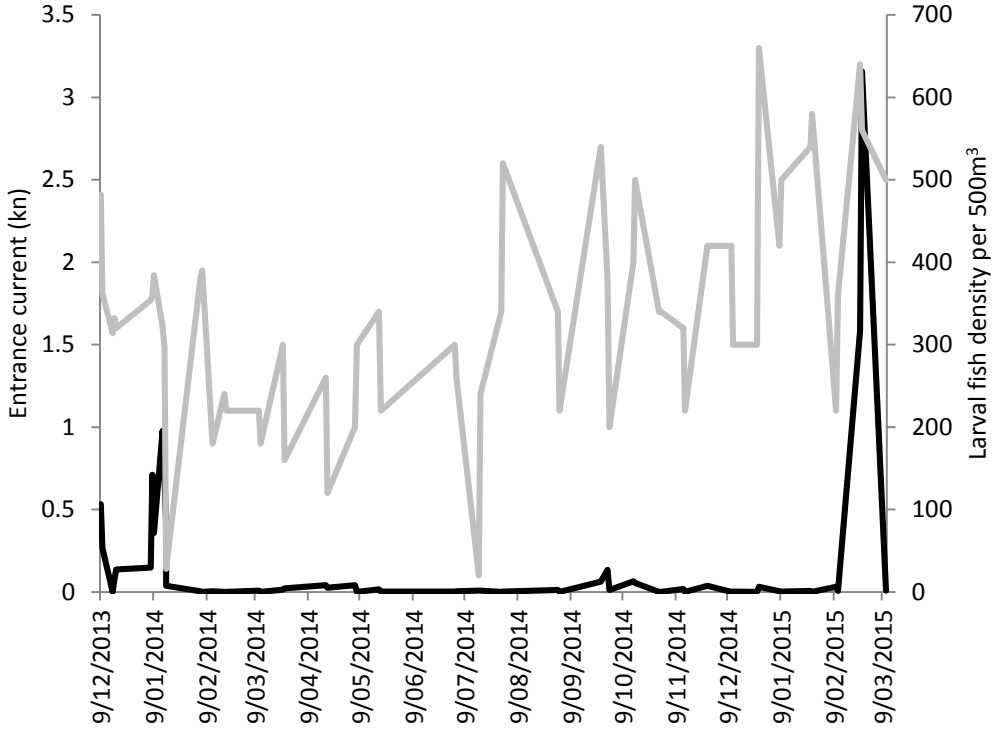



Figure 3.11: Density of larval fish per 500m$^3$ (black line) and entrance current (kn) (grey line) over the sampling period December 2013 to March 2015.

Table 3.6: ANOVA results of the density of larval fish compared to the oceanographic and environmental variables. Statistically significant variables are in bold.

| Water temperature | Wind speed | Entrance current |
|---|---|---|
| P = 0.340 | **P < 0.001** | P = 0.394 |
| F = 2.087 | **F = 9.761** | F = 1.975 |

## 3.4 Discussion

In New Zealand, only 99 fish species are described as larvae (Dolphin, 1997). In this study, the larvae of 13 species from 11 families were caught in this phase of sampling; with the species found being similar to those described in Chapter 2. There is often low diversity in estuaries, with estuarine populations generally consisting of high abundance of a few species, and a relatively large number of species that are considered rare (Ramos *et al*., 2006). No other studies have examined the larval fish assemblages found within Tauranga Harbour, so accurate comparisons of abundance and species present compared to other locations may be influenced by other factors rather than location. As was mentioned in Chapter 2, the range of species found in New Zealand estuaries varies greatly, so while the 13 species recorded in this study appears low; this is not unusual. No new species were captured compared to those caught in Chapter 2. A higher number of species use the harbour as adults (personal observation) so it is possible that larvae of those species do not use the estuary as a larval habitat, or the sampling effort was not sufficient to catch their larvae. The methods used to sample the larval fish in Tauranga Harbour were limited to using stationary channel net, so direct comparisons to other studies are unable to be made. Bonecker *et al*. (2009) states that sampling methods as well as the sampling effort and environmental conditions must be considered when comparing larval fish assemblages within estuaries. The species found in this study were similar to the species found by Roper (1986) in Whangateau Harbour. Species found in both studies were typical estuarine species of northeastern New Zealand, and include; anchovy *Engraulis australis,* pilchard *Sardinops sagax,* piper *Hyporhamphus ihi*, gurnard *Chelidonichthys kumu*, seahorse *Lissocapmus filum*, mackerel *Trachurus* sp., triplefins and Gobiidae.

The species found in higher abundances in this study are characteristic of temperate estuarine larval fish assemblages. Ramos *et al*. (2006) mentioned that studies within temperate estuaries are generally dominated by larval Gobiidae (resident species), or Clupeidae and Engraulidae (estuarine spawners). Gobiidae were the most abundant species found in this study, followed by the Engraulid, *Engrauilis australis*.

The anchovy *E. australis* was found almost year-round except for November 2014, and January and March 2015, which indicates that anchovy could spawn throughout the whole year in the Bay of Plenty. Crossland (1981) found anchovy eggs and larvae throughout October to January in the Hauraki Gulf during the two years he sampled, with higher numbers of larvae found during November and December. He stated that anchovy spawned from November to January; however, Kingsford (1988) mentioned that anchovy and various Clupeids have been captured over longer periods of time, such as nine months or more which is more similar to this study. Pipefish and Gobiidae were also found throughout most of the sampling period (with the exception of July, October-December for pipefish and February, July, October-December for Gobiidae). Crossland (1981) stated that pipefish were occasionally recorded in his study in the Hauraki Gulf, but made no mention of when they were present during the year. Neira *et al*. (1998) mentions that brooding in pipefish occurs multiple times during the year, and that larvae can be caught almost year round in Australia.

The results of this study showed a significant difference between seasons, with winter having the lowest densities of larval fish caught, and summer with the highest densities, characteristic of fish larvae abundance in estuaries (McLusky & Elliott, 2004; Suthers, 2009). Strydom (2003a) found a reduction of larval fish caught in winter, and attributed the lower abundances to the fact that most estuary-dependent fish species spawn during the spring/summer, and thus, this is the time of year that she found peak recruitment. Neira *et al*. (1992) found a peak in abundance of larvae mid-spring to early summer before the water reached its maximum temperature. A peak was observed mid-spring in this present study, which coincides with when the water begins to warm after reaching the lowest temperature in winter. Similar patterns were found in other temperate estuaries, with peaks during summer coinciding with peaks of recruitment for most fish species (Able *et al*., 2006; Neira & Potter, 1994; Pattrick & Strydom, 2014a; Primo *et al*., 2012; Ramos *et al*., 2006). Roper (1986) found a seasonal difference in abundance of larvae, with low densities found in autumn and winter, and peaks in mid-spring to early summer.

Higher abundances of larvae were caught at night compared to during the day, which supports the findings of the previous chapter. Larvae are generally found in higher abundances at night compared to during the day due to various strategies such as diel vertical migration (Hettler & Barker, 1993; Trnski, 2001; Islam *et al*., 2007; Pattrick & Strydom, 2014a), so this present study supports findings such as these.

It was found that there was also variability between the two summers sampled, as well as variability during the seasons throughout the year. The summer of 2013-2014 had a much higher variation in species (19 species from 18 families), but lower numbers of larvae (average of 22.19 larval fish per 500 $m^3$). The summer of 2014-2015 had lower variation in species, with eight species from seven families, but higher numbers of larvae, with an average of 74.30 larval fish per 500 $m^3$. This variability in species between the two summers is possibly attributed to the level of sampling during 2013/14. The sampling over the first summer (2013/14) was across all tides, both ebb and flood, during the day and night, which may have allowed a greater range of species to be caught. The sampling during 2014/15 was at selected times during the flood tide during the day and night, which could account for why fewer species were caught compared to the previous summer. Another possible reason is the abundance of Gobiidae over the summer of 2014/15. When the larvae from the family Gobiidae are excluded from the seasonal analysis, the abundance of the first summer sampled (2013/14) showed higher abundances of larvae compared to the summer 2014/15, which could also explain why it was difficult to find larvae to use in the choice chamber experiment (see chapter 4). Kingsford (1988) found that the abundance of larvae peaked at varying times between years, while Nordlie (2003) pointed out that the presence of marine species at a particular time and place can vary among years, so it seems it is not unusual that a variation was found in species composition and abundance, during the two summers sampled.

Bruno and Acha (2014) state that the main forces involved in the migration of larval and juvenile fish are wind, tides, longshore currents and river run-off, as well as factors related to tidal phase such as salinity, temperature and current velocity. The oceanographic and environmental factors (water temperature, wind

speed and entrance current) recorded for this study appeared to have no influence on the abundance of larvae caught over the 16 months sampled. Although there seems to be a trend of lower abundance when the water temperature was lower, and higher abundances when the water temperature was warmer, there is no statistical significance to confirm these patterns. Although wind speed was shown to have a significant difference on larval density, no clear trend is apparent, so the peaks at 5 and 11 knots must be outliers or isolated incidences where higher densities of larvae were found irrespective of the wind. Chen *et al*. (2014) found the main factors affecting the abundance of larvae were temperature and food availability, pointing out that temperatures of less than 20°C were generally unsuitable for the survival of larval fish. However, this study was based in Taiwan, not New Zealand, so the larval fish found within the temperate waters of New Zealand may have different relative temperature tolerances. Crossland (1981) found that lower water temperatures delayed spawning by 2-4 weeks, so it is possible that the temperature of the water caused the difference in abundance between the two years. Abiotic factors such as temperature and salinity may outweigh biotic factors in determining the species composition and abundance within estuaries (Nordlie, 2003).

Bruno & Acha (2014) found that the combination of wind speed and direction, and the season resulted in high abundances of larval and juvenile fish. The wind speed and entrance current that was recorded in this study appeared to have no discernible impact on the abundance of larvae caught; however, if analyses were able to be performed on the oceanographic and environmental variables and the seasons, perhaps the combination of the variables would have an influence on the abundance. Pattrick & Strydom (2014b) discovered that various species had different responses to oceanographic features such as upwelling events, with some species found to be more abundant in response to an increase in food availability.

There were a small number of issues that arose with this study. The weather during June and August made sampling unsafe, so there are gaps in the samples taken over the year, which may have caused a misrepresentation in the data that was collected. Statistical analyses were difficult to perform on this data due to the low abundance of larvae caught over the 16 months. Research may have been

more revealing if sampling was undertaken weekly instead of fortnightly over the year, although Hernández-Miranda *et al*. (2003) mentions that sampling monthly or more frequently can reveal some of these seasonal signals, so fortnightly sampling should have been adequate for showing patterns of abundance and community composition.

There have been studies that find the flood tide has higher abundances of larvae (Churchill *et al*., 1999; Islam *et al*., 2007), and those who find that ebb tides have higher abundances of larvae (Strydom & Wooldridge, 2005), so the tide chosen (the start of the flood tide) may not have been the time of tide when larvae were most active in Tauranga Harbour. The part of the tide sampled was chosen by the preliminary assessment of the densities caught in Chapter 2. Perhaps further initial analyses of the variability of larval density with tidal flow may have led to a more focussed sampling protocol and thereby enabled a better understanding of larval abundance and variability. Sampling at different locations within the harbour may also provide additional information about larval fish that are found in Tauranga Harbour. Patterns in abundance could be related to other environmental factors, such as salinity, lunar phase, and hydrostatic pressure, so further research would include monitoring those variables as well as the ones recorded in this study.

The species found in this study are characteristic of species found in estuaries in New Zealand. Seasonality plays a strong part in the abundance of larval fish, with peaks during spring/summer, timed with when species generally spawn. The diel cycle also has a strong influence on the abundance of larvae, with higher densities found at night. The oceanographic and environmental variables recorded appeared to have no influence on the density of larvae, so future research will examine a range of variables to establish the parts they play in the life history stages of larval fish within Tauranga Harbour.

# Chapter 4 – Olfactory cues in larval fish

## 4.1 Introduction

Many fish species that are estuary-associated as adults reproduce on the open coast. Consequently, egg and larval development occurs in the coastal zone, and larval and juveniles life stages must migrate from coast to estuary for completion of the fish's life history (James *et al*., 2008). For some species, it is necessary for the larvae to arrive at a suitable settlement habitat, such as an estuarine nursery area, after completing their development in the pelagic environment (Boehlert & Mundy, 1988; Islam *et al*., 2007; Radford *et al*., 2012). The recruitment of larvae into an estuarine nursery area is well documented (Whitfield, 1989; Strydom, 2003a; James *et al*., 2008), and is dependent on a number of physical and biological processes (Brown *et al*., 2005). These in theory include active transport to a potential settlement habitat and a range of environmental cues. However, very little is known about the mechanisms used by larval fish for migration or their selection of settlement habitat.

The mechanisms by which larval fish select a settlement habitat are not well understood (Radford *et al*., 2012). There are few early studies on habitat selection by marine fish larvae as larvae were assumed to have swimming abilities that were irrelevant to dispersal (Leis, 2006) and were considered planktonic, being carried passively by ocean currents (Irisson *et al*., 2009). However, the early development of strong swimming abilities suggests that the dispersal and recruitment of larval fish is in part due to active participation in the settlement process (Atema *et al*., 2002). Fish distribution or settlement patterns cannot be explained solely by the passive dispersal of larvae (Montgomery *et al*., 2001). It has been recorded that larval fish in the late development stages have the ability to travel large distances (Atema *et al*., 2002) having well developed swimming and sensory capabilities (Leis, 2006; Radford *et al*., 2012). Evidence suggests that larvae are able to navigate towards suitable settlement habitats using olfactory cues and reef sounds (Radford *et al*., 2012). Larval swimming abilities have been assessed by Dudley *et al*. (2000); Leis (2006); Stobutzki (1998); Stobutzki and Bellwood (1997) showing that the larvae of some temperate reef and coral reef

fish species have the ability and physiological capability to swim at a constant speed for an extended period of time. Larvae display morphological characteristics that suggest they are able to detect a variety of cues from the outset (auditory, vibration, vision) and, as development progresses, more senses are formed that can be used to orientate towards habitats (olfactory, magnetic, and in some species, electrical) (Kingsford *et al*., 2002). Understanding the behavioural and physiological capabilities of larvae may help to understand recruitment patterns (Montgomery *et al*., 2001).

Larvae are known to use environmental cues to select suitable settlement habitats (Kingsford *et al*., 2002; Huijbers *et al*., 2008), however, information remains limited on how animals are able to find suitable habitats based on such cues without prior experience (Huijbers *et al*., 2012). Sensory information allows for short and long distance navigation and orientation for many taxa (Huijbers *et al*., 2012). Navigational and orientation cues that are known to be used by larval and juvenile fish, can include physical factors such as current speed, temperature, salinity (Huijbers *et al*., 2012); turbidity, chemical stimuli such as olfactory cues (James *et al*., 2008), and other cues such as sound (Gerlach *et al*., 2007), visual, and magnetic cues (Kingsford *et al*., 2002). As settlement usually occurs during darkness when visual cues are ineffective, it highlights the importance of chemical signals received via gustation and olfaction (Coppock *et al*., 2013). Fish demonstrate high chemo-sensitivity, and it is reported that olfaction is the sense primarily responsible for locating settlement habitats (James *et al*., 2008; Coppock *et al*., 2013).

Research on the use of olfactory cues for settlement has concentrated on the larvae of coral reef fishes, showing that they use olfactory cues to detect reefs as settlement destinations (Atema *et al*., 2002; Gerlach *et al*., 2007; Coppock *et al*., 2013), and also predators and conspecifics (Huijbers *et al*., 2012; Coppock *et al*., 2013). Choice chamber experiments have been conducted to assess whether larvae are able to detect a difference between ocean and lagoon waters (Atema *et al*., 2002), between conspecifics and live corals (Lecchini *et al*., 2005; Coppock *et al*., 2013), between different reefs (Gerlach *et al*., 2007), between different habitats

(Huijbers *et al*., 2008, 2012; Radford *et al*., 2012), and between estuarine and riverine waters (James *et al*., 2008).

Here, I report an experiment conducted to examine the use of olfaction by larvae of the pelagic marine kingfish, *Seriola lalandi lalandi* (a subspecies of *S*. *lalandi*, Family Carangidae), which is found around New Zealand and Australia. Spawning occurs in offshore surface waters in spring/summer (November to February) (Neira, *et al*., 1998) in water temperatures above 17°C (Poortenaar *et al*., 2001; Moran *et al*., 2007). Eggs are pelagic with a single oil droplet, 1.0-1.4 mm in diameter, while larvae are 2.7-3.8 mm upon hatching, reach notochord flexion at 4.7-6.7 mm, and transformation at 9.0-19.4 mm. Larvae are heavily pigmented with all fins formed by 9.0 mm, prior to transformation (Neira *et al*., 1998).

Estuarine water is quite different from coastal water with highly variable salinities due to the freshwater inputs (Kennish, 2002), and home to a range of habitats that are known to be used as nurseries for larval fish (Beck *et al*., 2001). The water is often warmer due to the shallow nature of the estuary (Moyle & Cech, 2004) and more turbid due to the run off from the surrounding urban, agricultural and industrial lands (Kennish, 2002). In order to test the hypothesis that larval fish are able to make a distinction between water from different sources, an experiment was designed to test whether larval kingfish can differentiate between oceanic and estuarine water, and to establish which water type was the most attractive to the larvae. Kingfish are a pelagic species, larval kingfish do not typically occur in estuaries, and no kingfish larvae were found during the sampling conducted for Chapters 2 and 3. As such, kingfish were therefore a good candidate for an experiment designed to test behaviour based on olfactory senses. Kingfish larvae were available from the NIWA hatchery at Bream Bay. It was hypothesised that kingfish larvae are using olfactory senses to choose between water sources for habitat selection and that they would prefer oceanic water.

## 4.2 Methods

Experiments were conducted at the University of Waikato Coastal Marine Field Station (CMFS) in Tauranga, on the 30th April 2015. The field station is situated at Sulphur Point next to Tauranga Harbour, by the entrance to Waikareo Estuary.

### 4.2.1 Study animals

Flexion stage larval kingfish *S. l. lalandi* (Figure 4.1) were collected from the NIWA aquaculture facility in Bream Bay on the 29th April 2015 where they had been bred from captive broodstock. The larvae were transferred into two holding tanks at the CMFS lab in Tauranga. The holding tanks were kept at room temperature (20°C). The larvae were fed a mixture of *Artemia* and rotifers twice daily while held at the lab. For the experiment, each larva was only used once. Following a trial, used larvae were placed into a second holding tank and all larvae euthanised using clove oil at the conclusion of the experiment (as requested by NIWA).

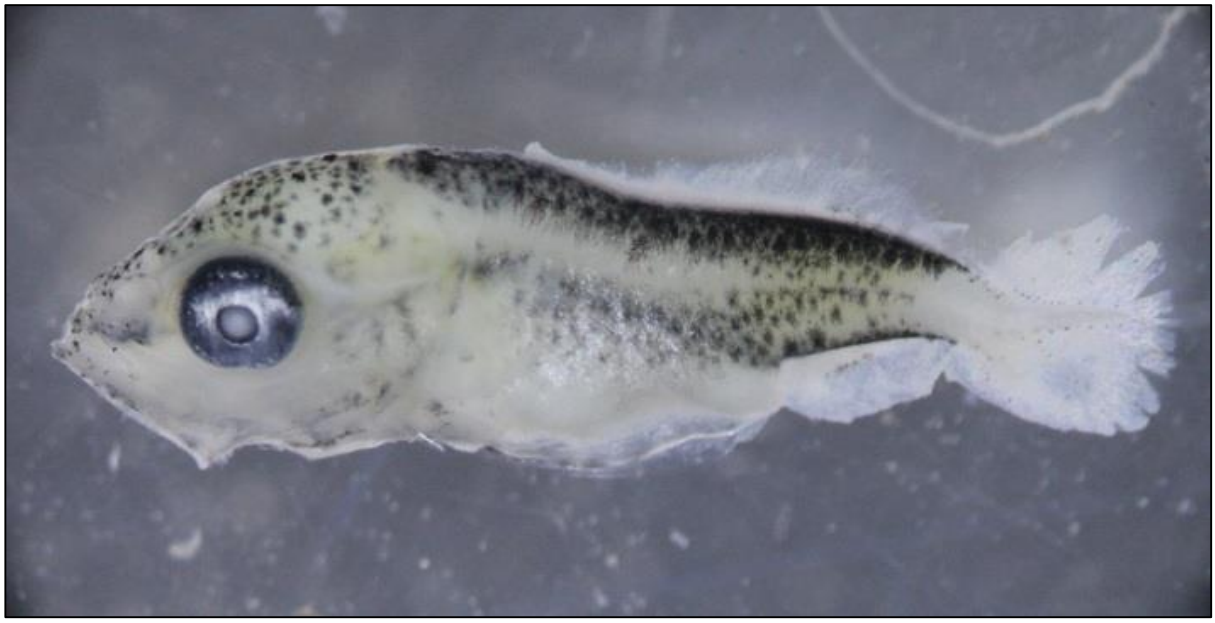


Figure 4.1: Larval kingfish, 9 mm long.

### 4.2.2 Water collection and storage

Two 1000 L storage tanks were set up at the CMFS for holding water for the experiment. Water from two sources, oceanic and estuarine, was collected and

stored separately in the two 1000 L tanks. The oceanic water was collected in 20L buckets from an area approximately 20 km off the Tauranga coastline on the 20th and 24th March 2015. Estuarine water was collected from the Sulphur Point boat ramp, at the mouth of the Waikareo Estuary on the outgoing tide on the 20th April 2015 (Figure 4.2). Both the estuarine and oceanic water was kept at room temperature (20°C) for the duration of the experiment. Salinity varied between water types with estuarine water at 29 ppt (polyhaline) and oceanic water at 37 ppt (euhaline). Immediately prior to each trial, the water from the two 1000 L tanks was pumped into the 20 L buckets attached to the experimental apparatus, oxygenated by the transfer between the tanks and buckets (Figure 4.3).

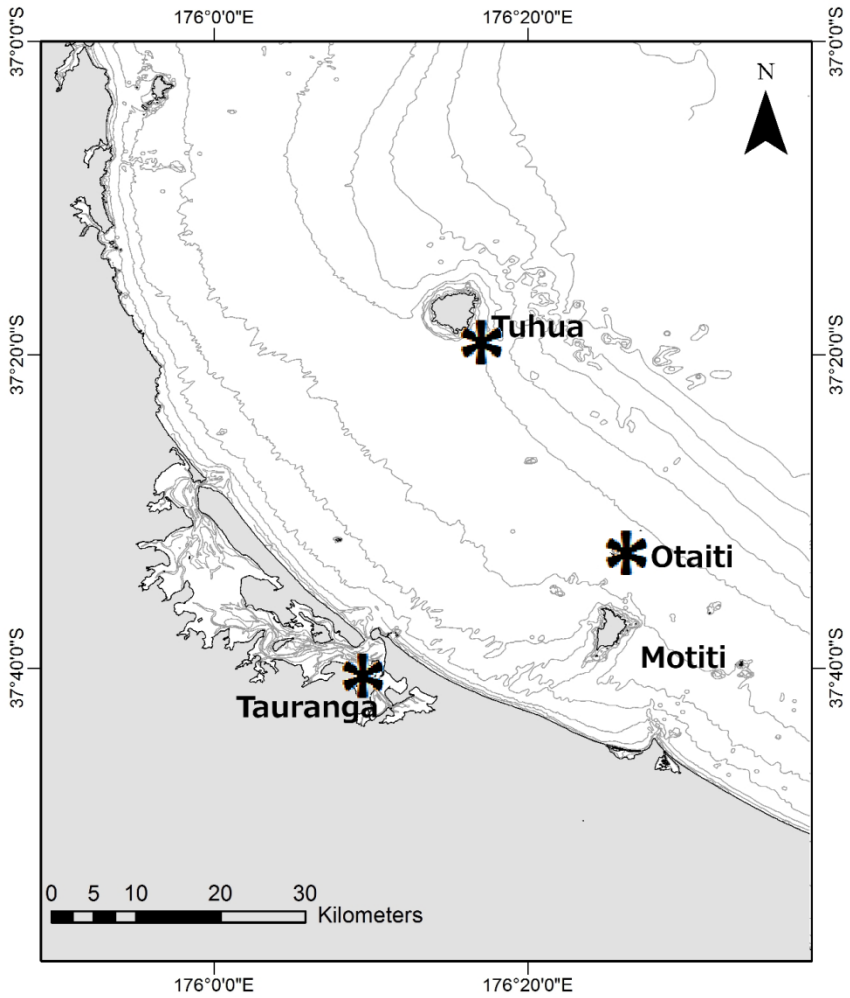



Figure 4.2: Location of the water collection sites in Tauranga Harbour (estuarine water), Mayor Island (Tuhua) and Astrolabe Reef (Otaiti) (oceanic water), marked by asterisks.

### 4.2.3 Choice chamber

The choice chamber used for this experiment was made of black perspex, 115 cm long by 24 cm wide by 16 cm high (Figure 4.4). The main chamber holds approximately 18 L of water. A piece of thick polystyrene was placed in the bottom of the flume to provide a white background for contrast so that the larvae were able to be seen more easily. Mesh sponges were placed in front of the funnels. This allowed water flow but prohibited larvae from entering the funnel chambers. A sponge was placed on top of the outflow weir to catch the larvae if they were unable to swim into the flow. Two 20 L buckets were attached to the inflow end of the flume (shown in the experiment set up in Figure 4.3), one containing oceanic water and one containing estuarine water. Two Resun SP-500 submersible pumps were used to pump water through 8mm pipe into the choice flume at a rate of 3.2 L per minute (one pump in each bucket, 1.6 L per minute per side). One side of the chamber held oceanic water, and the other side held estuarine. The trials were conducted during the day with natural light over the chamber.

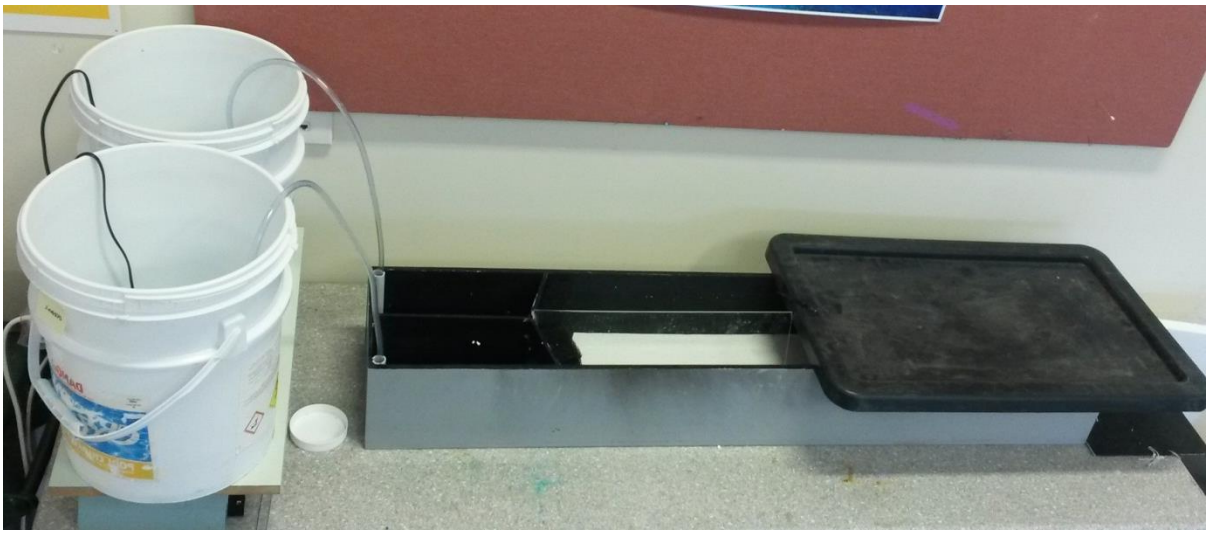


Figure 4.3: Photo of the experiment set up, the black lid covering the mix area.

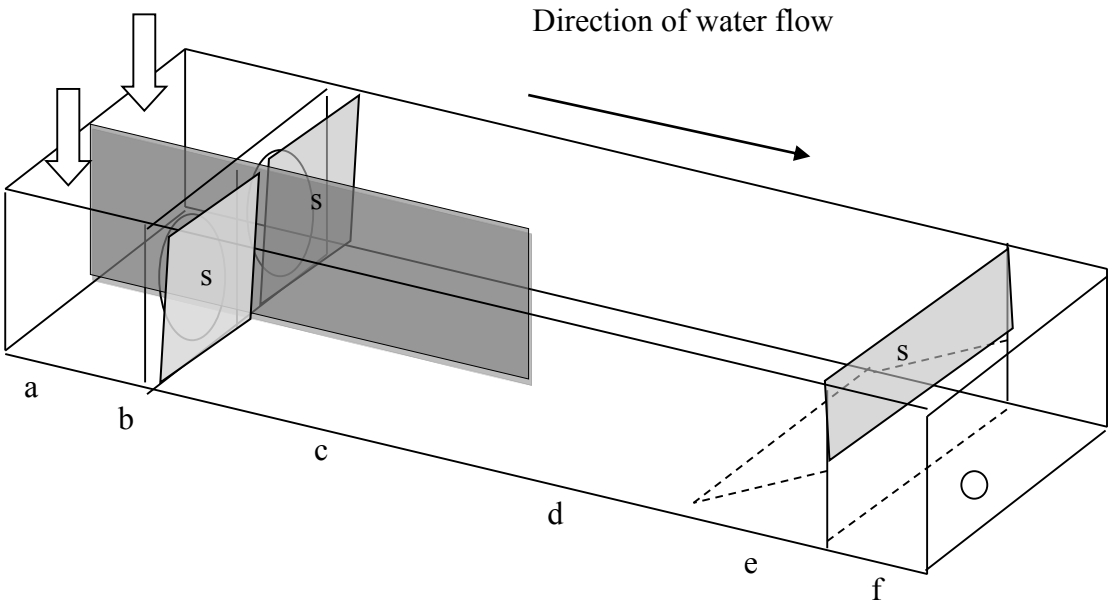



Figure 4.4: Choice chamber schematic, overall size 115 × 24 cm, water depth ~8 cm. (a) inflow compartments (26 cm long), two water sources (arrows) can be switched manually by moving two hoses; (b) funnels with sponges (marked with an 's') in front to homogenise turbulence; (c) barrier separated channels (43 cm long); (d) mixing area where larvae were placed at the start of each replicate (46 cm from edge of channel barrier to top of ramp); (e) ramp to outflow weir and sponge (marked with an 's') to contain test fish; (f) outflow weir and drain pipe.

A dye test was run prior to the experiment to demonstrate that the chamber contained two distinct flowing water masses which stayed separated until the mix area with minimal eddies or turbulence (Figure 4.5). The mix area was considered a neutral area for observation purposes, however, as seen in Figure 4.5, the two water flows stayed mainly separated.

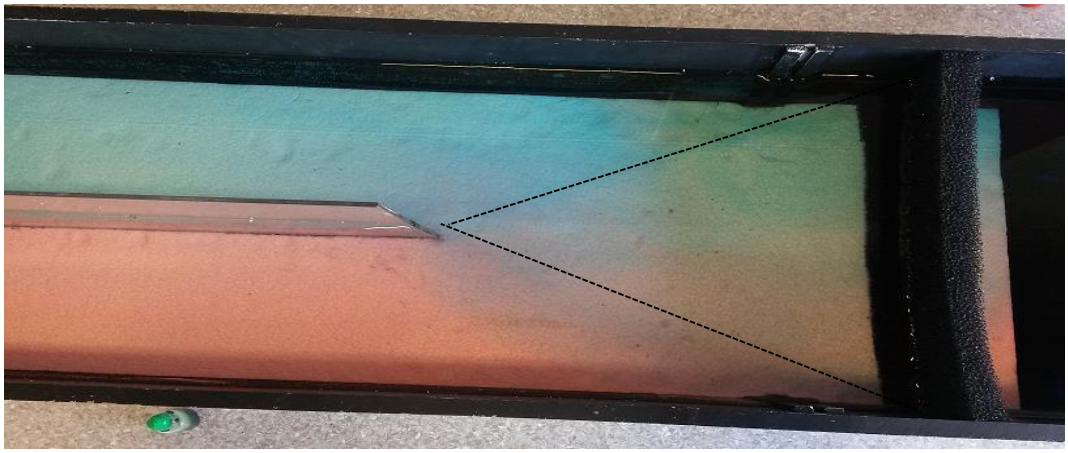


Figure 4.5: Photo showing the dye test in the choice chamber. The dotted lines show the edge of the mixing area.

### 4.2.4 Experimental protocol

The flume was filled with a mixture of estuarine and oceanic water prior to the start of the trials. 10 larvae were placed into the mix area of the flume with both water sources running, allowing two minutes for the larvae to acclimatise to the water. A black lid was placed over the mix area and the larvae were observed for five minutes, with the number of larvae in each section recorded every minute. The flume was divided into three sections and labelled A – C for the purposes of recording position (Figure 4.6). After the observation period, the larvae were caught and placed in the post-experiment holding tank. This concluded a trial. During the experiment, the water sources were switched as a control for possible bias. Thirteen trials were run, using a total of 130 larvae. Six trials were run with estuarine water in section A, and seven were run with oceanic water in section A.

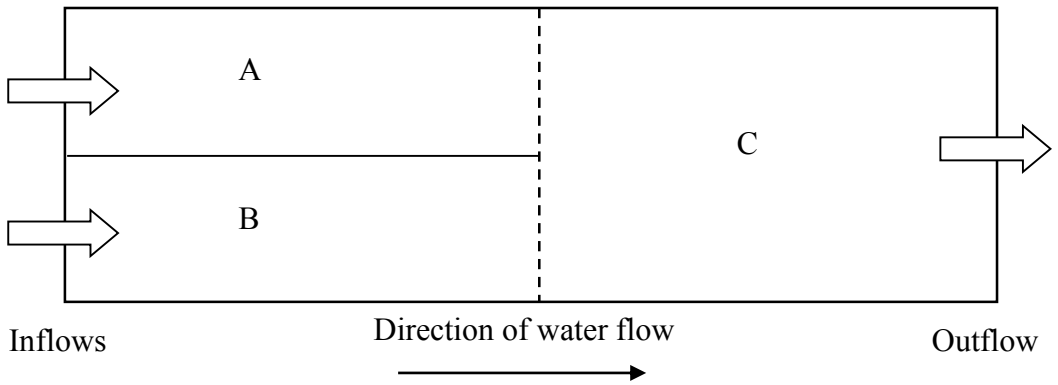



Figure 4.6: Diagram of the sections within the choice flume. A and B are the two water sources while C is the mix/neutral area that was covered by the black lid.

### 4.2.5 Data analysis

The data were collated and analysed in Microsoft Excel. An analysis approach similar to that used by James (2008) was used to test for preferential fish positioning. A student's t-tests were performed to test for differences between (i) the mean number of larvae that were present in either the oceanic or estuarine side of the chamber over each five minute observation period, and (ii) the number of larvae present on each side of the chamber during the final minute of the observation period. A chi-square test was used to detect if a statistical significance existed between larvae that participated and larvae that did not participate. A

larvae was deemed to participate when it swum into either of the two flowing water sources (larvae that remained within the dark mix area for the duration of the observation period and did not swim up either of the channels did not participate). Observed frequencies were compared to expected frequencies. The expected frequency was 50% (65) of the tested larvae (130). The null hypothesis was accepted if the chi-square value was less than the critical value of 3.841.

Chi-square tests were then conducted to analyse if the water choices by the larval fish in the experiment were statistically significant. This approach was taken by Dixson *et al*. (2008) and Radford *et al*. (2012). Larvae that did not participate were excluded from this analysis, as in Huijbers *et al*. (2012). The expected frequency was 50% (14.7) of the tested larvae (29.4). All chi-square tests were conducted on the sum of the averages over the 5 minute observation period, and on the sum of fish recorded in the final minute of the observation period.

## 4.3 Results

The results of the choice chamber experiment are shown in Figures 4.7, & 4.8 and in Table 4.1. Over the course of a five minute trial (tallies made at 1 minute intervals), an average of 22% of fish participated (made a choice). Of the participating fish, 68% chose the oceanic water and 32% chose the estuarine water (Figure 4.7). When only examining the final minute of each observation period, 27% participated, and of those 74% chose the oceanic water and 26% chose the estuarine water (Figure 4.8).

The results of the chi-square tests are shown in Table 4.1. The null hypotheses of no difference between numbers of larvae participating and not participating, and no difference between numbers of larvae choosing estuarine and oceanic waters were tested. The null hypotheses were rejected as the chi-squared value was higher than 3.841 (bold values), showing that the test indicated a difference between number participating and between the water sources (for the final minute of the experiment). The p-values confirm that the mean number of larvae found in the oceanic or the estuarine waters was significantly different (Table 4.1).

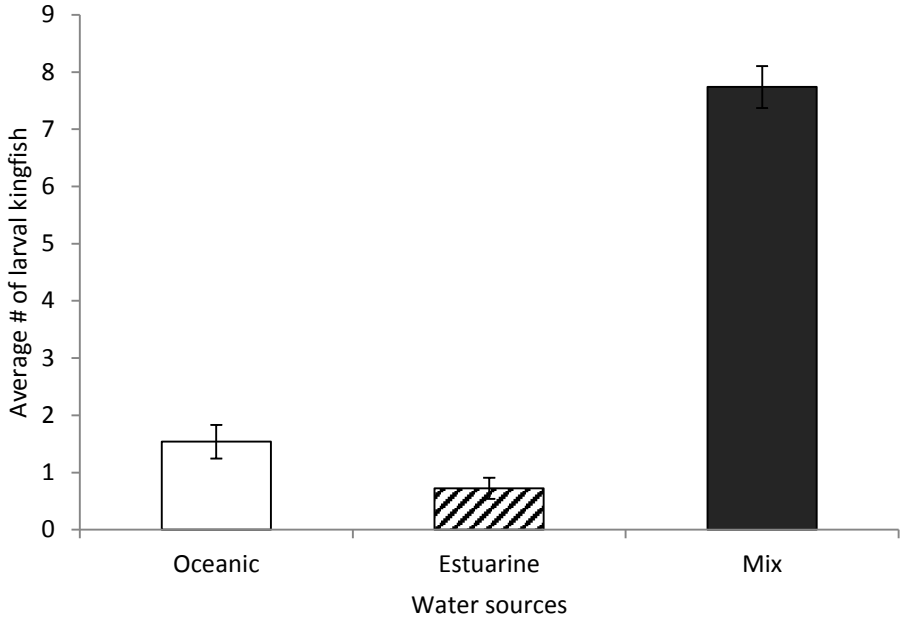



Figure 4.7: Mean preference (±SE) of larval kingfish over the 13 replicates found in each of the water sources throughout the 5 minute duration of the observation period.

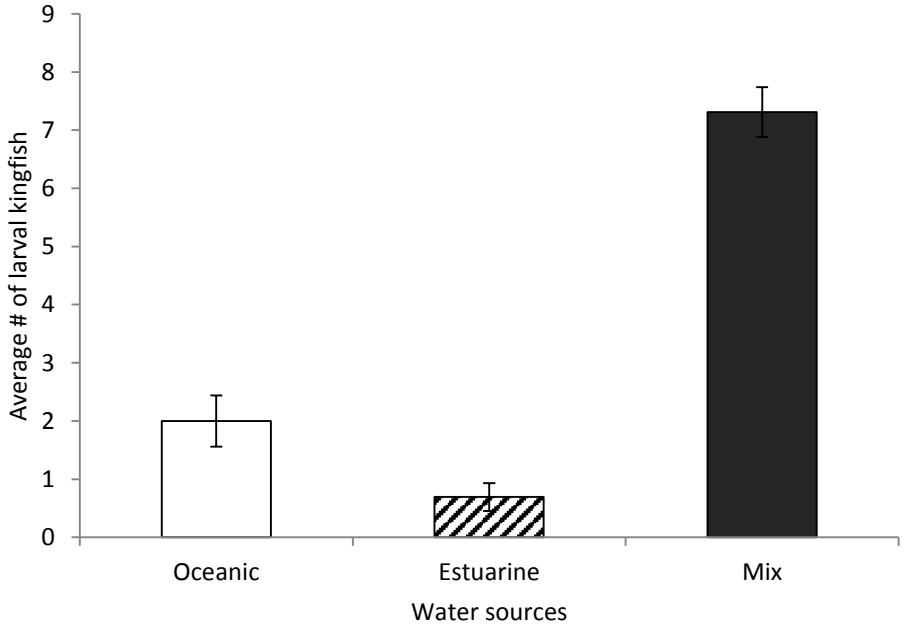



Figure 4.8: Mean preference (±SE) of larval kingfish over the 13 replicates for each of the water sources during the final minute of the 5 minute observation period.

Table 4.1: p-values from the t-tests and chi-square test values for the larvae for participation vs non participation, and oceanic vs estuarine waters in the choice chamber experiment. Significant values are shown in bold.

| | p-value | $x^2$ | |
|---|---|---|---|
| | | Participation vs non participation | Oceanic vs estuarine |
| Over full duration | **0.0280** | **38.996** | 3.822 |
| In final minute | **0.0149** | **27.692** | **8.257** |

## 4.4 Discussion

The results of this experiment demonstrate that larval kingfish preferentially positioned themselves in oceanic water when given the choice between oceanic and estuarine water. The results of the t-tests over the full duration and in the final minute of the observation period showed there was a significant difference between the average numbers of fish in each of the two water sources. The chi-square tests had differing results depending on if the full duration was tested, or if just the final minute of the observation period was tested. Interestingly, the number of larval fish that chose not to participate in the experiment was high, with around 75% of the larvae choosing neither water types and instead remained in the mixed area or few flushed to the back of the flume.

Various water flows (0.3 L, 0.75 L, 1 L, 1.5 L and 1.6 L per minute per channel) were tested to gauge the swimming capacity of the larvae and identify a water velocity that would induce up-current swimming. Flows of less than 1.5 L per minute appeared to have no effect on the larvae, with larvae swimming in a non-directional manner or floating around in the mix section of the flume. Flows greater than 1.5 L per minute caused many larvae to be pushed into the sponge at the back of the flume if they did not swim against the current or stayed near the edge of the chamber. However, at greater speeds some fish did show up-current swimming behaviour. It was decided to use the water flow of 1.6 L per minute per channel, as from personal observations this appeared to induce the strongest swimming response from the larvae.

To encourage larvae to make a choice the mixed area of the chamber was covered with a black plastic lid. When the chamber was dark the larvae swam towards the lighter part of the chamber (the channels with the different water sources), so this was added into the experimental protocol for the replicates. Larval fish can display positive phototaxis (Mueller & Neuhauss, 2010). This could explain why light traps are commonly used when catching larval fish, and why they are selective with the species and size of fish they catch (Hickford & Schiel, 1999). It seemed logical to use the attraction of light to induce the larvae to make a choice between the two water sources.

Kingfish are a pelagic marine species and, during the course of sampling for Chapters 2 and 3, were not caught within Tauranga Harbour. The results of this study are consistent with the *a priori* hypothesis that the larvae of this species would not be attracted towards estuarine water and would preferentially select oceanic water. To my knowledge, no other studies have investigated the attraction to oceanic water/avoidance of estuarine water by a pelagic species. Montgomery *et al*. (2001) suggests that it is unlikely that the larvae of pelagic species actively select specific habitats. It is therefore possible that results of this study may not be habitat selection by kingfish larvae but rather avoidance of low salinity estuarine waters. It was interesting to observe that even though these kingfish were hatchery reared they still exhibited the behaviour of attraction to the oceanic water or, conversely, avoidance of the estuarine waters. This suggests that this behaviour was either learnt in the brief period post-hatch (15-20 days) or is a function of natal imprinting.

For many species, the larval stages are required to choose a suitable settlement site to complete their lifecycle (Radford *et al*., 2012). Estuarine-associated fish species generally spawn offshore, and their larvae must make their way into an estuary (James *et al*., 2008). Strydom (2003a) suggests that surf zones are temporary accumulation areas for larvae before they complete their recruitment into an estuary. Larvae are able to control their dispersal through processes such as vertical migration and tidal stream transport; although these dispersal strategies are dependent on oceanographic processes (Montgomery *et al*., 2001). As larvae are thought to play an active role in selecting a settlement site (Atema *et al*., 2002),

they must have a way of navigating towards suitable habitats (Radford *et al*., 2012).

Various physical factors (such as water chemistry, light, magnetic fields) (Huijbers *et al*., 2012), and a range of cues such as 'smell' or sound (Kingsford *et al*., 2002) are thought to be used by fish larvae for orientation within the marine environment. Chemo-sensory cues appear to be used for selecting settlement sites, although the majority of studies researching this have been conducted using small spatial scales (Montgomery *et al*., 2001). Coppock *et al*. (2013) stated that the primary cue was thought to be olfaction, due to the ineffectiveness of visual cues during the night when settlement occurs.

Choice chambers have been used to test the use of olfactory cues with coral reef species (Gerlach *et al*., 2007), and to a lesser extent, with temperate marine species (James *et al*., 2008; Radford *et al*., 2012), indicating choice chambers are an appropriate method of examining the response of aquatic animals to chemical cues. James *et al*. (2008) conducted a choice chamber experiment with postflexion *Rhabdosargus holubi* (family Sparidae) larvae, assessing the attraction between three different water types (riverine, estuarine and marine water), and finding that the *R*. *holubi* showed a preference for estuarine water over marine water. Radford, *et al*. (2012) trialled *Pagrus auratus* (family Sparidae) larvae, and assessed the attraction between five different water types within the Kaipara Harbour (sea grass beds, harbour entrance, Asian date mussel beds, artificial seawater and artificial seawater which had seagrass soaked in it). He found that larval *P*. *auratus* indicated a preference for seawater taken from above seagrass habitats over other habitats in the harbour. These two studies indicate that this type of investigation is suitable for temperate species as well as the coral reef fishes that are more frequently studied using these methods.

Gerlach *et al*. (2007) and Radford *et al*. (2012) conducted choice chamber experiments with reef fish and snapper larvae, respectively. Both used a "mini flume", a chamber 13 x 4 cm, vastly different from the 115 x 24 cm chamber used in this experiment. The water flow used in the mini flume was 0.1L/min per channel. After running a trial in the choice chamber with a water flow of 1.6L/min

per channel, the rationale for using a mini flume with a much lower water flow, such as in Gerlach *et al*. (2007); Radford *et al*. (2012), became apparent. The kingfish larvae were tiny (0.9 cm long) in comparison to the flume (115 cm) making them hard to see (Figure 4.9), and only some had a strong enough swimming ability to be able to swim up the flow into one of the channels.

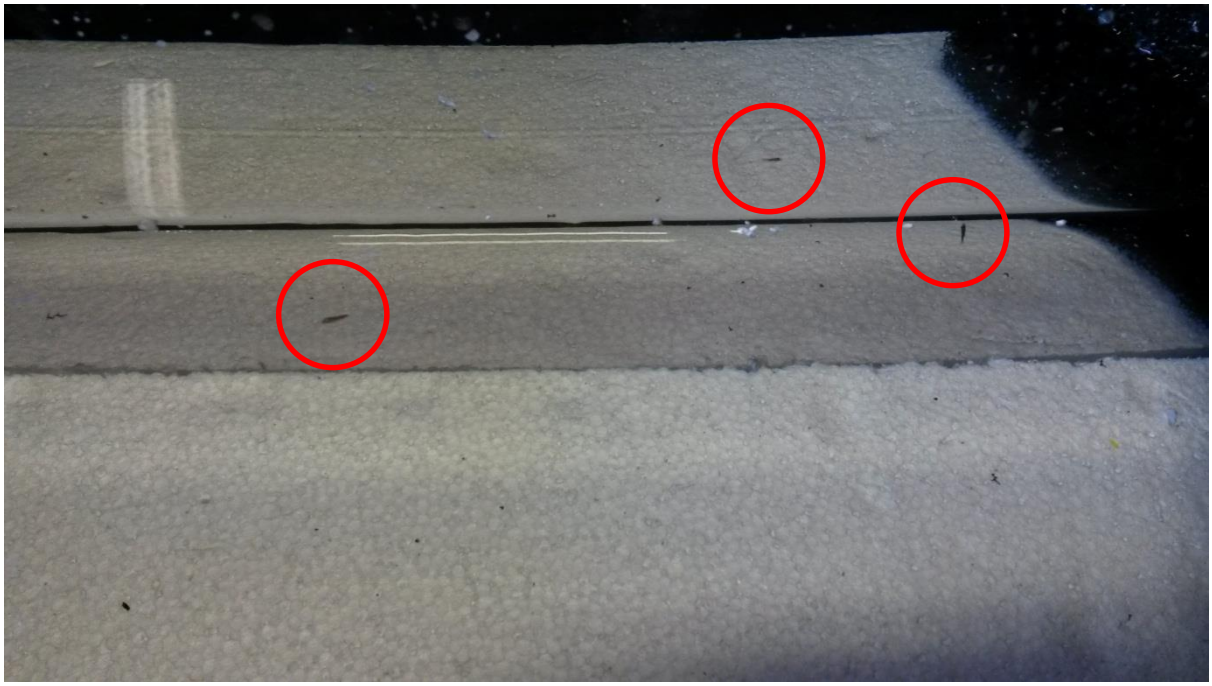


Figure 4.9: Photo showing the kingfish larvae in the choice chamber. Larvae are circled in red.

Montgomery *et al*. (2001) mentioned that temperate larvae do not have the strongest swimming capabilities compared to coral reef fish larvae. Although, when larvae of similar taxonomic groups from tropical and temperate waters were compared there was little evidence to suggest that tropical larvae were stronger swimmers than temperate larvae (Dudley *et al*., 2000). However, this possible misrepresentation of the abilities of temperate larval fish could attest to why the larvae of coral reef fish are often the subject of choice chamber experiments. Dudley *et al*. (2000) investigated the sustained swimming ability of a range of reef fish species found in the temperate waters of New Zealand and, as a comparison to pelagic species, found that *Trachurus* sp. larvae (family Carangidae) were able to swim for up to 379 hours at a speed of 13.5 $cm^3$ $s^{-1}$ (equivalent of 0.81 L per minute in the flume used here), a standard speed used when assessing the

sustained swimming ability of larval fish. The test species kingfish are from the same family as the *Trachurus* sp. larvae, and it is thought that they may have comparable swimming abilities, however, the larvae used in this study were smaller in size than the *Trachurus* sp. used by Dudley *et al*. (2000) (9.0 mm compared to 12.3-46.8 mm) and the water flow used was double the standard speed.

Following the methods of Coppock *et al*. (2013), Gerlach *et al*. (2007) and Huijbers *et al*. (2012), the replicates in this experiment were planned to be run as a single fish per trial. However, once it became clear that not all larvae had the same swimming capabilities (or would choose to swim), it was decided to use multiple fish for each replicate. This approach was taken by Atema *et al*. (2002) and James *et al*. (2008).

As a pilot study, this experiment was trialled on juvenile yellow eye mullet *Aldrichetta forsteri,* which displayed schooling behaviour. Due to this behaviour, and the assumption that the kingfish larvae would behave in a similar manner, the experiment was designed to observe the larvae every 5 seconds in a 2 minute period, recording which section of the choice chamber the school was in at those 5 second intervals, following the methods used by Coppock *et al*. (2013) and Dixson *et al*. (2008). However, after running a trial with the kingfish larvae and discovering they did not exhibit schooling behaviour, it was necessary to revisit the way the larvae were observed and choice recorded. It was decided to record the number of larvae in each chamber every 60 seconds for the five minutes duration of the trial. This approach is similar to that used by Atema *et al*. (2002) and James *et al*. (2008).

As the salinity of the estuarine water was not adjusted to match the oceanic water, a possible fish behaviour might have been a response to differences in salinity as opposed to the 'smell' of the waters. The oceanic water (37 ppt) had a higher salinity than the estuarine water (29 ppt) meaning it was denser and would sink below the estuarine water. For future experimentation it would be prudent to adjust the salinity so it was equal for both water types removing the variable of different salinities. Similarly, fish could be presented estuarine water of normal vs.

adjusted salinity (37 ppt) to further address the mechanisms by which choices are being made. In nature salinity and 'smell' will co-vary where estuarine water mingle with coastal waters and both may be an important navigational cues (Huijbers *et al*., 2012). Studies investigating the 'smell' of habitats are useful for learning more about larval fish behaviours, as it is known that olfaction is the most important sense used for locating settlement habitats (Coppock *et al*., 2013; James *et al*., 2008).

If logistics had allowed, it would have been preferable to have a smaller flume with a lower flow rate, and to run the experiment with individual fish. Recording the fish repeatedly or when the fish crossed from one side to another such as in James *et al*. (2008) or Huijbers *et al*. (2012) would give more informative results. If further research was to be undertaken, it would follow the methods of studies such as those mentioned. Larvae of estuarine-associated species (such as *P. auratus*) or common estuarine species (such as the anchovy *Engraulis australis* or triplefins (family Tripterygiidae)) would also be appropriate species to test the attraction of estuarine water versus oceanic water. Unfortunately, on this occasion it was not possible to source sufficient numbers of estuarine larval fish to conduct the experiment (Chapter 3). Although this experiment doesn't look at estuarine species *per se*, it does provide additional evidence that larval fish can orientate themselves towards different water types. The kingfish larvae examined here were able to detect differences between water sources, preferentially selecting oceanic water of estuarine water, suggesting that olfactory cues may play an important part in the selection of habitats by larval fish.

# Chapter 5 – General conclusions

## 5.1 Thesis design

The purpose of this thesis was to further understand how larval fish use Tauranga Harbour. The three objectives of this study were to:

1. Establish which species of larval fish are present in the harbour and to investigate the tidal and diel abundance of larvae.
2. Examine the temporal distribution of larval fish and establish which species are present over the course of the year.
3. Investigate whether kingfish larvae show a preference for either oceanic or estuarine water.

## 5.2 Summary

Estuaries are important nursery habitats for many fish species (Francis *et al*., 2005) on account of their high primary production and shallow warm waters (Jordan, 2012). It is well known that anthropogenic impacts can degrade the ecological value of estuaries (Kennish, 2002), yet there is little understanding of the effect this might have on the life history of the larval fish that utilise these habitats (França *et al*., 2012). Knowledge of the distribution and migration patterns of fish larvae will help us better understand the potential for human activities to impact fish stocks, allowing us to identify nursery habitats which can be protected. Information on larval fish within New Zealand remains limited. No previous research has been undertaken in the Bay of Plenty, so the findings of this study can provide baseline information for future research.

### 5.2.1 Summer sampling conclusions

In Chapter 2 of this thesis, I investigated what species of fish use Tauranga Harbour during their larval stage, and when they were active in the water column. This was investigated by looking at the tidal and diel abundance to assess if behaviours were shown to result in export out of or retention within the estuary. The range of species caught included mainly common reef fish, and a few commercially and recreationally important species such as gurnard, snapper and jack mackerel. The larvae were found in higher abundances at night, which

supports the hypothesis made at the start of the study, similar to the findings of (Hettler & Barker, 1993; Trnski, 2007; Islam *et al*., 2007; Pattrick & Strydom, 2014a). It was hypothesised that larvae would be found in higher abundances on flood tides suggesting a tidal behaviour to enhance retention within the estuary, however, the results of this study showed higher abundances of larvae on the ebb tides at night. Diel phase was the primary variable found to affect the abundance of larvae, followed by the tidal phase, so perhaps the findings of higher abundances on the ebb tides at night are not overly significant for the larvae using the harbour as a nursery.

During this study, some larvae were observed avoiding the ropes of the net, which only provides stronger evidence that larvae are able to control their position within the water column and are not merely passive particles at mercy of the current. It is thought that the salps and the sea lettuce that clogged the net also caused the larvae to avoid it as samples containing large amounts of salps and sea lettuce were found to contain lower numbers of larvae.

Samples that had larger amounts of seagrass were found to have higher numbers of larvae is similar to the findings of Kingsford & Choat (1985) who found a positive correlation between drift algae, fish and invertebrates in estuaries and oceanic waters. The findings from this study indicated that perhaps floating seagrass mats were an important habitat for larval fish. (Kingsford, 1993) found that biotic structures such as jellyfish, marine snow and flotsam can provide shelter that may influence the survival and distribution of larval fish, so it would be interesting to find out if larvae are attracted to the seagrass in particular, or any marine flotsam. A pilot study was attempted in an effort to investigate this further, for part of this thesis, however on the two days chosen for sampling, no seagrass mats were found within the harbour and, due to time constraints, the project was set aside.

### 5.2.2 Temporal distribution conclusions

In Chapter 3 of this thesis, I investigated the temporal distribution of larvae found within Tauranga Harbour, looking at when different fish species were present in

their larval stages to discover if seasonality and physical features had an effect on the abundance of larval fish. A range of species were found across the 16 months sampled, similar to the species found in Chapter 2 of this thesis. Larval fish abundance peaked in summer and was the lowest in winter, as hypothesised, similar to the findings of (Roper, 1986; Neira & Potter, 1994; Able *et al*., 2006; Ramos *et al*., 2006; Primo *et al*., 2012; Pattrick & Strydom, 2014a). Higher abundances of larvae were found at night, similar to the findings of Chapter 2, possibly due to diel vertical migrations. It was hypothesised that water temperature would have an effect on the abundances of larvae present; however, none of the physical factors measured appeared to have an effect on or show a trend for larval fish abundance. Water temperature is linked to seasonality, however, and seasonality did have an effect on larval fish abundance, so perhaps there was not sufficient data to show a significant trend for this study.

Sampling was not completed in June and August due to unsafe weather conditions, which may have impacted the analyses on the seasonality of abundance of larvae. As these two months are in autumn and winter, it was predicted that the larval fish abundance would be fairly low compared to the abundances found in summer.

Table 5.1 below shows a summary of when larvae are expected to be caught, or have been caught in temperate waters of both Australia and New Zealand. When compared to the spawning times of species in Table 1.2, it is apparent why larvae of the majority of species appear to be seasonal with most spawning occurring over the spring and summer months. Table 3.3 shows the species found in this study and when they were found during the year. The spawning times in Table 1.2 shows that a greater range of species could have been caught compared to those listed in Table 3.3 In fact, a number of species can be found as larvae throughout all, or the majority of the year, so it is unclear why these species were not caught in this study. A possible theory is that the species that use the harbour as juveniles or adults, do not use the estuary as larvae. Another theory is that the times sampled were not when the larvae were most active/abundant in the water column, or there was an insufficient amount of sampling effort performed and sampling in more locations and more often is required to accurately represent the larvae present in the harbour over the course of a year.

Table 5.1: Calendar of fish larvae of species that could be found in Tauranga Harbour. Modified from Crossland (1981); Kingsford & Milicich (1987); Neira *et al*. (1998); Roper (1986).

| Species | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Anchovy *Engraulis australis* | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| Pilchard *Sardinops sagax* | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| Gurnard *Chelidonichthys kumu* | | | | ■ | ■ | ■ | ■ | ■ | | | | |
| Jack mackerel *Trachurus novaezelandiae* | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| Jack mackerel *Trachurus declivis* | ■ | ■ | ■ | ■ | | | | | | | | ■ |
| Bigbelly seahorse *Hippocampus abdominalis* | ■ | ■ | | | | | | | | | | ■ |
| Parore *Girella tricuspidata* | ■ | ■ | ■ | ■ | ■ | | | ■ | ■ | ■ | ■ | ■ |
| Snapper *Pagrus auratus* | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| Leatherjacket *Meuschenia scaber* | ■ | ■ | | | | | | | | ■ | ■ | ■ |
| Kingfish *Seriola lalandi* | ■ | ■ | ■ | ■ | ■ | | | | | ■ | ■ | ■ |
| Oyster blenny *Omobranchus anolius* | ■ | ■ | ■ | ■ | ■ | | | | | ■ | ■ | ■ |
| Long-finned goby *Favonigobius lateralis* | ■ | ■ | ■ | ■ | | | | | ■ | ■ | ■ | ■ |
| Blue warehou *Seriolella brama* | | | | | | | | ■ | ■ | ■ | ■ | |
| Tommyfish *Limnichthys fasciatus* | | | ■ | ■ | ■ | | | | | | ■ | |

### 5.2.3 Choice chamber conclusions

In Chapter 4 of this thesis, I attempted to determine whether kingfish larvae were able to distinguish between waters from oceanic or estuarine origins, and establish if a preference for one of the water types existed. The kingfish larvae exhibited behaviours that indicated a preference for the oceanic water, or possibly an avoidance of the estuarine water, which supports the hypothesis that they would not be attracted to the estuarine water due to being a pelagic marine species. However, it is not certain whether the larvae preferred the oceanic water, or were simply avoiding the estuarine water.

For the purposes of this thesis, an estuarine dependent species would have been preferred to use in the choice chamber experiment, as it would have been possible to test the hypothesis that larvae are actively seeking refuge within the estuary. Species such as anchovies, gobies and triplefins were found in high abundances for the sampling undertaken for Chapters 2 and 3, and would have been the ideal species to use in the choice chamber experiment as they are estuarine dependent species, not a marine pelagic species like kingfish. The variation in abundance between summers meant that when larvae were sought for the choice chamber, none were to be found, so kingfish were used in this experiment as they were able to be obtained via methods other than fishing for larvae. The kingfish used in this experiment were larvae from captive broodstock at the NIWA Bream Bay Aquaculture Park. The larvae were kindly donated by Michael Bruce for the use of the experiment and were euthanised after the experiment was completed.

It was interesting to compare the larvae used in the experiment to the illustrations in Neira *et al*. (1998) and those in the ID guide (see appendix, Figure 27). It appears that even though the larvae were 9 mm in length, their fins were not as developed and pigmentation not as heavy as the wild caught larvae illustrated, suggesting that the bred *S. l. lalandi* were not as developed as wild larvae of the same body length. The literature states that all fins are developed by 9 mm (Neira *et al*., 1998), which is why larvae of that length were requested from the NIWA Bream Bay Aquaculture Park, however the larvae clearly did not have fully formed fins (Figure 4.1), which would have affected their ability to swim in the choice flume.

Dudley *et al*. (2000) assessed the sustained swimming abilities of temperate reef fish from New Zealand waters and, as a comparison, also assessed a few pelagic species of fish. The larvae they used were larger than the larvae used in this study (9.0 mm), with the smallest larvae being 12.3 mm long, and the largest 46.8 mm. Radford *et al*. (2012) used settlement stage *P*. *auratus*, but did not mention the size of the larvae. Huijbers *et al*. (2012) used larvae that ranged in size from 8-30 mm in length, while James *et al*. (2008) used larvae that were 13-15 mm in size. The 9 mm larvae used in this study may have been too small in size for significant results to be produced. The use of a mini flume such as in Gerlach *et al*. (2007) and Radford *et al*. (2012) may also help larvae to make a choice instead of the large flume that was used in this study.

## 5.3 Conclusions and future research

### 5.3.1 Further research

The sampling method used in this study (stationary channel net) may limit the species that are caught as larvae. Sampling using a scoop net was used during the pilot study in 2013 and on occasion during the summer periods of 2013/14 and 2014/15 as well. Different species of larvae were sometimes caught using the scoop net compared to the species that were caught by the stationary channel net. The range of species that were caught during the research for this thesis are not indicative of what species use the estuary, as larvae or adults. Further research would include using different sampling methods to gain a more accurate idea of what additional species use the harbour as a nursery.

Sampling at a certain part of the tides, during the day and night, during the course of the year, was performed for Chapter 3 of this thesis; however, it is possible that the wrong part of the tide was sampled, which could have caused possible skewing of the results of what larvae are present within the harbour. However, there were still a number of larvae caught over the 16 months studied, and these results provide information on what larvae are using the harbour as a nursery. Future research should look more closely at what part of the tide should be sampled, or sample over the entire flood and ebb tides as in Chapter 2, to make sure that the optimal times for catching larval fish are sampled. It would also be beneficial to include sampling to coincide with the lunar phases in an effort to

establish if that has an effect on the abundance of larval fish. As annual variability was seen between the summers of 2013/14 and 2014/15, it would be interesting to continue sampling over upcoming summers to assess the extent of the variability between years.

As Tauranga Harbour is home to a range of habitats (seagrass meadows, mangroves, mudflats), it would be interesting to sample across these habitats in an effort to establish if all habitats are used by larval fish, and which ones are the most used by larvae. Other parts of the harbour should also be sampled to investigate the spatial distribution of larvae as well as the temporal distribution. Looking further into the use of floating seagrass mats by larvae would also be a consideration for future research in an effort to establish how larvae use the harbour.

In order to more accurately test the active transport of larvae into an estuary, by the use of olfactory cues, future research could include a choice chamber experiment using larvae of estuarine dependent fish species. I believe the choice chamber experiment may have been more accurate and had more significant results if larger larvae had been used. Wild caught larvae may have had stronger swimming abilities due to being more developed than farmed larvae. Failing using larger larvae, the use of a mini flume would be recommended for future research.

### 5.3.2 General conclusions

While the findings of this study support typical larval fish behaviour in regards to seasonality and the diel cycle, (with larvae found in higher abundances during the spring and summer months, and at night), there is insufficient evidence to draw any substantial conclusions about the use of Tauranga Harbour as a nursery ground for larval fish. As larvae do use the estuary, I believe the information collected here on larval fish abundance across seasons and the tidal and diel cycle can be used to form a baseline. However, for this research to be used for other purposes, such as predicting fish stocks or assessing the effects of anthropogenic impacts on the larval community, further research on how larval fish use Tauranga Harbour is necessary.

# Chapter 6 - References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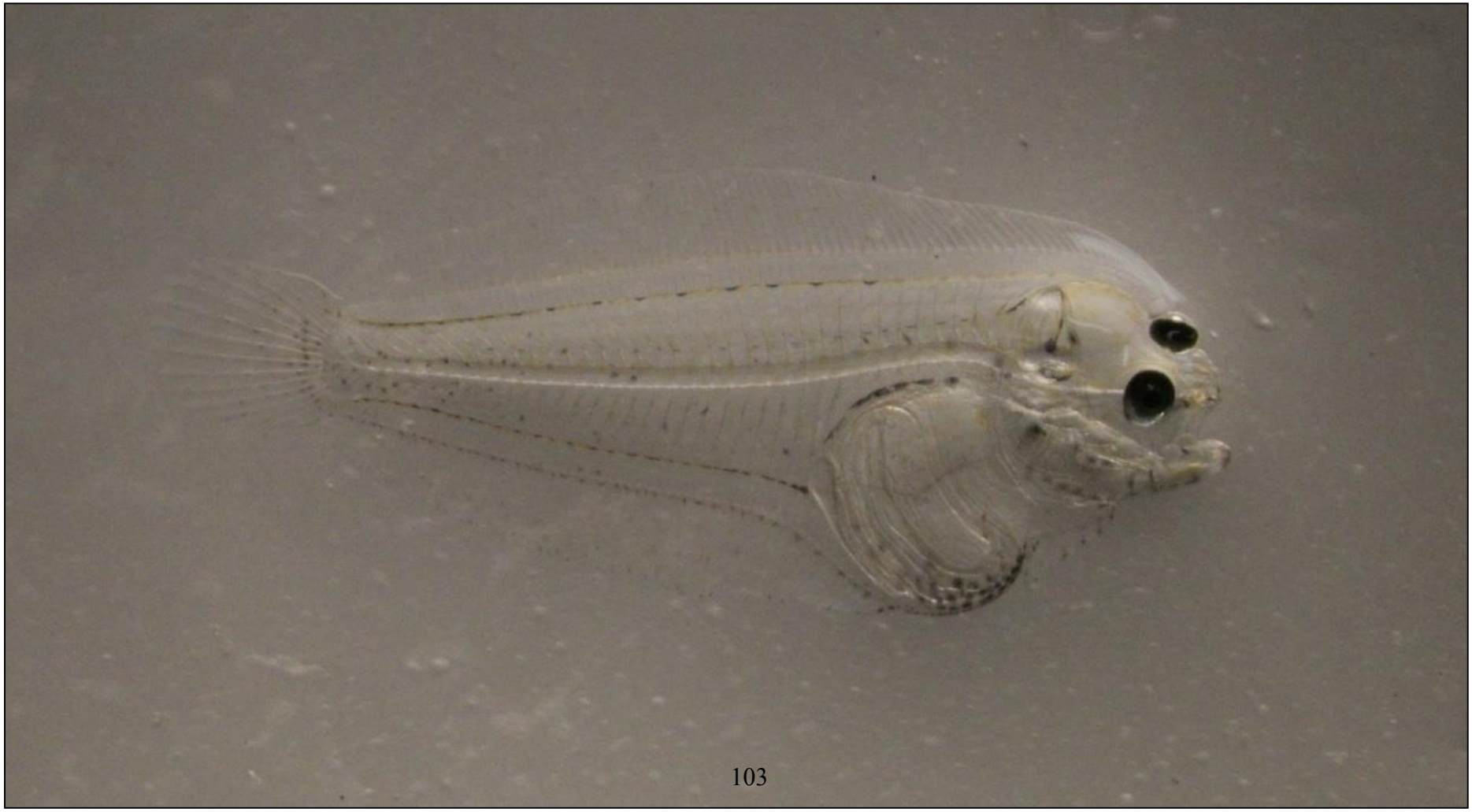
# –Appendix 1

Identification guide to Larval fishes of Tauranga Harbour, New Zealand: an identification guide.

Originally submitted June 2014 as a Special Topic for BIOL588, University of Waikato.



## Abstract

Little is known of the early life stages of fishes found within New Zealand waters. Larval stages have been described for less than 10% of New Zealand fish species. Studies on larval fishes have mainly been focused in northeastern New Zealand, and around the Otago Peninsula in the South Island. This guide gives a brief introduction to the methodology used in identifying and describing larval fish, with explanations of terminology and characters used. Fifteen larval species accounts have been included, from nine families, and six orders. These species were caught within an estuary of Tauranga Harbour, in the Bay of Plenty, New Zealand. This guide aims to be a resource for larval fish identification to aid future research.

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# 1 Chapter One - INTRODUCTION

## 1.1 Introduction

The most comprehensive identification guide for New Zealand fish contains 923 species (Paulin *et al*., 1989), however this is greatly outdated, with 25 years of new discoveries and taxonomic revisions not accounted for. Paul (2000) mentions that over 1200 marine cartilaginous and bony fishes are known from New Zealand waters, and that a much smaller number (150-200) are commonly seen or caught. The number of larval fish species described around the world is relatively low, with only 10% of species known as larvae (Kendall & Matarese, 1994). In New Zealand, 99 species are known in their larval form (Dolphin, 1997). A number of studies have examined aspects of larval fish ecology and biology in New Zealand (see section 1.1.1 and Table 1). However, no single publication covers the identification of all known larval fish found within New Zealand. This produces problems when studying larval fish, as correct identification relies on the availability of multiple resources, some of which are over 30 years old. Being able to identify which species you have caught is a very key element of the ecological or biological research. There is an obvious need for a publication that covers identification of the larvae of common fish species found within New Zealand.

This guide seeks to provide information on identification of larval fish species found in Bay of Plenty estuaries, as an aid for future research, and to provide direction for identifying fish that are not in this guide. Where possible, references have been given that will provide further information about larval identification for a family or species.

### 1.1.1 Ichthyoplankton research in New Zealand

There are a number of unpublished theses that provide information on the identification of larval fish in New Zealand (Elder, 1966; Robertson, 1973; Frentzos, 1980; Thompson, 1983; Kingsford, 1986; Dolphin, 1997; Keith, 2000; ). The majority of the studies on larval fish in New Zealand have taken place in northeastern North Island, or around Kaikoura and the Otago Peninsula in the South Island (Table 1). Very little work has been done around Central North Island, and none in the Bay of Plenty.

Table 1: Outline of studies on larval fish undertaken in New Zealand

| Region | Type of study | Reference(s) |
|---|---|---|
| Northeastern North Island | Seasonality | Thompson (1983)<br>Kingsford (1986)<br>Roper (1986) |
| | Vertical distribution patterns | Kingsford (1986)<br>Kingsford and Choat (1986)<br>Kingsford & Milicich (1987) |
| | Horizontal distributions | Crossland (1980, 1981b, 1982)<br>Kingsford (1986)<br>Cole (1987)<br>Kingsford and Choat (1989)<br>Tricklebank *et al*. (1992) |
| | Age & growth | Kingsford (1980)<br>Park (1984)<br>Milicich (1986)<br>Atkinson (1987)<br>Kingsford & Milicich (1987) |
| | Onshore transport | Kingsford (1986)<br>Kingsford and Choat (1986) |
| North Island – Hauraki Gulf | Distribution & seasonality | Crossland (1981b, 1982) |
| South Island – Otago Peninsula | Descriptive | Anderton (1906)<br>Graham (1939)<br>Graham (1956) |

| | | |
|---|---|---|
| | Larval fish and eggs | Robertson & Raj (1971)<br>Robertson (1973, 1975a, 1975b, 1976, 1978, 1980, 1981) |
| South Island – Kaikoura Peninsula | Horizontal and vertical distribution | Hickford (2000) |
| South Island – Chatham Rise | Ichthyoplankton assemblages | Robertson (1976, 1978)<br>Robertson *et al*. (1978)<br>Robertson & Mito (1979) |

### 1.1.2 Species included

This guide provides descriptions for the larvae of 15 fish species from nine families and six orders. The species included were caught from Tauranga Harbour in the Bay of Plenty, New Zealand, during 2013-2014. Additional species were caught but have not been included in this guide due to not being positively identified, time constraints or inadequate literature regarding their descriptions.

Table 2: Families represented in coastal marine waters from New Zealand, with the families mentioned in this guide in bold. References to families included and not included in this guide. Adapted from Neira *et al*. (1998).

| Family | References of larvae from families both included and not included in this guide. | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Crossland (1981b). | Crossland (1982). | Moser *et al*. (1984). | Okiyama (1988). | Leis and Trnski (1989). | Matarese *et al*. (1989). | Moser (1996). | Neira, *et al*. (1998). |
| Acanthoclinidae | ▪ | ▪ | | | | | | |
| Anguillidae | | | | ▪ | | | | |
| Antennariidae | | | | ▪ | ▪ | | ▪ | |
| Arripidae | | ▪ | | | | | | ▪ |
| Blenniidae | ▪ | ▪ | | | | | ▪ | ▪ |
| Bothidae | ▪ | ▪ | ▪ | ▪ | ▪ | | ▪ | |
| Bovichthyidae | | | | | | | | ▪ |
| **Carangidae** | ▪ | ▪ | | | | | ▪ | ▪ |
| Carapidae | | | ▪ | | | | ▪ | |
| Centrolophidae | | | | | | | ▪ | ▪ |
| Cepolidae | | ▪ | | ▪ | ▪ | | | |
| Clinidae | ▪ | ▪ | | | | ▪ | ▪ | |
| **Clupeidae** | ▪ | ▪ | | | | | ▪ | ▪ |
| Congiopodidae | | | ▪ | | | | | |
| Congridae | ▪ | ▪ | | | | | ▪ | |
| Creediidae | ▪ | ▪ | | | | | | ▪ |
| Diodontidae | ▪ | ▪ | ▪ | ▪ | | | ▪ | |
| Eleotridae | ▪ | ▪ | | | | | ▪ | ▪ |

| Family | References of larvae from families both included and not included in this guide. | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Crossland (1981b). | Crossland (1982). | Moser, *et al*. (1984). | Okiyama (1988). | Leis and Trnski (1989). | Matarese, *et al*. (1989). | Moser (1996). | Neira, *et al*. (1998). |
| **Engraulidae** | ▪ | ▪ | | | | | ▪ | ▪ |
| Exocoetidae | ▪ | ▪ | | | | | ▪ | |
| Galaxiidae | | | | | | | | ▪ |
| Gempylidae | ▪ | ▪ | | | | | ▪ | ▪ |
| Girellidae | | | | | | | | ▪ |
| Gobiesocidae | | ▪ | ▪ | ▪ | | ▪ | ▪ | |
| Gobiidae | | | | | | | ▪ | ▪ |
| **Hemiramphidae** | | | ▪ | ▪ | ▪ | | ▪ | |
| **Kyphosidae** | | | | | | | ▪ | |
| Labridae | ▪ | ▪ | ▪ | ▪ | | | ▪ | |
| Leptoscopidae | | | | | | | | ▪ |
| **Monacanthidae** | ▪ | ▪ | ▪ | ▪ | | | ▪ | |
| Moridae | ▪ | ▪ | ▪ | ▪ | | ▪ | ▪ | |
| **Mugilidae** | ▪ | ▪ | | ▪ | ▪ | | ▪ | |
| Muraenidae | ▪ | ▪ | | | | | ▪ | |
| Myctophidae | | ▪ | | | | | ▪ | |
| Odacidae | | ▪ | | | | | | ▪ |
| Percophidae | | ▪ | | | | | | ▪ |

| Family | References of larvae from families both included and not included in this guide. | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Crossland (1981b). | Crossland (1982). | Moser, *et al*. (1984). | Okiyama (1988). | Leis and Trnski (1989). | Matarese, *et al*. (1989). | Moser (1996). | Neira, *et al*. (1998). |
| Pinguipedidae | | | | | | | | ▪ |
| Pleuronectidae | ▪ | ▪ | ▪ | ▪ | ▪ | | ▪ | |
| Retropinnidae | | | ▪ | | | | | |
| Scomberesocidae | | ▪ | | | | | ▪ | ▪ |
| Scombridae | ▪ | ▪ | | | | | ▪ | ▪ |
| Scorpaenidae | | ▪ | | | | | ▪ | ▪ |
| Serranidae | | | | | | | ▪ | ▪ |
| **Sparidae** | ▪ | ▪ | | | | | ▪ | ▪ |
| Sternoptychidae | | ▪ | | | | | ▪ | |
| Syngnathidae | ▪ | ▪ | | | | | ▪ | ▪ |
| Trachichthyidae | ▪ | ▪ | | | | | | ▪ |
| Trichiuridae | | ▪ | | | | | ▪ | ▪ |
| **Triglidae** | ▪ | ▪ | | | | | ▪ | ▪ |
| Tripterygiidae | ▪ | ▪ | ▪ | ▪ | | | ▪ | |
| Uranoscopidae | ▪ | ▪ | | ▪ | | | ▪ | |
| Zeidae | ▪ | ▪ | ▪ | ▪ | | | ▪ | |

## 1.2 Methods

### 1.2.1 Source of material

Some of the larval fish described in this guide were caught using a set channel net 1 m by 2 m with 0.8 mm mesh or with a scoop net in Tauranga Harbour, New Zealand. A detailed description of methodology is in the process of being written. Other fish mentioned are common species found within or near the harbour.

### 1.2.2 Identification of larval fishes

Larval fish often look quite different to their adult counterparts, which can make their identification difficult (Moser, *et al*., 1984). Larval fish can be identified using literature descriptions, biochemical methods, the series method, or by rearing larvae in a laboratory until they have identifiable adult characteristics (Neira, *et al*., 1998). The larval fish described in this guide were identified to family, genus or species level using published and unpublished literature and, following that, by using the series method.

#### 1.2.2.1 Literature descriptions

There is a reasonably large collection of unpublished literature which is useful for the identification of larval fish, however caution needs to be taken as the quality of the descriptions and illustrations can be poor and cause misidentifications, particularly for early works. Published identification books for larval fish found in Australia (Neira, *et al*., 1998), indo-pacific (Leis & Trnski, 1989; Leis & Carson-Ewart, 2004), Northeast pacific (Matarese, *et al*., 1989) and Japan (Okiyama, 1988) have shown to be useful for identification of species that are also found in New Zealand.

#### 1.2.2.2 Biochemical and series identification methods

Using biochemical methods is not usually practical for identifying specimens caught during field studies because of the high cost and time involved. However, biochemical methods can be used in conjunction with the series method to great effect (Leis & Carson-Ewart, 2004). The series method is the process of identifying larval fishes by using known characters from adult fish, such as fin meristics, to identify the largest larva or smallest juvenile, and then creating a developmental series of specimens using characteristics such as general morphology or pigmentation. Larval characters are more useful for smaller specimens, and adult characters become less useful. A large number of specimens is required (Neira, *et al*.,

1998). This method can lead to false identification of a species if a similar species is mixed in with an incorrect series (Leis & Carson-Ewart, 2004).

#### 1.2.2.3 Laboratory rearing

A large amount of equipment is needed for rearing of eggs and larvae which can be expensive. Rearing is an excellent way of identifying a species from unknown eggs, or for creating a series of developmental stages for eggs from a known adult. However, for taxonomic work it is not advisable to solely rely on reared larvae, as the pigment, meristic characters and body proportions can develop differently to wild larvae (Leis & Carson-Ewart, 2004).

### 1.2.3 Description of larval fishes

The description of larval fishes is intended to help others identify larvae, and to give a description of changes that occur during development. Leis (1993) published minimum requirements for what the description of larval fishes should contain; including a section on how you identified the larvae, information on how others can identify the larvae, citations of similar species, a table of meristic and morphometric characters, a dynamic approach in the description, and detailed accurate drawings.

### 1.2.4 Terminology

#### 1.2.4.1 Abbreviations used in text

| | | | |
|---|---|---|---|
| A | Anal fin | PAL | Preanal length |
| BD | Body depth at pectoral fin base | $P_1$ | Pectoral fin |
| BDA | Body depth at anus | $P_1L$ | Pectoral fin length |
| C | Caudal fin | $P_2$ | Pelvic fin |
| D | Dorsal fin | SL | Standard length |
| $D_1$ | First dorsal fin | SnL | Snout length |
| $D_2$ | Second dorsal fin | TL | Total length |
| ED | Eye diameter | V | Vertebrae |
| FL | Fork length | VAFL | Gap length |
| HL | Head length | | |

#### 1.2.4.2 Glossary

Leis and Carson-Ewart (2004) and Neira, *et al*. (1998) have full glossaries of terms commonly used when studying larval fish. The definitions below are ones more relevant to this guide.

**adipose fin** A small fin found posterior to the dorsal fin, made of fleshy adipose tissue.
**body depth (BD)** Body depth measured at base of pectoral fin. See figure 3.
**body length** Length of body from snout to tip of notochord.
**bud** Undifferentiated tissue at the base of where paired fins will form (eg pectoral-fin bud).
**caudal peduncle** The area between the base at the posterior end of the dorsal/anal fin and the base at the start of the caudal fin.
**eye diameter (ED)** The distance horizontally across the pigmented region of the eye at the midline.
**finfold** A membrane that runs along the body of a larva that develops into the dorsal, caudal and anal fins.
**fin spines** Bony structures present at the anterior end of dorsal and anal fins that support the fins.
**flexion stage** The stage of development where the notochord tip bends upwards to form part of the caudal fin.
**forebrain** Forward region of the brain.
**foregut** Forward region of the gut.
**gas bladder** A sac above the gut used for buoyancy, also known as a swim bladder.
**head length (HL)** The length between the snout and the opercular membrane. See Figure 3.
**hindbrain** Rear region of the brain.
**hindgut** Rear region of the gut.

**icthyoplankton** Plankton including fish eggs and larvae.

**juvenile** The developmental stage where a fish has full external meristics but has not yet reached sexual maturity.

**larva** The developmental stage between hatching and attaining full external meristics (juvenile stage).

**melanophores** Nucleated cells that can change in shape and size, which contain the pigment melanin (black and brown). Melanophores remain after preservation which makes them useful in identification of larval fish.

**meristic characters** Characters which can be counted (e.g. fin rays, myomeres), useful for identification.

**midbrain** The middle sector of the brain.

**midgut** The middle section of the gut.

**morphometric characters** Characters expressed by a numerical value that can be measured.

**myomeres** Muscle bands separated by myosepta that are aligned sequentially along the trunk and tail. The number of myomeres gives an indication of the number of vertebrae.

**myoseptum** Connective tissue that separates two myomeres. Plural myosepta.

**notochord** Skeletal tissue which is later replaced by vertebrae, provides support for the body of larval teleost fish. See Figure 4.

**notochord length** See **body length**

**pectoral-fin length ($P_1L$)** The length between the base of the pectoral fin to the longest ray.

**postflexion stage** The developmental stage that occurs after notochord flexion and before the juvenile stage.

**preanal length (PAL)** The length between the snout and the posterior side of the anus.

**preflexion stage** The developmental stage that occurs from hatching to the start of the upward bending of the notochord tip. Some larvae skip the preflexion stage as the notochord is flexed at hatching.

**settlement stage** When a larva is morphologically ready to live as a substrate-associated individual. This doesn't apply to pelagic species.

**snout** Area between the tip of the jaw and eyes.

**soft ray** Flexible structure that supports fins.

**straight gut** A gut that is not twisted or coiled.

**striated gut** A gut with folds that resemble lines.

**tail** The region of the body behind the anus.

**total length (TL)** The length between the snout and the rear edge of the caudal fin rays.

**transformation** Metamorphosis at the end of the larval stage to become a juvenile.

**trunk** The area between the head and tail.

**yolk sac** A nutrition filled sac-like extension of the gut.

### 1.2.5 Larval fish characters used in this guide

The main identifying characters discussed in this guide are morphology, fin meristics, pigmentation, myomeres and head spines. Some characters remain after metamorphosis; however the remainder of characters present in the larval stage have disappeared or become heavily reduced by the juvenile stage (Neira, *et al*., 1998).

#### 1.2.5.1 Morphometrics and general body morphology

The body length (BL), body depth (BD), preanal length (PAL) and head length (HL) are standard body measurements that are used to describe the morphology of larvae in this guide (Figure 3). BD, PAL and HL are given as percentages of BL.

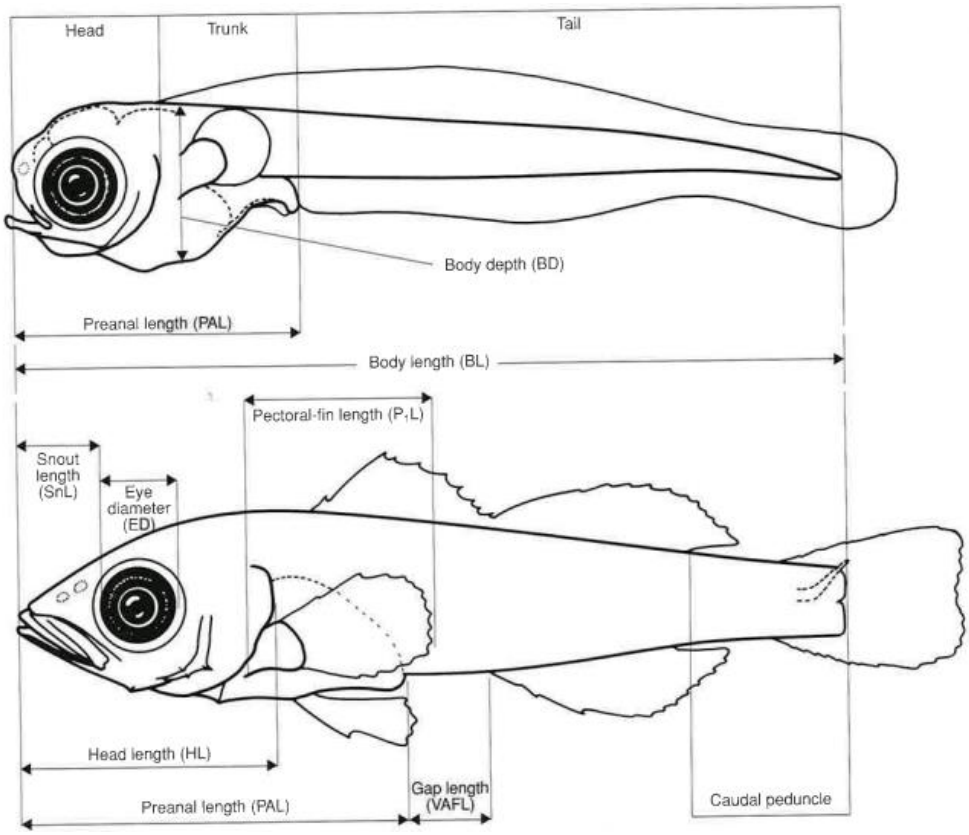



Figure 1: Standard body measurements of larval fish. From Neira, et al. (1998).

BL is the distance from the tip of the snout to the tip of the notochord (notochord length). BD is the relative body depth of a larvae measured at the base of the pectoral fin, used to classify the body shape into elongate, moderate, deep categories. PAL referred to the size of the gut relative to the BL, classified into short, moderate, long, or very long categories. The gut can be straight, coiled, twisted and/or striated. HL is the relative size of the head to BL, small, moderate or large classifications (Leis & Carson-Ewart, 2004; Neira, *et al*., 1998).

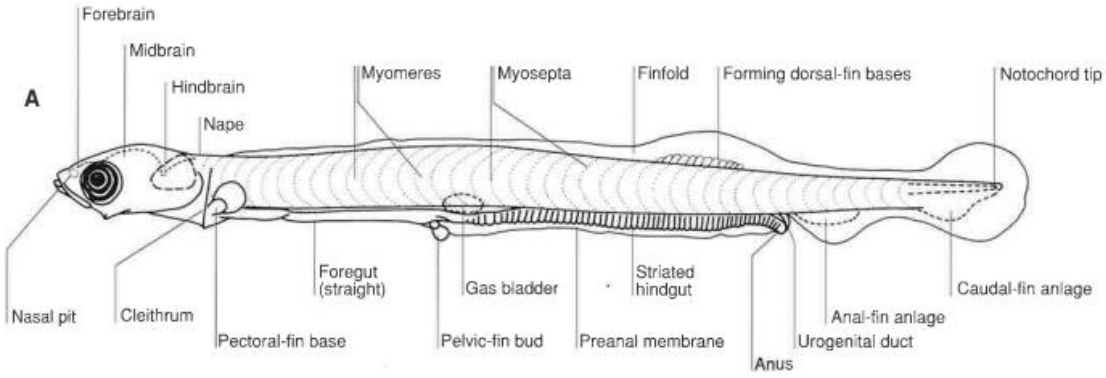
### 1.2.5.2 Fin meristics

Counting soft rays and spines is a useful tool for linking larvae when using the series method, but care should be taken as the elements may not be in their adult form. Fin spines are usually smooth, hard and pointed, and can be found at the anterior end of dorsal, anal, pectoral and pelvic fins. The number of spines present is given as a Roman numeral. Soft rays are present in all fins and are flexible. The number of soft rays present is given as an Arabic numeral. When the fins are continuous, a comma separates the counts of spines and soft rays. When the fins are separated, a plus sign separates the counts of the two fins (Neira, *et al*., 1998; Leis & Carson-Ewart, 2004). The below example shows the first dorsal fin with six spines and 13 soft rays, the second dorsal fin with seven soft rays, the anal fin with two spines and 12 soft rays, and the pectoral fin with one spine and five soft rays.

| D | A | $P_1$ |
|---|---|---|
| VI, 13 + 7 | II, 12 | I, 5 |

### 1.2.5.3 Myomeres and vertebrae

Myomeres are sequentially aligned muscle bands. They occur along the body of larvae and are separated by connective tissue called myosepta, and correspond to the number of vertebrae of a species (Figure 4). For this reason, the number of myomeres is useful in identifying larval fish, and is usually expressed as preanal + postanal = total (Neira, *et al*., 1998; Leis & Carson-Ewart, 2004).



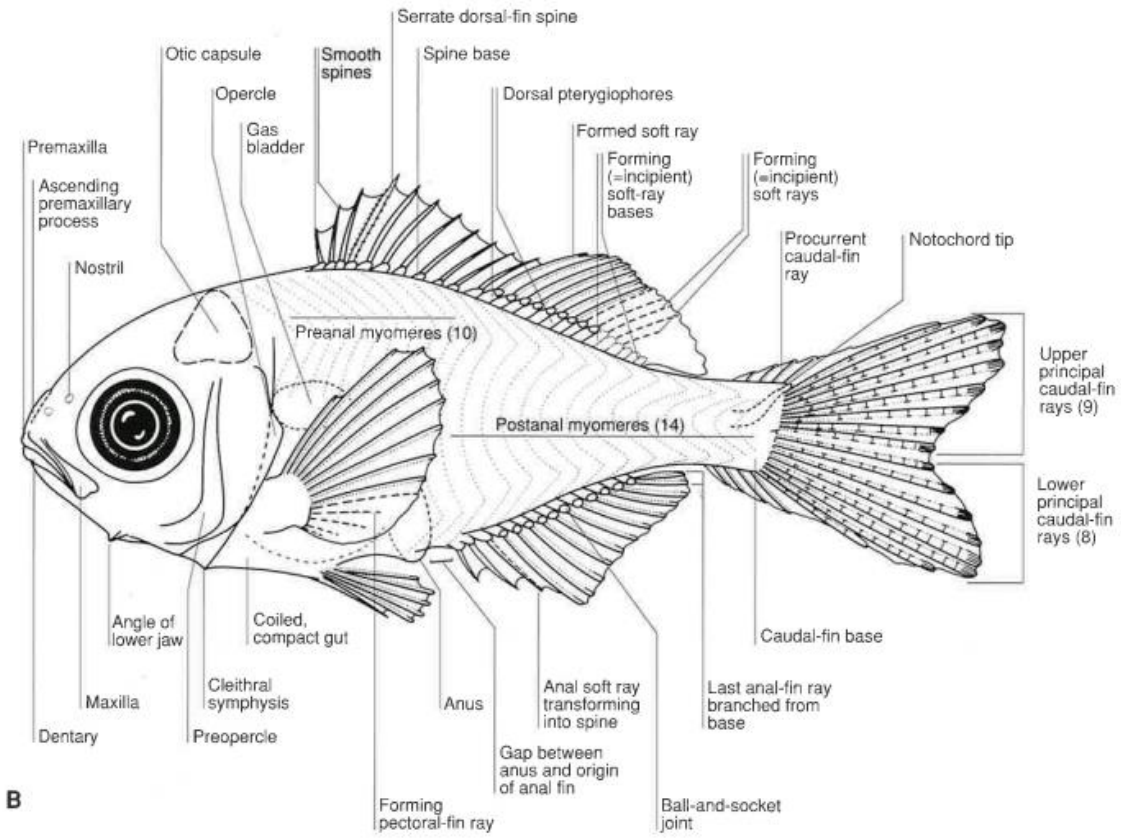



Figure 2: Morphological characters used in this guide, A – preflexion larva, B – flexion larva. From Neira, *et al*. (1998).

### 1.2.5.4 Pigment

Pigment refers to melanophores, nucleated cells of melanin (a black and brown pigment) that remains in larvae after preservation. The location, number, and distribution of melanophores are useful in the identification of larval fish (Figure 5). Melanophores differ in appearance depending on the expansion of pigment in the cells (Figure 6) (Neira, *et al*., 1998; Leis & Carson-Ewart, 2004).

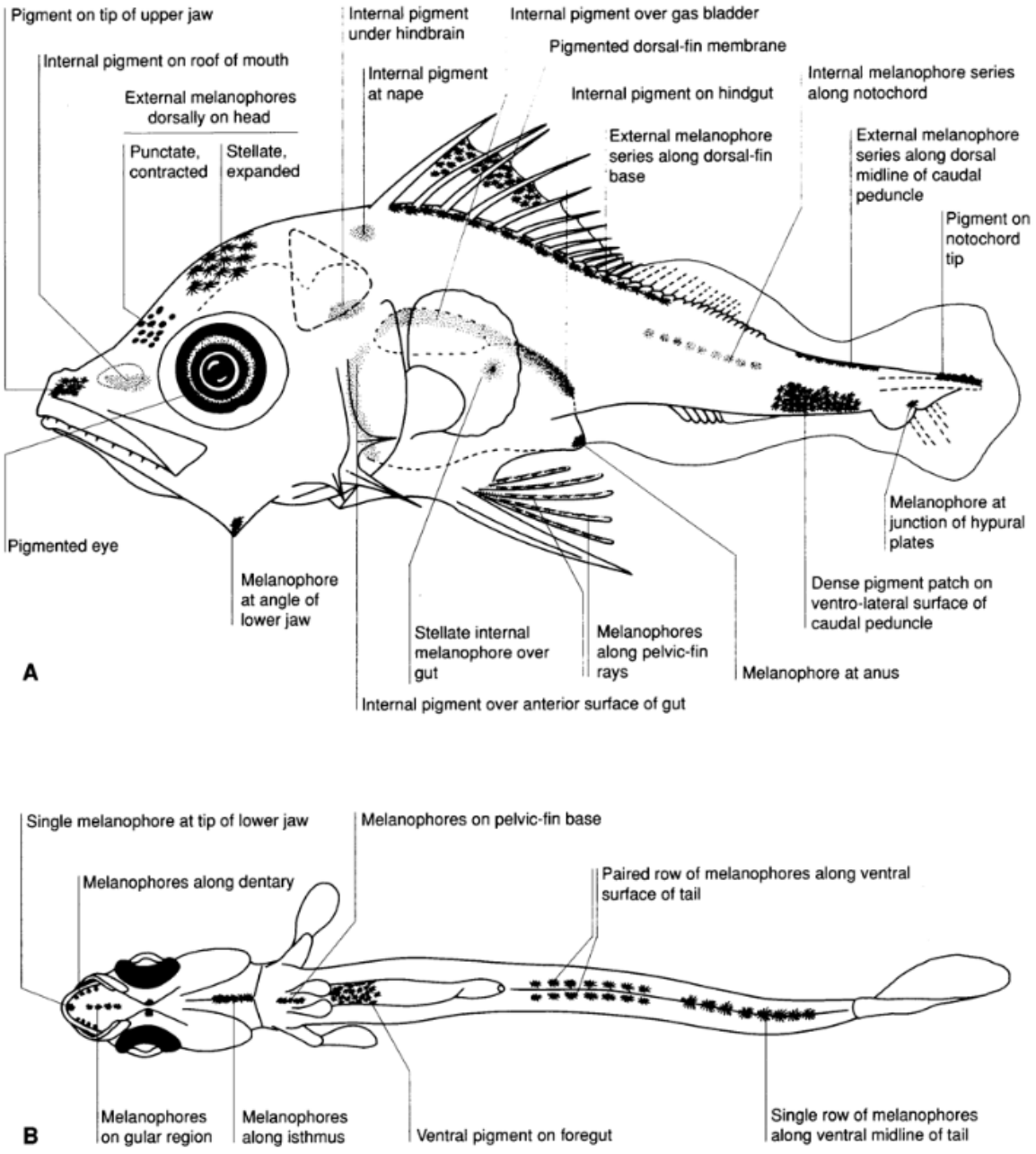



Figure 3: Major pigmentation characters used in this guide. A - lateral, B - ventral. From Neira, *et al*. (1998).


Figure 4: Different appearances of melanophores. From Faber (2013).

### 1.2.5.5 Head spines

In general, head spines on larvae are a specialisation for defence against predators, and most spines are usually lost before the end of the larval period, although some do remain during the adult stage. The bone which the spine originates from dictates the name (Figure 7). Spines are important for the identification of some species (Neira, *et al*., 1998).

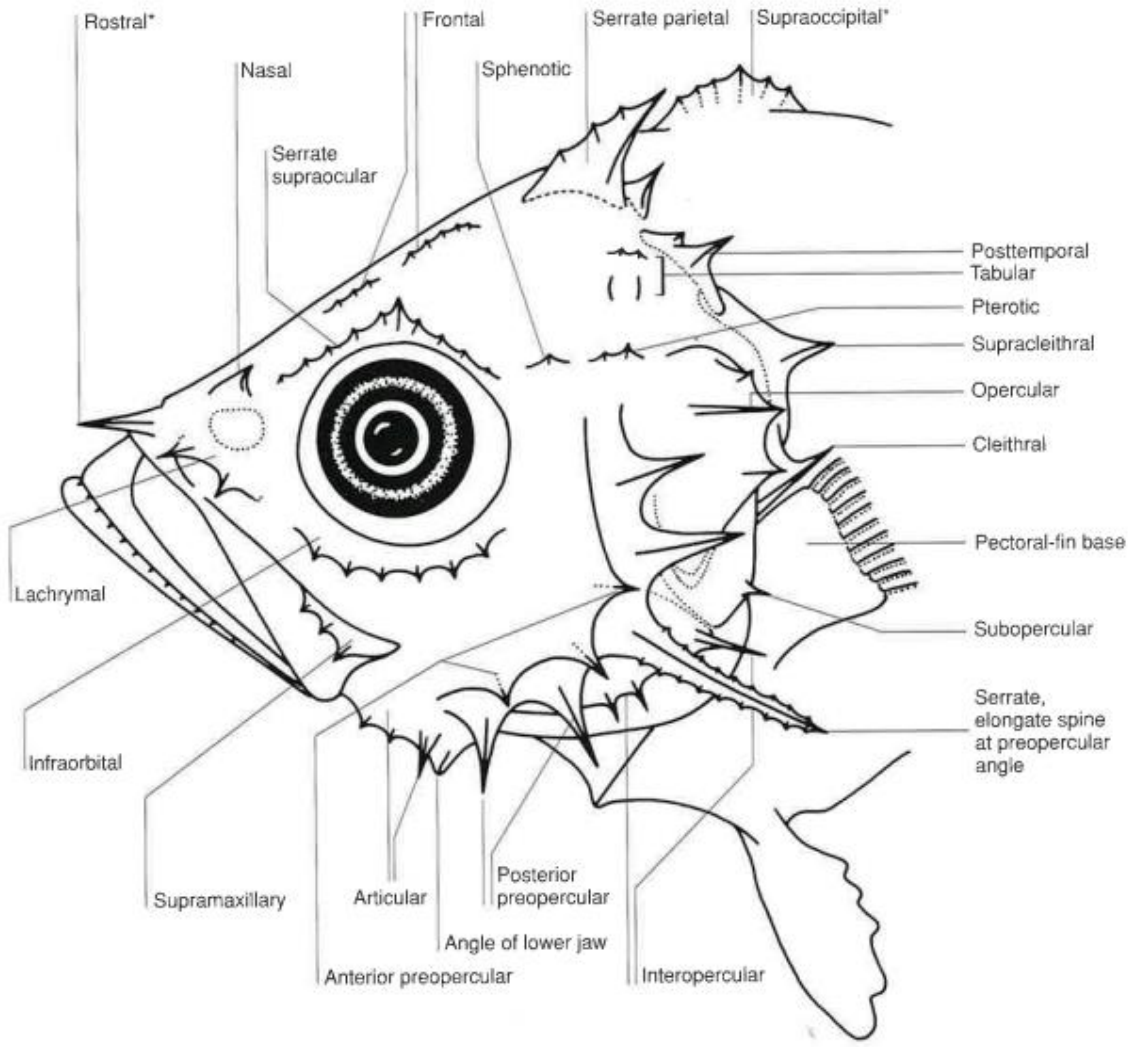



Figure 5: Different types of head spines found on larval fish. From Neira, *et al*. (1998).

### 1.2.5.6 Developmental stages

The terminology used when describing the developmental stages of larvae differs between authors, and there are difficulties defining discrete stages with firm boundaries (Keith, 2000). Kingsford (1988) states the importance of authors defining their terminology, and that the type of fish being studied should dictate the terminology used.

Leis and Carson-Ewart (2004) and Neira, *et al*. (1998) define a larval fish as the stage between hatching and having all external meristic characters, while losing specialisations used in larval life. Dolphin (1997) defines the larva stage as the period from yolk-sac absorption until the juvenile form is attained, and considers a yolk-sac larvae before, and a pre-juvenile after the larva stage. His description allows an overlap in terms, and uses modifiers (early and late stage) to give further detail of the stage of development, however this is too broad and can cause confusion.

In this guide, terminology used is based on the system found in Kendall *et al*. (1984) and in Neira, *et al*. (1998), however, the terminology described is not intended to be tightly definitive of stages. As outlined in Figure 1 and shown in Figure 2, there are five transitional stages and subdivisions in the primary developmental stage of a larva; yolk sac larva, preflexion larva, flexion larva, postflexion larva and a transformation larva.

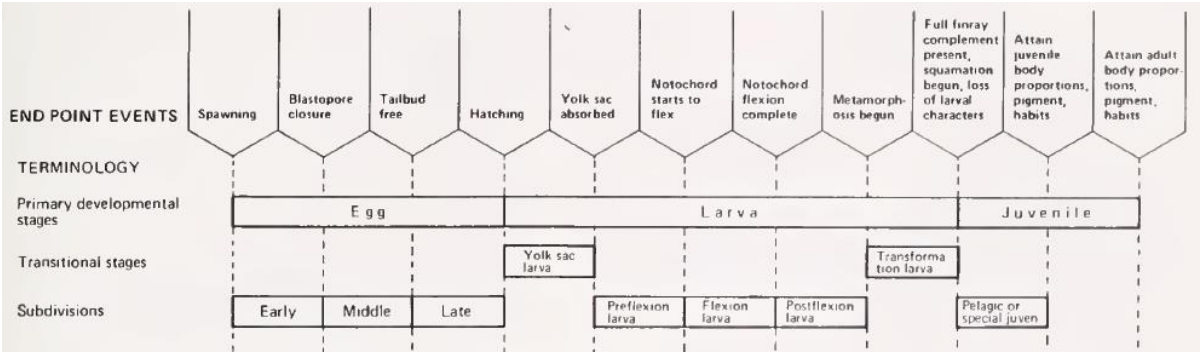



Figure 6: Developmental stages of larval fishes, outlined by end point event, modified from Kendall, *et al*. (1984).

The first larval stage is the yolk sac larva, which is defined as the larva from hatching until the yolk sac is absorbed. Most fishes are yolk sac larvae when they hatch; they lack a functional mouth so receive their nutrition from the yolk. Some demersal species consume the yolk while in the egg, and hatch ready to feed (Kendall, *et al*., 1984; Miller & Kendall, 2009).

The following stage is a preflexion larva, which spans from the previous stage until when the notochord starts to flex. Throughout this stage, the larva's locomotory and sensory powers

are developing as it now must be able to capture its prey. The finfold has not yet separated into individual fins, although the pectoral fins are developed (Kendall, *et al*., 1984; Miller & Kendall, 2009).

Notable developments occur during the flexion stage. There is usually a change in body shape, the fin rays rapidly develop, the feeding behaviour changes and the stage ends when notochord flexion is complete. This stage is followed by the postflexion stage, which lasts until metamorphosis begins. Whilst in postflexion, the specialisations for larval life become better developed, the gut and respiratory system further develop and the larva increases in size. (Kendall, *et al*., 1984; Miller & Kendall, 2009).

Transformation is the final stage before the attainment of juvenile body proportions, pigment and habits. The length of this stage varies widely between species and is often accompanied by a change in habitats, usually from planktonic to demersal or pelagic. For demersal and benthic species, the transition is usually short and ends when the larva has settled into the juvenile habitat, referred to as 'settlement'. For pelagic larvae who remain pelagic as adults, the transition is referred to as 'transformation' (Neira, *et al*., 1998).

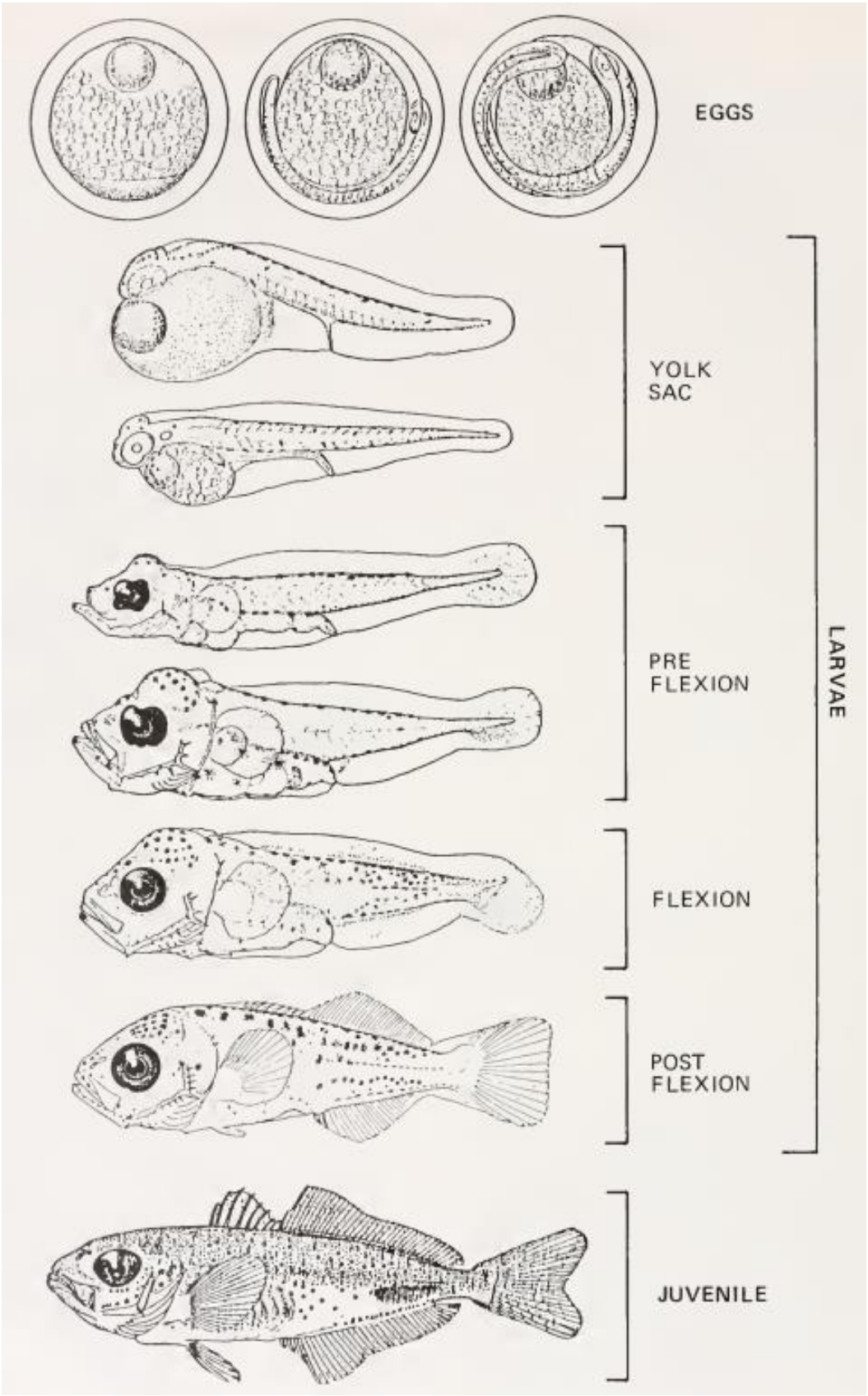



Figure 7: Early life history stages of *Trachurus symmetricus*, showing the different developmental stages. Modified from Ahlstrom and Ball (1954).

### 1.2.6 Larval fish illustrations

Larval fish illustrations have come from both published and unpublished literature. Under the guidelines of Leis (1993); drawings should show the correct number of myomeres and fin rays, and should clearly show head spination, melanophore distribution, the gas bladder and gut, and the relative position of all structures. A camera lucida is a highly recommended means of accurately illustrating fish larvae, as photographs are often inadequate and do not show a satisfactory level of detail (Leis, 1993).

Illustrators have individual techniques and styles for drawing larval fish, and often reflect the area in which they work. Common illustrating techniques include drawing forming spines and soft rays with dashed lines, while formed spines are drawn with a solid line. Formed soft rays are drawn with a solid line for the anterior edge, and a dashed line for the posterior edge. The gas bladder and notochord tip are drawn with dashed lines. External melanophores are drawn with dark stippling while internal melanophores are drawn with light stippling (Neira, *et al*., 1998).

### 1.2.7 Layout of descriptions

The sequence of orders and suborders follows that of Nelson (2006), while the families within each order and suborder, and species within each family are in alphabetical order. The order Perciformes was divided into suborders due to its large size. The descriptions of larvae are based on descriptions from literature, and of material examined.

#### 1.2.7.1 Order

An introductory section is included to provide an overview on the order, including but not limited to the number of suborders (if applicable), families and species worldwide, the number found in marine waters, and common characteristics of species found within the order. A list of families and species included in this guide is also given.

#### 1.2.7.2 Species accounts

The family, genus, species, author, date of original description, and common name are provided. A table of meristic characters, D, A, $P_1$, $P_2$, C and V, are given, and '-' is used if the information is not known. Diagnostic characters provide a brief overview of distinguishing characters useful for the identification of the species mentioned. The description of the larvae provides more in-depth information on the morphology, size at notochord flexion and transformation/settlement, and internal and external pigmentation found on the head, dorsal, ventral, and caudal sections of the larvae. Material examined details

the total number, size of specimens and location of capture. Similarities give the species that are similar to the species mentioned. References are listed where further information can be found. Illustrations from various published and non-published material have been included, as well as a photograph where possible.

# 2 Chapter Two - Larval descriptions

## Order CLUPEIFORMES

The order Clupeiformes is a small order with only five families and 364 species. Clupeiformes are primarily marine species, with 79 freshwater species and 85 species that use freshwater for some part of their life history (Nelson, 2006). The five families are Clupeidae (herrings), Chirocentridae (wolf herrings), Denticipitidae (denticle herrings), Engraulidae (anchovies), and Pristigasteridae (longfin herrings) (Neira, *et al*., 1998; Nelson, 2006). Clupeiformes are pelagic and often found in schools. Common characteristics include fins that lack spines, pelvic fins placed posteriorly (Neira, *et al*., 1998; Leis & Carson-Ewart, 2004) and a high number of vertebrae (Leis & Carson-Ewart, 2004). Three species of Clupeidae and one species of Engraulidae are found within New Zealand waters (Paul, 2000). Larvae have an elongate and slender body, a long straight gut, melanophores in series, dorsal and anal fins which are posteriorly placed, and a dorsal fin which migrates anteriorly towards the conclusion of the larval phase. Most taxa have a cross-hatched pattern on the muscle fibres of the myomeres ( McGowan & Berry, 1984; Neira, *et al*., 1998; Leis & Carson-Ewart, 2004).

**Families and species included in this guide**

CLUPEIDAE

*Sardinops sagax*

*Sprattus antipodum*

*Sprattus muelleri*

ENGRAULIDAE

*Engraulis australis*

**Clupeidae** *Sardinops sagax* (Jenyns, 1842) Pilchard

Adapted from Neira, *et al*. (1998).

| D | A | $P_1$ | $P_2$ | C | V |
|---|---|---|---|---|---|
| 17-20 | 16-21 | 16-19 | 8-9 | 19 | 47-53 |

**Diagnostic characters**

- 36-42 + 10-13 = 48-53 myomeres
- Muscle fibres cross-hatched pattern visible until 14 mm
- Between 3.9 and 25.1 mm the anus migrates forward to myomere 36 from 42
- Anal fin origin 4-6 myomeres behind posterior end of dorsal fin.
- A paired series of melanophores along foregut, single series internally along hindgut

(Neira, *et al*., 1998)

**Description of larvae**

Morphology

Body elongate (BD 5-8%), after 20 mm (BD 9-12%). Small head (HL 10-22%). Very long gut (PAL 79-86%), striated hindgut. Dorsal-fin posterior end in front of anal-fin origin. Scales are formed between 34 and 40 mm (Neira, *et al*., 1998).

Size at

Notochord flexion 9.8-12.2 mm

Transformation 35.0-40.0 mm

Pigmentation

*Head:* 1-2 melanophores above hindbrain. 1-2 melanophores under eye.

*Dorsal:* Melanophores along lateral midline of trunk and tail, dorsal-fin base, and caudal peduncle by 24 mm.

*Ventral:* Several melanophores along isthmus Elongate melanophores in a paired series dorsolaterally along foregut, single series ventrally along hindgut, anus has 1 melanophore above it. Two melanophores at base of pelvic-fin. Anal-fin base and midline of caudal peduncle have melanophores.

*Caudal:* Notochord tip with small melanophores underneath, which remain in postflexion along the base of the lower caudal-fin rays (Neira, *et al*., 1998)

**Material examined**

32 larvae, ~10 – 50 mm BL, caught from Bridge Marina in Tauranga harbour.

**Similarities**

Similar to anchovy (*Engraulis australis),* distinguished by the dorsal and anal fins which overlap on the anchovy. Similar to sprat (*Sprattus antipodum*) which have a single row of melanophores along the ventral surface, compared to pilchard that have paired melanophores on the foregut. Similar to Galaxiidae, which have dorsal and anal fins directly opposite. Similar to smelt (*Retropinna retropinna*) which have an adipose fin.

**References**

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Blackburn (1941); Baker (1972); McGowan and Berry (1984); Matarese, *et al*. (1989); Moser (1996).

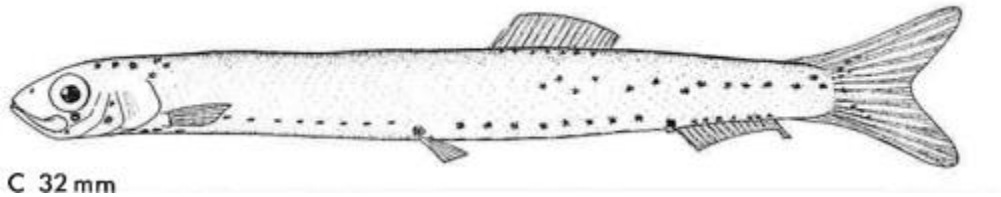


Figure 8: Larval *S*. *sagax* showing pigmentation and placement of fins from Baker (1972).

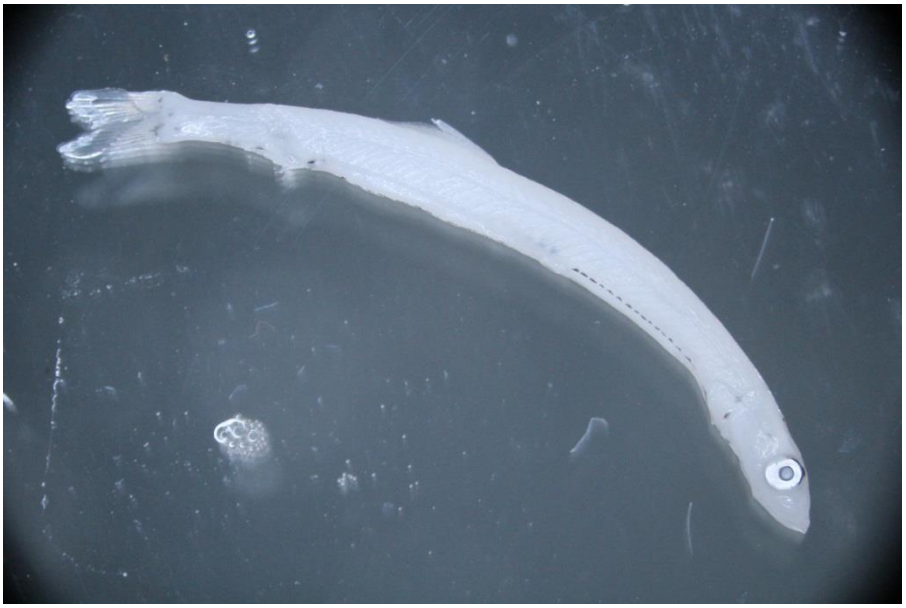

Figure 9: Photograph of *S*. *sagax*. Note the position of the posterior of the dorsal fin is anterior to the anus.

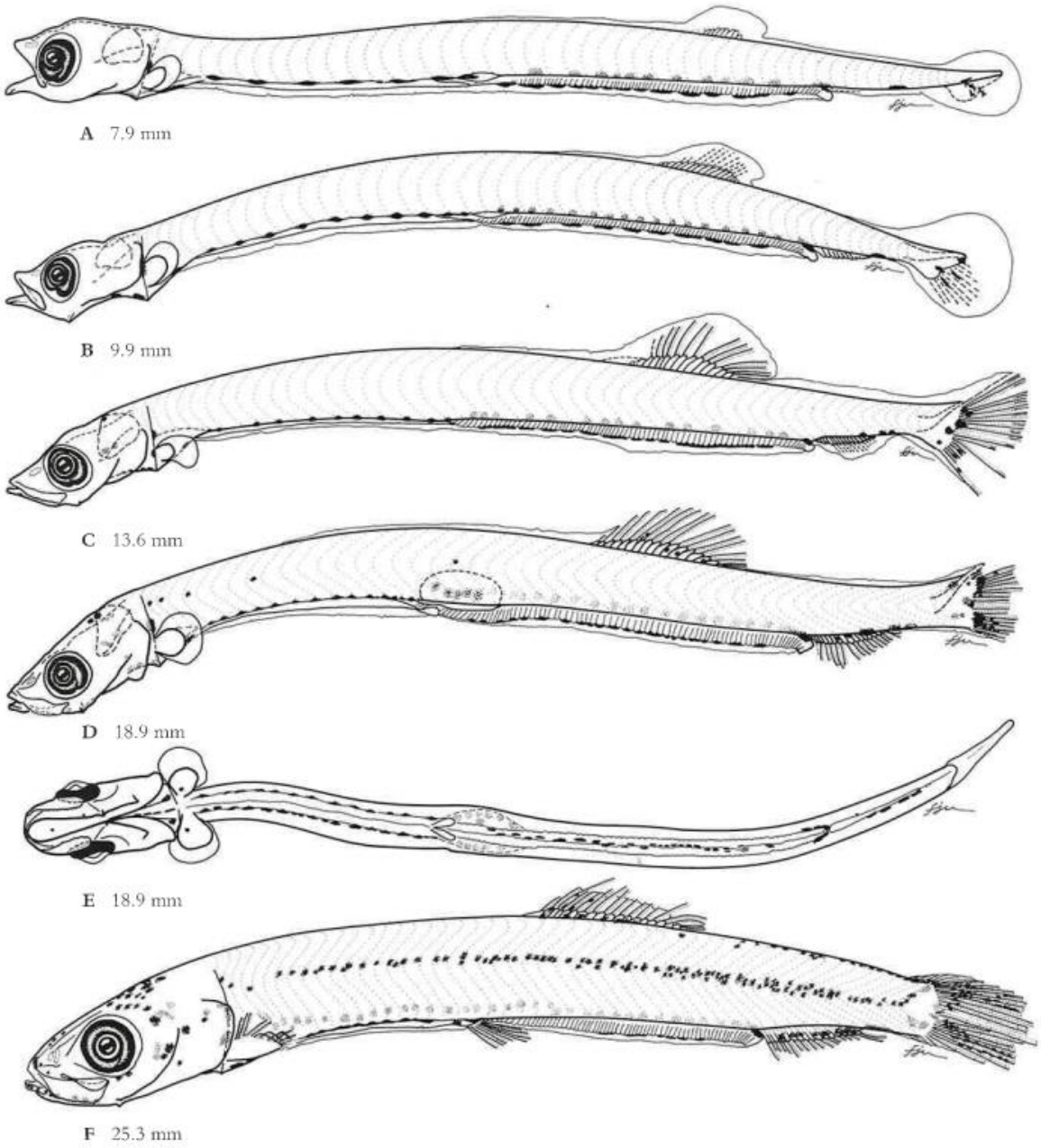


Figure 10: Developmental series of *S. sagax*. A - preflexion, B - flexion, C - late flexion, D - postflexion, E - ventral postflexion, F - transforming stage. From Neira, *et al*. (1998).

**Clupeidae** *Sprattus antipodum* (Hector, 1872) Slender sprat
*Sprattus muelleri* (Klunzinger, 1880) Stout sprat

Adapted from Baker (1972); Keith (2000).

| D | A | $P_1$ | $P_2$ | C | V |
|---|---|---|---|---|---|
| 15-16 | 14-18 | 7 | - | - | - |

**Diagnostic characters**

- Slender body, typical clupeoid shape
- Single row of melanophores along gut.
- Posterior of dorsal fin in front of origin of anal fin.

(Keith, 2000).

**Description of larvae**

Morphology

Body elongate (BD ~7.4%), at 29 mm (BD ~10%).Yolk sac absorbed by 5.5 mm. Dorsal fin developed ~8 mm, anal fin developed ~12 mm, pelvic fin developed ~17 mm. At flexion gut is convoluted (Keith, 2000).

Size at

Notochord flexion 9-12 mm

Transformation ~30 mm

Pigmentation

*Head:* After postflexion, pigmentation becomes heavy on the head

*Dorsal*: After postflexion melanophores form along dorsal midline of body, increasing in numbers during transformation.

*Lateral:* Melanophore above origin of pectoral fin. Melanophores form along lateral line after flexion, becoming smaller, increasing in numbers and extending forward during transformation.

*Ventral:* Single row of melanophores along the dorsal side of gut, extending to the anus during development.

*Caudal:* Light pigmentation on caudal peduncle nearing transformation (Dolphin, 1997; Keith, 2000).

**Material examined**

30 larvae, ~10 – 50 mm BL, caught from Bridge Marina in Tauranga harbour.

**Similarities**

Larvae of *S*. *antipodum* and *S*. *muelleri* are indistinguishable until around 50 mm and the tongue is fully formed. *S*. *muelleri* are more common in coastal waters, while *S*. *antipodum* are found in sheltered coastal waters (Dolphin, 1997). Similar to anchovy (*Engraulis australis)*, distinguished by the dorsal and anal fins which overlap on the anchovy. Similar to pilchard (*Sardinops sagax*) which have a paired series of melanophores along the foregut, compared to sprat which have a single row of melanophores on the ventral surface. Similar to Galaxiidae, which have dorsal and anal fins directly opposite. Similar to smelt (*Retropinna retropinna*) which have an adipose fin.

**References**

Baker (1972, 1973); Robertson (1973, 1975a); Frentzos (1980); Crossland (1981b, 1982); Thompson (1983).

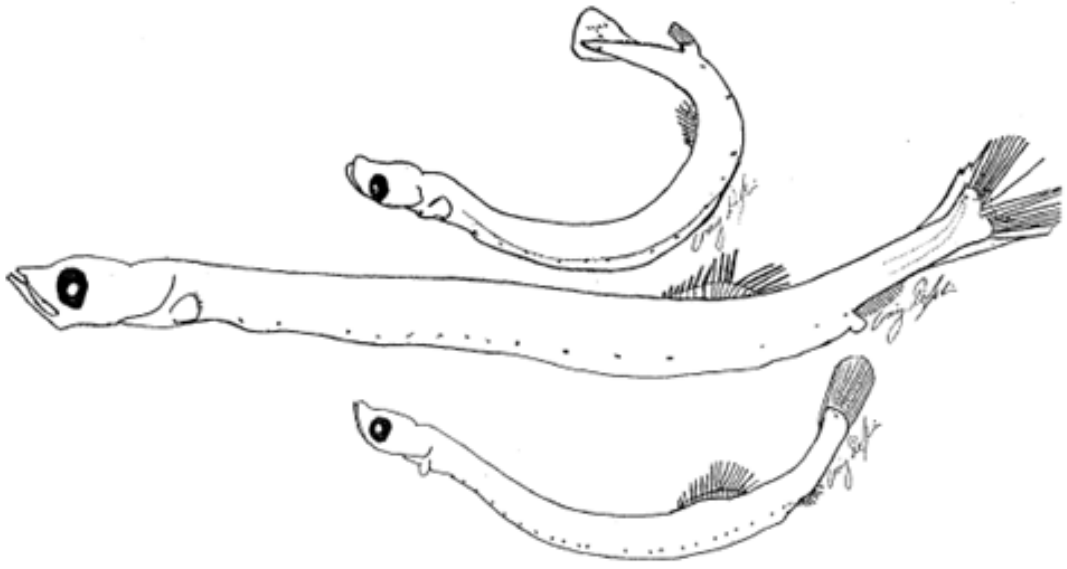

Figure 11: Development of *S*. *muelleri*. A - 9 mm, B - 15.5 mm, C - 17.8 mm. From Dolphin (1997).

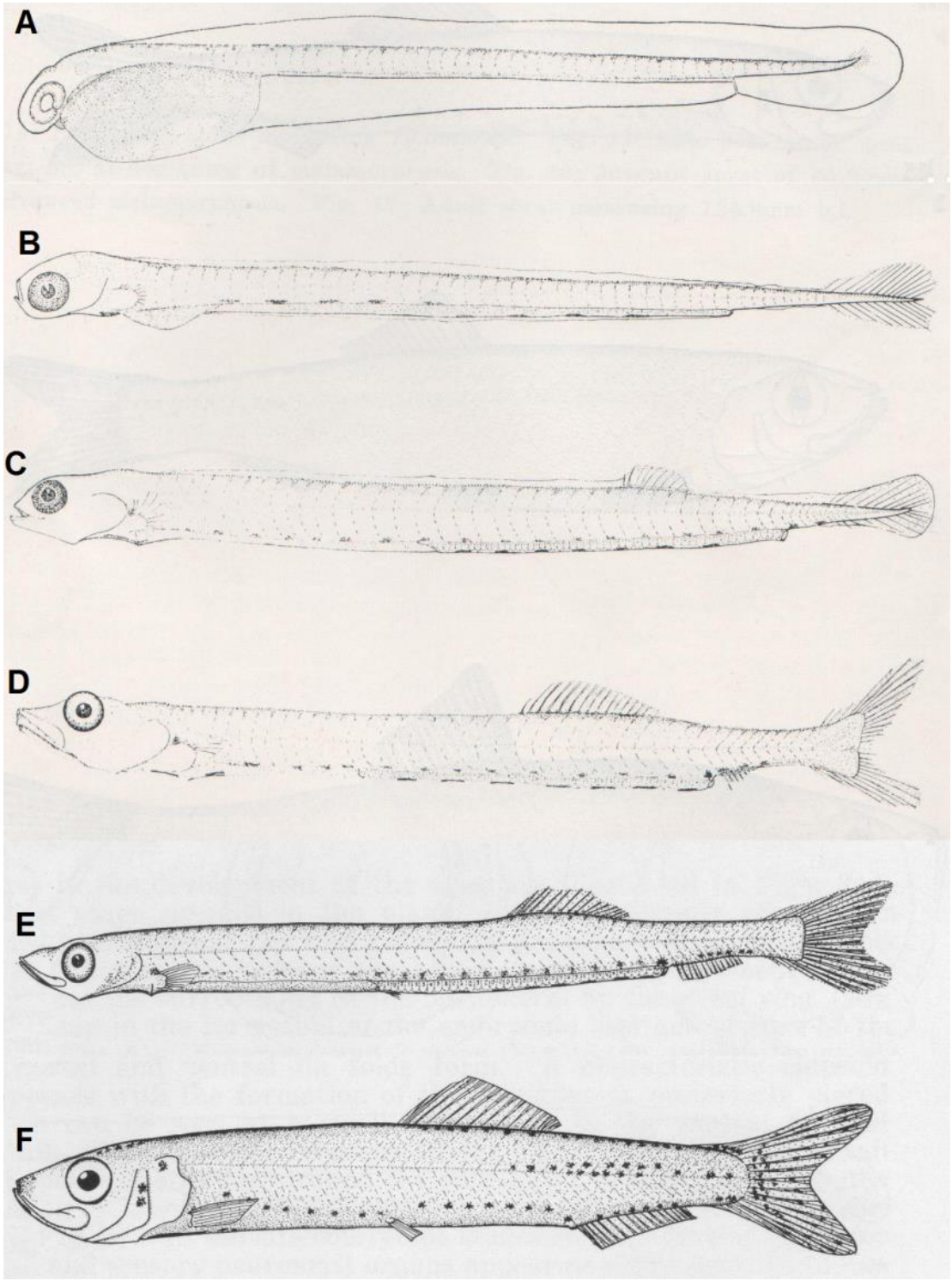

Figure 12: Development of *S. antipodum* larvae, A – 4 mm, B – 4.7 mm, C – 8.5 mm, D – 12 mm, E - 19.5 mm, F - 31 mm. Adapted from Baker (1973).

## **Engraulidae** *Engraulis australis* (White, 1970) Anchovy

Adapted from Neira, *et al*. (1998).

| D | A | $P_1$ | $P_2$ | C | V |
|---|---|---|---|---|---|
| 13-18 | 17-19 | 15-17 | 7 | 19 | 40-48 |

**Diagnostic characters**

- 26-33 + 13-20 = 44-47 myomeres
- Muscle fibres cross-hatched pattern visible until 12 mm
- Posterior end of the dorsal fin and the origin of anal fin overlap by 3 or less myomeres
- Underslung jaw
- Melanophores develop along dorsal surface of hindgut during the flexion stage. (Neira, *et al*., 1998).

**Description of larvae**

Morphology

Elongate body (BD 7-15%). Small to moderate head (HL 14-24%). Gut long and straight (PAL 66-80%), with striated hindgut. Lower jaw underslung from transformation stage. Anus migrates forward to myomere 26 from 33 by 32.2 mm (Neira, *et al*., 1998).

Size at

Notochord flexion 7.6-11.1 mm

Transformation >29 mm

Pigmentation

*Head:* Melanophores (3+) on head and opercle in postflexion. Internal pigment in otic region, and along cleithrum in postflexion.

*Dorsal:* Melanophores along trunk in transforming larvae.

*Ventral:* 1-2 melanophores on isthmus. Elongate melanophores in a paired series along foregut, single series along hindgut. Two melanophores above anus.

*Lateral:* Flexion larvae have internal melanophores on gas bladder, and along hindgut.

*Caudal*: Melanophores ventrally along midline of tail, along caudal peduncle and anal-fin base, increasing in number during postflexion. In preflexion small melanophores are found under the notochord tip, which remain in postflexion on lower caudal-fin rays (Neira, *et al*., 1998).

**Material examined**

1000 larvae, ~7 – 70 mm BL, from Bridge Marina in Tauranga harbour.

**Similarities**

Similar to pilchard (*Sardinops sagax*) and sprat (*Sprattus antipodum*). The posterior end of the dorsal fin does not overlap the origin of the anal fin for pilchard and sprat. Development of dorsal and anal fins occurs much earlier in the anchovy. Also similar to Galaxiidae, which have dorsal and anal fins directly opposite, and a weakly striated gut. Similar to smelt (*Retropinna retropinna*) which have an adipose fin.

**References**

Blackburn (1941); Elder (1966); Baker (1972); Robertson (1973); Crossland (1981b); Miskiewicz (1987); .

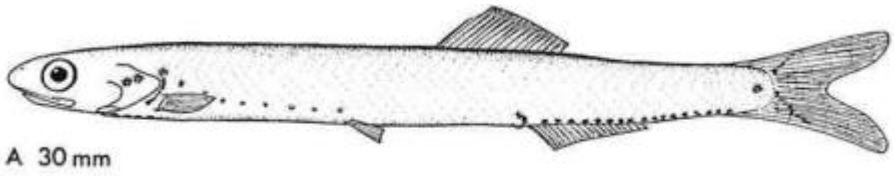


Figure 13:Transformation *E. australis*, showing pigmentation and position of fins, from Baker (1972).

Figure 14: Photo of *E. australis*. Note overlap of dorsal fin and anus, distinguishing the clupeid as *E. australis*.

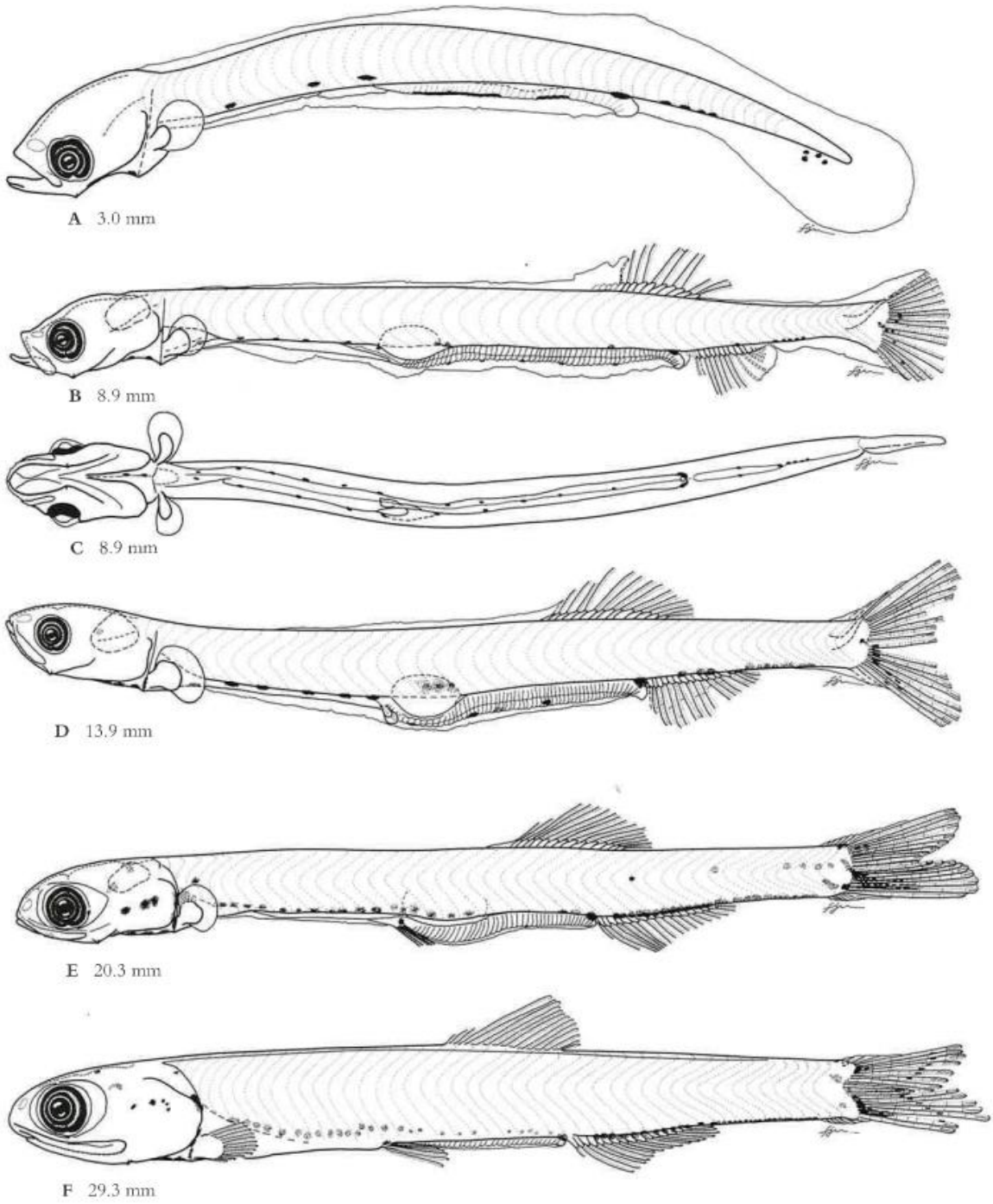


Figure 15: Developmental series of *E. australis*. A - preflexion, B – early postflexion, C – ventral postflexion, D - postflexion, E - postflexion, F - transforming stage. From Neira, *et al*. (1998).

## Order MUGILIFORMES

There is much controversy surrounding the order Mugiliformes. Some consider it as a suborder Mugiloidei of the order Perciformes. The family Mugilidae have separated dorsal fins with spines and soft rays, high pectoral fins, very faint or absent lateral line, and a long gut. Worldwide there are 17 genera with about 82 species (Nelson, 2006). There are two species of mullet in New Zealand (Paul, 2000).

**Families and species included in this guide**

MUGILIDAE
*Aldrichetta forsteri*
*Mugil cephalus*

**Mugilidae** *Aldrichetta forsteri* (Valenciennes, 1836) Yellow-eye Mullet

Adapted from Dolphin (1997); Paulin & Roberts (1992) and Keith (2000).

| D | A | $P_1$ | $P_2$ | C | V |
|---|---|---|---|---|---|
| IV, I, 8-10 | III, 12-13 | i, 14 | I, 5 | - | - |

*Mugil cephalus* Linnaeus, 1758 Grey Mullet

Adapted from Leis and Carson-Ewart (2004).

| D | A | $P_1$ | $P_2$ | C | V |
|---|---|---|---|---|---|
| IV, 9-10 | III, 8-9 | i, 15-17 | I, 5 | 8 + 7 | 11-12 + 12-13 = 24 |

**Diagnostic characters**

- Heavy pigmentation over body, particularly around the head, and a stripe along the lateral midline.
- Elongate shape.
- Two dorsal fins that are well separated.
- Anal fin ray counts

**Description of larvae**

Morphology

Caudal fin begins to develop at 4-5 mm, anal and dorsal fins start development around 5.5-6 mm, pelvic fins develop ~7.2 mm, with adult fin ray counts present by 12-13 mm (Kingsford & Tricklebank, 1991). Elongate to moderate body (BD 17-30%) during preflexion, becoming moderate by postflexion (BD 23-34%). Head increasing in size through development becoming moderate to large by postflexion (HL 27-39%). Gut long and coiled in both preflexion (PAL 56-78) and postflexion (PAL 62-72%) (Leis & Carson-Ewart, 2004).

Size at

Notochord flexion: ~4.8 mm

Transformation: ~12-18 mm

Pigmentation

Preflexion larvae have melanophores on the snout, over the brain, and on the dorsal, lateral and ventral midlines of trunk and tail. During development pigmentation increases so the whole body is pigmented by postflexion. The postflexion larvae/juveniles are a silver colour when alive (Leis & Carson-Ewart, 2004).

**Material examined**

19 *A. forsteri*, & 2 *M. cephalus* juveniles, 20-23 mm BL, from Bridge Marina in Tauranga harbour.

**Similarities**

The two mullet are distinguishable by the number of soft anal-fin rays (*A. forssteri* have 12-13, *M. cephalus* have 8-9, both have 3 spines).

**References**

Crossland (1981b); Okiyama (1988).

Figure 16: Photo of juvenile *A. forsteri*.

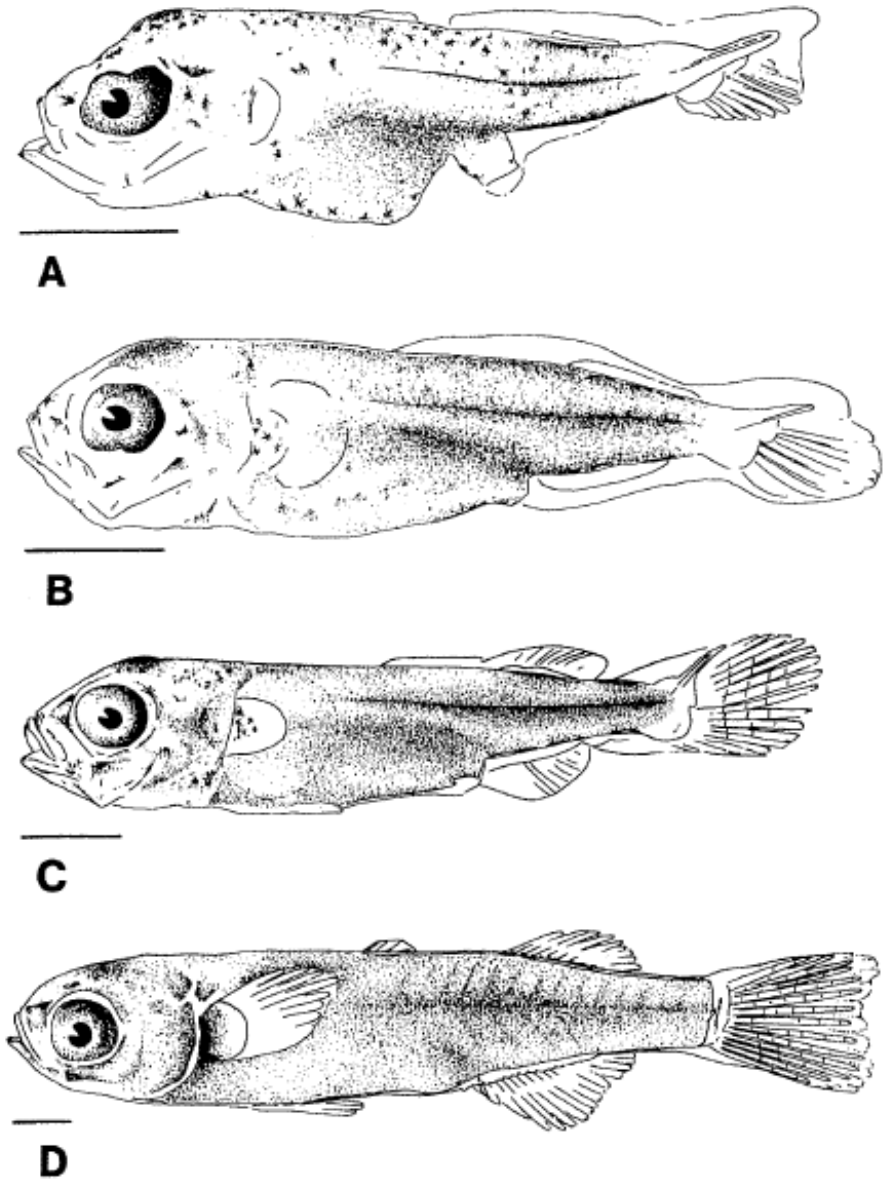


Figure 17: Development of *A. forsteri*. A – 4.8 mm, D - 12 mm. From Kingsford & Tricklebank (1991).

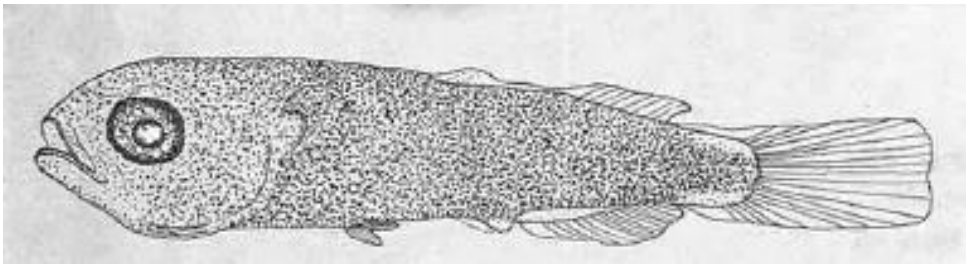

Figure 18: Postflexion *A. forsteri*, 10.5 mm. From Crossland (1981b).

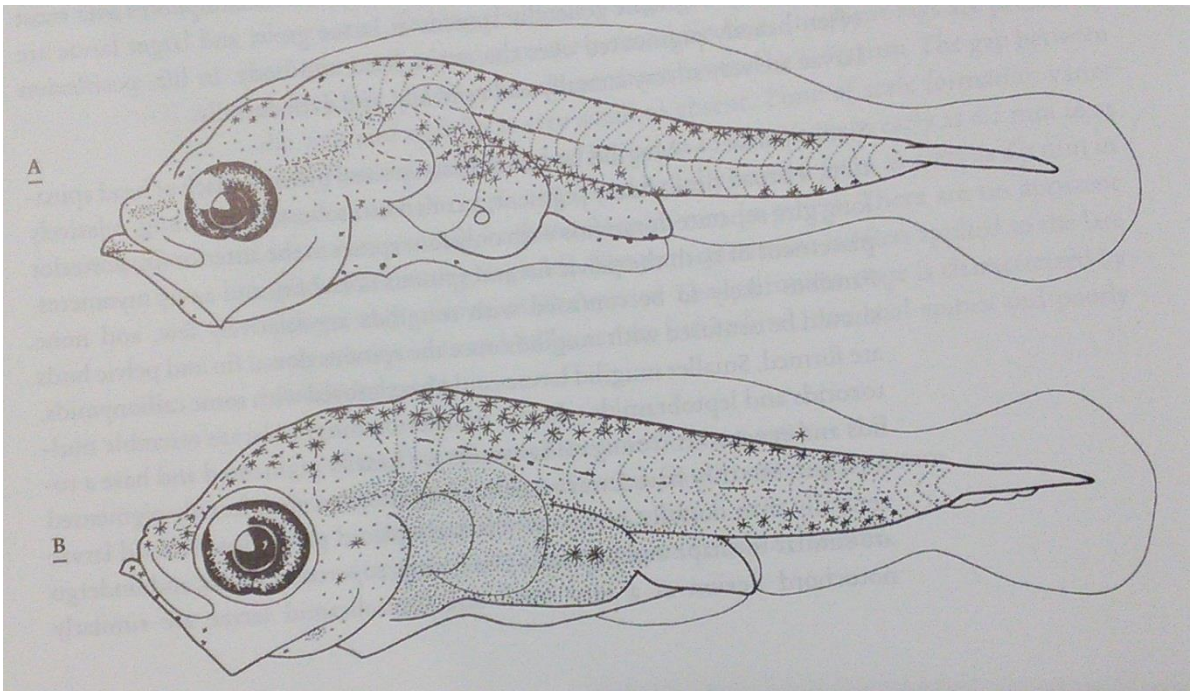

Figure 19: Larvae *M. cephalus*. A - 2.7 mm, B - 3.2 mm. From Leis and Carson-Ewart (2004).

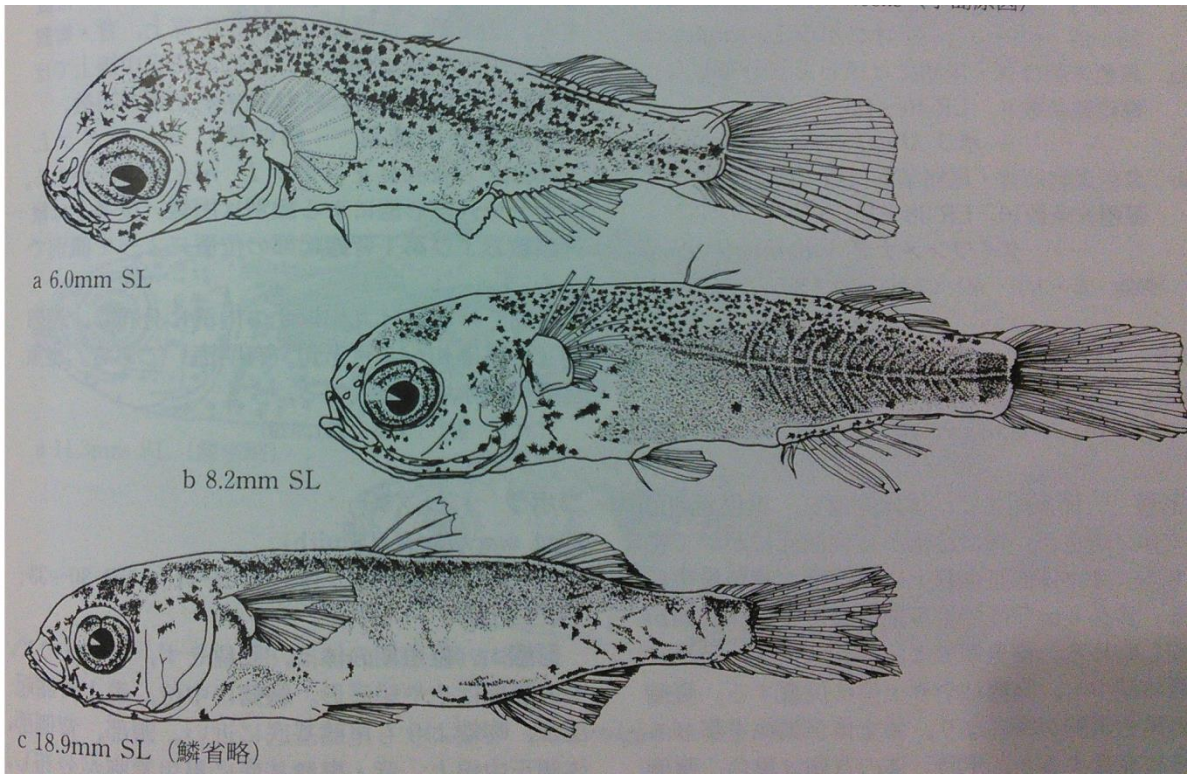

Figure 20: Developmental series of the Grey Mullet *M. cephalus* from Okiyama (1988).

## Order BELONIFORMES

Beloniformes, the needlefishes and halfbeaks, contains five families, 36 genera and 227 species worldwide. The families are Adriancihthyidae, Exocoetidae, Hemiramphidae, Belonidae and Scombersocidae. Members in the family Hemiramphidae have an elongate lower jaw, a short upper jaw, short pectoral and pelvic fins, and are herbivorous (Nelson, 2006). Only one species in the family Hemiramphidae occurs in New Zealand waters (Paul, 2000) and is endemic (Nelson, 2006).

**Families and species included in this guide**

HEMIRAMPHIDAE
*Hyporhampus ihi*

**Hemiramphidae** *Hyporhamphus ihi* Phillips, 1932 Piper/Garfish

Adapted from Leis and Carson-Ewart (2004).

| D | A | $P_1$ | $P_2$ | C | V |
|---|---|---|---|---|---|
| 12-18 | 13-19 | 10-13 | 6 | 15 | 45-61 |

**Diagnostic characters**

- Double series of melanophores dorsally
- Lower jaw extends out further than the upper jaw.

**Description of larvae**

Morphology

Caudal fin development, mouth formation, and notochord flexion occur prior to hatching (Collette *et al*., 1984). Dorsal and anal fins showing all fin rays by 7-9.4 mm. Pectoral fins forming by 13 mm. All fins fully developed around 16 mm. Elongate body (BD 8-13%). Gut is long and straight (PAL 69-78%) Small to moderate head (HL 17-29%). Lower jaw elongated. Scales present at a size greater than 21 mm (Leis & Carson-Ewart, 2004).

Size at

Notochord flexion: 5.3-7.1 mm

Transformation: >12.8 mm

Pigmentation

Moderate to heavy pigmentation. Paired series of melanophores dorsally along trunk and tail, melanophores in rows along the ventral midline of trunk and tail. Pigmentation on the head, and laterally on the gut.

**Material examined**

15 postflexion larvae, ~20-50 mm BL, from Bridge Marina in Tauranga harbour.

**Similarities**

Similar to larvae from the families; scomberesocidae, belonidae and exocoetidae. *H*. *ihi* are distinguished by the myomeres counts, pigmentation and timing of fin and scale development (Leis & Carson-Ewart, 2004).

**References**

Collette (1974); Crossland (1981b).

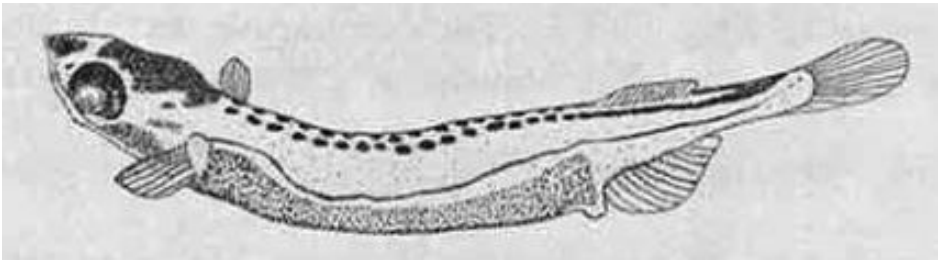

Figure 21: Larva of *H. ihi*, 11.3 mm. From Crossland (1981b).

Figure 22: Photo of postflexion *H. ihi*.

## Order SCORPAENIFORMES

The order Scorpaeniformes, the mail-cheeked fishes, is a large one, containing 26 families, 279 genera and 1477 species worldwide. The family Triglidae contains 10 genera, with 105 species, and are distinguished by large pectoral fins with the lower three rays free, used for looking for food, and two dorsal fins, the first with spines, the second with soft rays (Nelson, 2006). There are five species of Triglidae in New Zealand, the most common of these being the red gurnard *Chelidonichthys kumu* (Paul, 2000).

**Families and species included in this guide**

TRIGLIDAE
*Chelidonichthys kumu*

**Triglidae** *Chelidonichthys kumu* (Cuvier, 1829) Red gurnard

Adapted from Neira, *et al*. (1998).

| D | A | $P_1$ | $P_2$ | C | V |
|---|---|---|---|---|---|
| VIII-IX + 15-16 | 14-15 | 10-11+3 | I, 5 | 13 | 33-35 |

**Diagnostic characters**

- Pectoral fins large and pigmented.
- Fins distinctive and fully formed by 10 mm.
- Extensive head spination, also on opercular and pre-opercular margins.
- Patch of melanophores over caudal peduncle.
- Heavy pigmentation by 15 mm.

(Neira, *et al*., 1998).

**Description of larvae**

Morphology

Postflexion: Body moderate (BD 29-36%), head large (HL 37-42%), gut moderate and coiled (PAL 48-50%), pectoral fin large ($P_1$L 30-32%). Visible gas bladder. Head spination from 10 mm: See (Neira, *et al*., 1998) for full details.

Size at

Notochord flexion: <10.0 mm

Settlement: ~15.0 mm

Pigmentation

*Head:* Light pigmentation at 10 mm, heavy by 15 mm.

*Dorsal:* Pigmentation on membrane of first dorsal fin.

*Trunk:* Light pigmentation at 10 mm. Heavy pigmentation by 15 mm. Heavy pigmentation on pectoral fins. Internal pigment over gas bladder and gut.

*Ventral:* Pigmentation on membrane of pelvic fins.

*Caudal:* Light pigmentation on tail and heavy pigmentation on caudal peduncle at 10 mm.

**Material examined**

2 postflexion larvae, ~10 – 20 mm BL, from Bridge Marina in Tauranga harbour.

**Similarities**

Similar to Scorpaenids. *C. kumu* have two dorsal fins, in contrast to the single dorsal fin of Scorpaenids. *C. kumu* is heavily pigmented by 15 mm and have more myomeres than Scorpaenids, which are lightly pigmented before settlement and have 24-31 myomeres (Neira, *et al*., 1998).

## References

Anderton (1906); Robertson (1973, 1975a); Dolphin (1997); Keith (2000) .

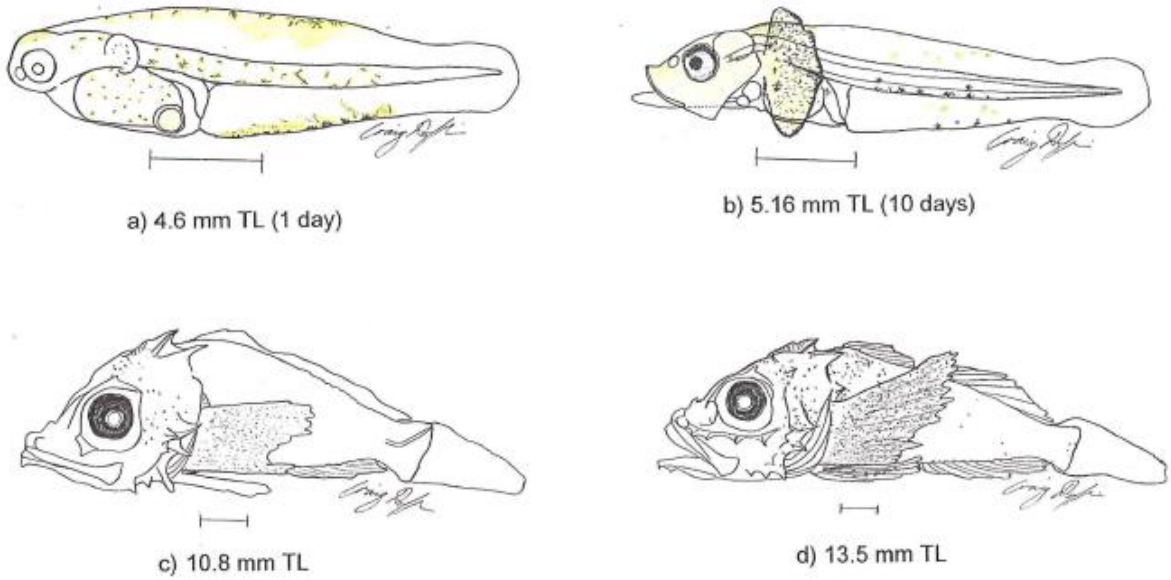


Figure 23: Development of *C. kumu*. Modified from Dolphin (1997).

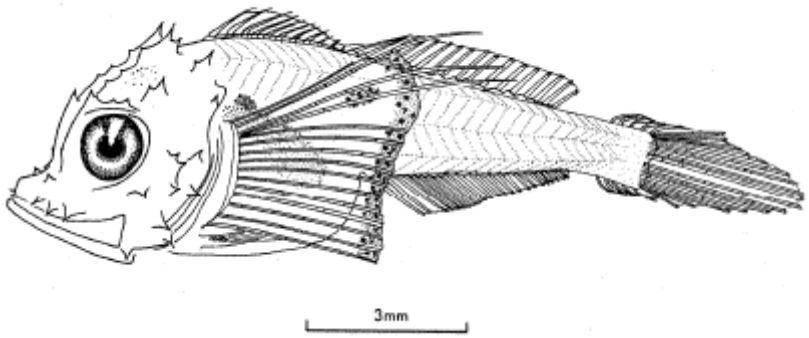


Figure 24: Postflexion larvae of *C. kumu*. From Robertson (1973).

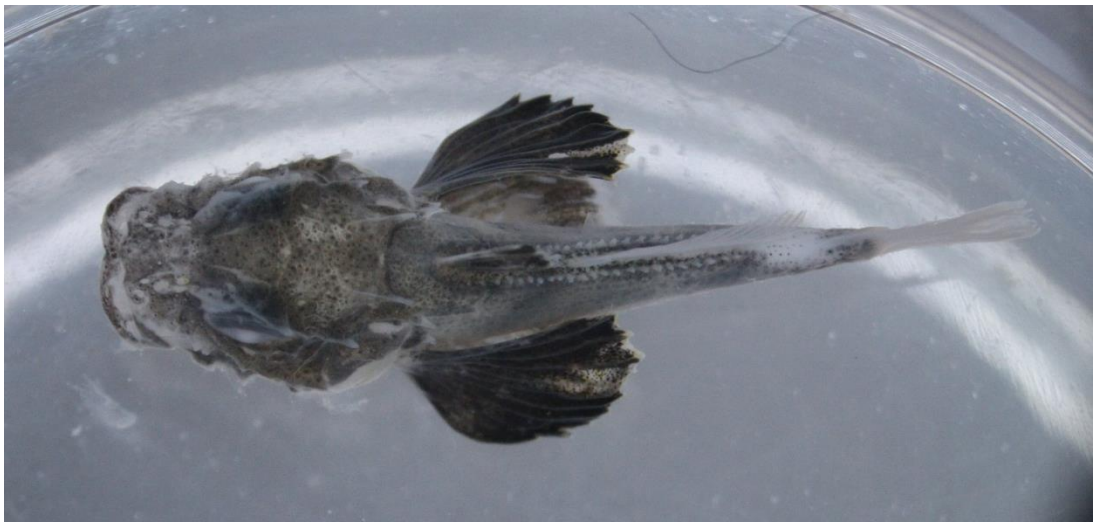

Figure 25: Ventral view photo of *C*. *kumu*.

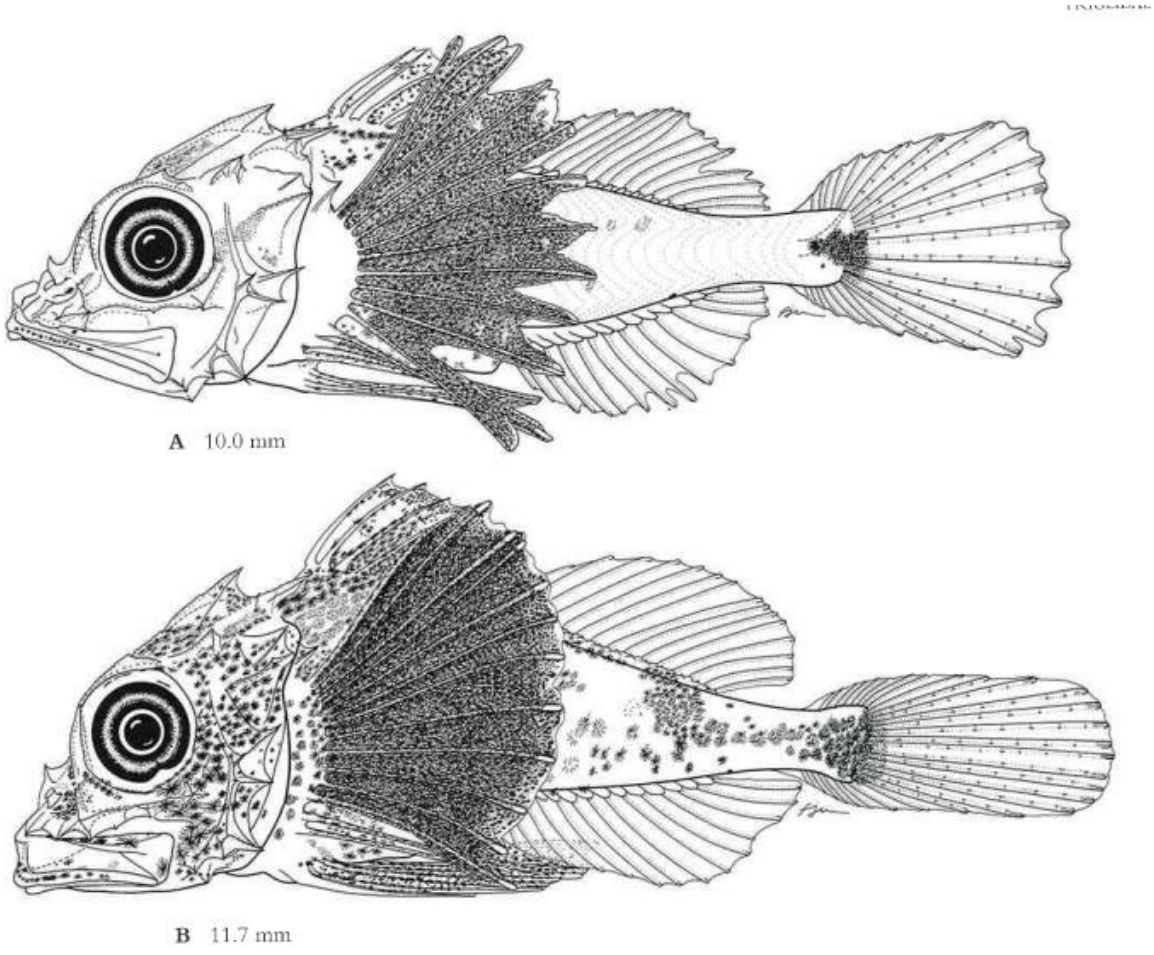


Figure 26: Development of *C*. *kumu*. From Neira, *et al*. (1998)

## Order PERCIFORMES

The order Perciformes is the largest order of fishes, and the largest order of vertebrates, including 20 suborders, 160 families and 10,033 species. Three quarters of the perciform species are accounted for in the suborders Percoidei, Labroidei, and Gobioidei. The eight largest families; Gobiidae, Cichlidae, Serranidae, Labridae, Blenniidae, Pomacentridae, Apogonidae, and Sciaenidae, comprise of over half of all the perciform species. The majority of perciforms are marine shorefishes, although 2,040 species are exclusively freshwater, and 2,335 species are found in freshwater environments for part of their life history (Nelson, 2006). Common characteristics of perciforms include; 17 or less caudal-fin rays, no adipose fin, spines present in anal and dorsal fins, pelvic fins with one spine and five or less rays and found below or anterior to the pectoral fins (Neira, *et al*., 1998; Leis & Carson-Ewart, 2004).

**Suborders included**

Percoidei

## Percoidei

The largest suborder of the Perciformes is Percoidei. This suborder contains 79 families, 549 genera, and 3176 species worldwide. The family Carangidae is one of the ten largest in the suborder, containing over 100 species, Kyphosidae has 16 genera with 45 species, and Sparidae has 33 genera with 115 species (Nelson, 2006). In New Zealand, there are eight species in the family Carangidae (Paul, 2000), although he only mentions three of the four Jack mackerels known to be found in New Zealand waters. There is only one species found in the family Sparidae (Paul, 2000).

**Families and species included in this guide**

CARANGIDAE

*Seriola lalandi*

*Trachurus declivis*

*Trachurus novaezelandiae*

*Trachurus symmetricus*

KYPHOSIDAE

*Girella tricuspidata*

SPARIDAE

*Chrysophrys auratus*

**Carangidae** *Seriola lalandi* Valenciennes, 1833 Yellowtail kingfish
Adapted from Neira, *et al*. (1998).

| D | A | $P_1$ | $P_2$ | C | V |
|---|---|---|---|---|---|
| VI-VII + I, 22-37 | II + I, 16-22 | 18-23 | I, 5 | 17 | 24-25 |

**Diagnostic characters**

- 13-19 + 7-11 = 24-26 myomeres
- Long gut
- Preopercular spines and supraoccipital crest present
- Heavily pigmented body
- All fins formed by 9.0 mm.

**Description of larvae**

Morphology

Caudal fins form at 3.4-6.5 mm, dorsal and anal fins form at 3.8-9.0 mm, pelvic and pectoral fins form at 4.3-8.3 mm. Moderate body (BD 20-35%) and head (HL 26-32%), becoming large prior to flexion (HL 35-41%. Various preopercular spines and supraoccipital crest forming from preflexion. Gut coiled and long (PAL 66-75%). Small gas bladder (Neira, *et al*., 1998).

Size at

Notochord flexion: 4.7-6.7 mm

Transformation: 9.0-19.4 mm

Pigmentation

External melanophores on snout, head and opercule. Melanophores along dorsal and ventral midline of trunk and tail. Bands of melanophores on trunk and beginning of tail. Larvae become heavily pigmented as development progresses, with pigment forming on the membranes of the fins by postflexion (Neira, *et al*., 1998).

**Material examined**

2 juveniles, BL ~50-70mm, caught in Bridge Marina, Tauranga Harbour.

**Similarities**

Similar to larvae from the family Kyphosidae (Neira, *et al*., 1998).

**References**

Laroche *et al*. (1984); Manabe and Ozawa (1988); Moser (1996).

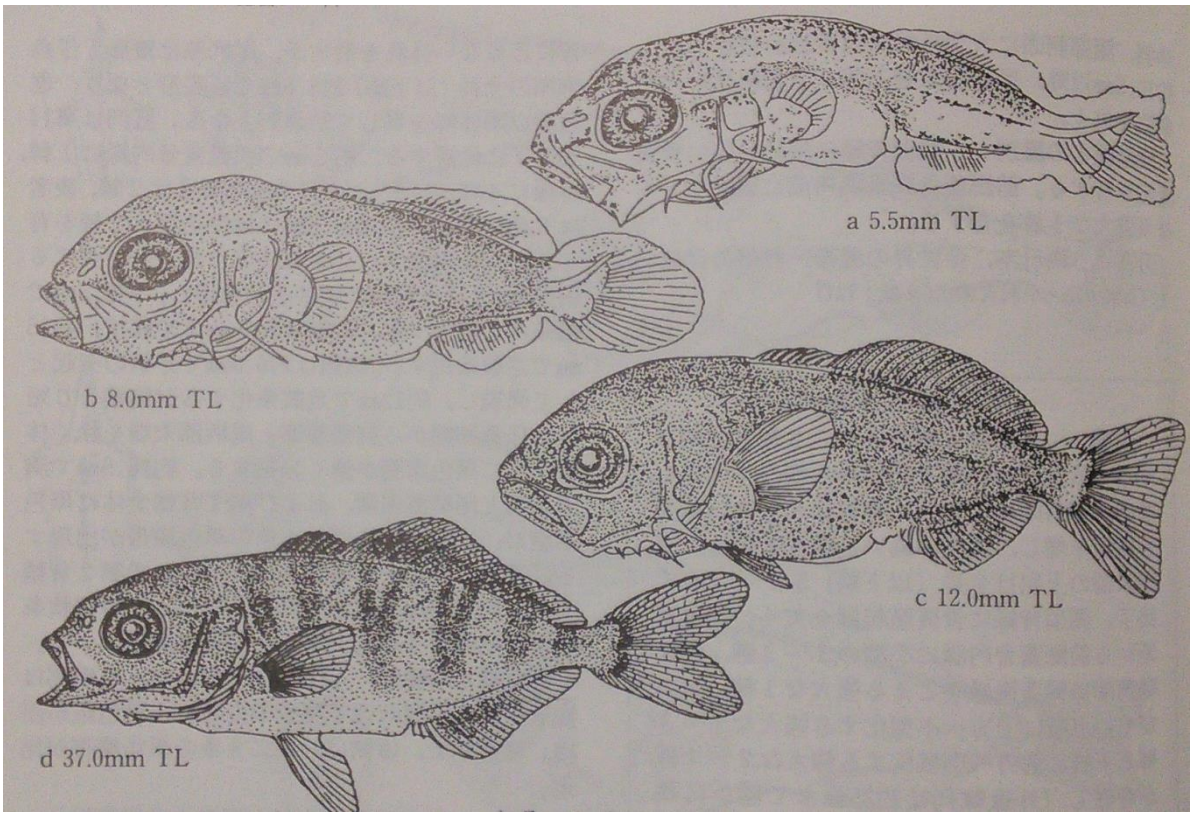


Figure 27: Developmental stages of the Yellowtail kingfish *S. lalandi* from Manabe & Ozawa (1988).

**Carangidae** *Trachurus declivis* (Jenyns, 1841) Jack mackerel

Adapted from Neira, *et al*. (1998)

| D | A | $P_1$ | $P_2$ | C | V |
|---|---|---|---|---|---|
| VIII + I, 29-35 | II + I, 24-29 | 20-21 | I, 5 | 17 | 24 |

*T. novaezelandiae* Richardson, 1843 Yellowtail scad

Adapted from Neira, *et al*. (1998)

| D | A | $P_1$ | $P_2$ | C | V |
|---|---|---|---|---|---|
| VIII + I, 27-33 | II + I, 22-29 | 21-22 | I, 5 | 17 | 24 |

*T. symmetricus* (Ayres, 1855) Jack mackerel

Adapted from Matarese, *et al*. (1989).

| D | A | $P_1$ | $P_2$ | C | V |
|---|---|---|---|---|---|
| VIII + I, 28-38 | II + I, 22-33 | - | I, 5 | 9 + 8 | 23-25 |

**Diagnostic characters**

- 9-13 + 11-15 = 24-25 myomeres
- Melanophore below pectoral-fin base on gut, becoming internal as flexion progresses.
- Supraoccipital crest smoothing slightly by postflexion.
- Melanophores along dorsal, lateral and ventral surfaces of trunk and tail.
- Internal melanophores below pectoral-fin base on gut.
- Pigment on crown.
- All fins formed ~122 mm

(Neira, *et al*., 1998).

**Description of larvae**

Morphology

Preflexion: Body elongate to moderate (BD 19-33%), head moderate (HL 22-33%). Gut long (PAL 52-63%), becoming coiled and compact by ~3.8 mm. Gas bladder obvious. Formation of various head spines and supraoccipital crest.

Postflexion: Body moderate (BD 27-33%), head large (HL 34-39%), by 10 mm the supraoccipital crest has lowered, and other head spines have smoothed or lowered. Scales forming at transformation.

Size at

Notochord flexion: 4.7-11.0 mm

Transformation: ~12.8 – 15.0 mm

Pigmentation

*Head:* Melanophores along dentary and angle of lower jaw. Melanophores over fore-, mid- and hindbrain by postflexion. Internal melanophores on roof of mouth.

*Dorsal:* Melanophores along midline of trunk, increasing in number to become an alternate paired series by flexion.

*Lateral:* External melanophore on gut, below pectoral-fin base, becoming internal during flexion. Melanophores along lateral line. Internal pigment over gut and gas bladder.

*Ventral:* Melanophores (1-4) along isthmus, and a series along midline of gut, tail, and preanal membrane.

*Caudal:* Very light pigmentation at base of caudal-fin, series of melanophores along midline of tail, reaching the notochord tip. Scattered pigmentation over caudal-fin (Ahlstrom & Ball, 1954; Neira, *et al*., 1998).

**Similarities**

There are four species of mackerel in New Zealand; *Trachurus novaezelandiae*, *T*. *declivis* , *T*. *murphyi* and *T*. s*ymmetricus*. It is difficult to distinguish between the four species of mackerel in New Zealand when the specimens are less than 35 mm (Crossland, 1981b). Keith (2000) states that the pigmentation on *T*. *declivis* is heavier than that on *T*. *novaezelandiae*, with distinctive melanophores in series along the dorsolateral and ventro-lateral surfaces of the body. *T*. *symmetricus* has heavier pigmentation dorsolaterally than the other *Trachurus* species found in New Zealand.

**References**

Crossland (1982); Matarese, *et al*. (1989).

Figure 28: Photo of a postflexion *Trachurus* larva.

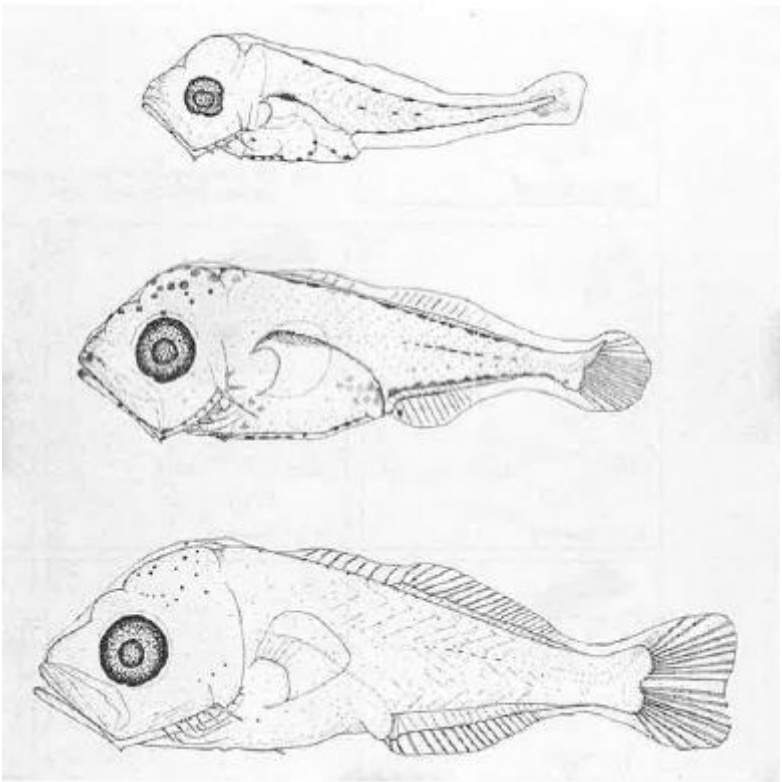

Figure 29: Developments stages of *T. novaezelandiae*. Larvae are 4.4, 7.6, and 8.9 mm. From Crossland (1981b).

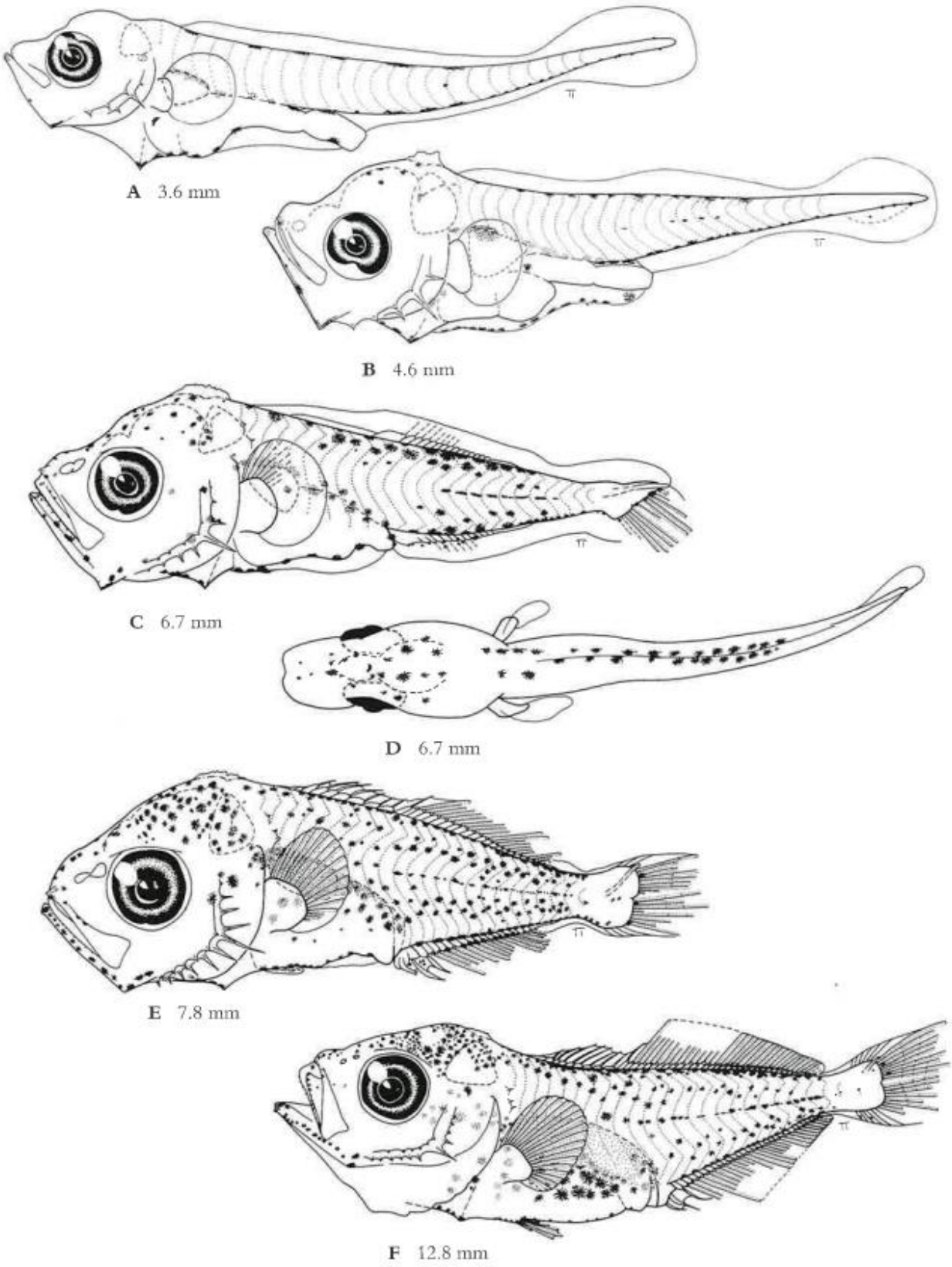


Figure 30: Developmental stages of *T. declivis*. A - preflexion, B - preflexion, C - early flexion, D - dorsal flexion, E - post flexion, F - late postflexion. From Neira, *et al*. (1998).

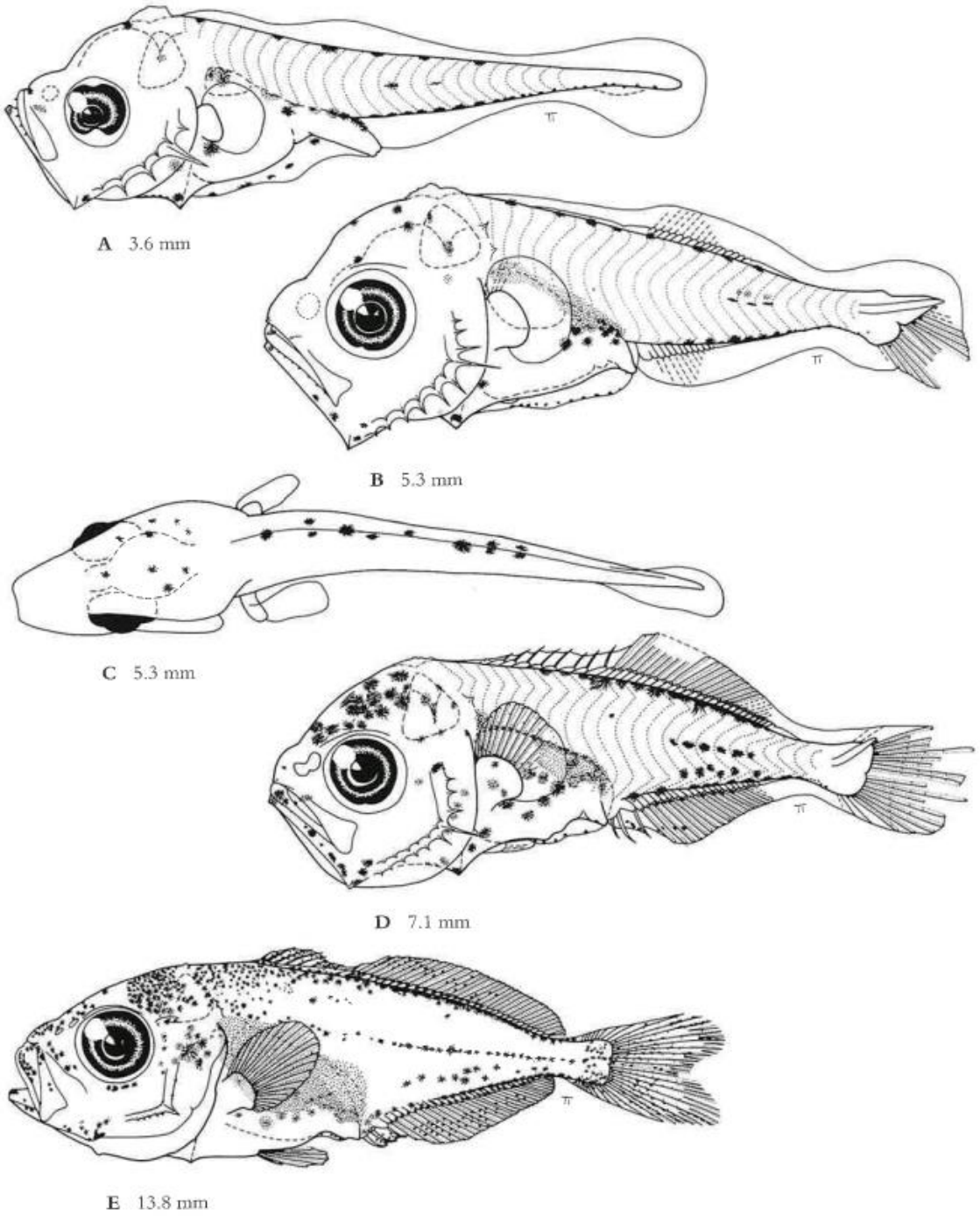


Figure 31: Developmental stages of *T. novaezelandiae*. A - preflexion, B - flexion, C - dorsal view flexion, D - postflexion, E - late postflexion. From Neira, *et al*. (1998).

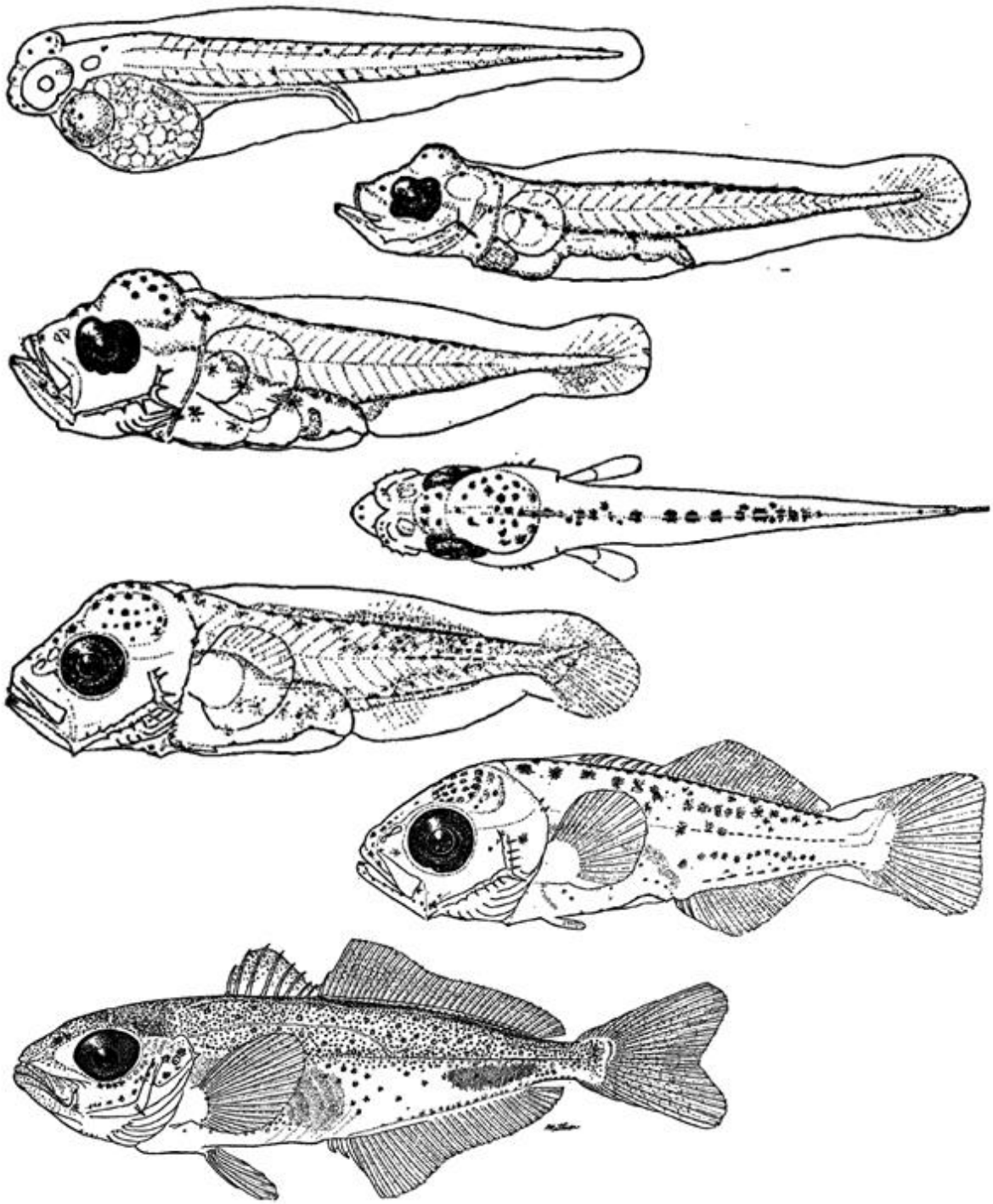

Figure 32: Development of *T. symmertricus*, 2.8 mm, 3.5 mm, 4.9 mm, 4.9 dorsal, 7.4 mm, 10.0 mm, 28.0 mm. From Ahlstrom and Ball (1954).

**Kyphosidae** *Girella tricuspidata* (Quoy & Gaimard, 1824) Parore

Adapted from Neira, *et al*. (1998).

| D | A | $P_1$ | $P_2$ | C | V |
|---|---|---|---|---|---|
| XIV-XVI, 11-13 | III, 11-12 | 16 | I, 5 | 17 | 27 |

**Diagnostic characters**

- 6-11 + 15-21 = 26-27 myomeres.
- Preopercular spines developing late preflexion.
- Large melanophores on midline of tail, dorsally and ventrally.
- Preflexion larvae have melanophores under notochord tip.

(Neira, *et al*., 1998).

**Description of larvae**

Morphology

Preopercular spines starting forming late preflexion, and increase in numbers through to postflexion. Body moderate with a moderate to long head (BD 20-26%, HL 22-34%). Preflexion larvae have a moderate gut (PAL 41-47%), postflexion larvae gut is moderate to long (PAL 48-52%). Anus and origin of anal fin separated by a large gap, which reduces in size through development. Scales forming at settlement.

Size at

Notochord flexion: 4.4-6.3 mm

Settlement: 12.3-14.5 mm

Pigmentation

*Head:* Melanophores that increase in numbers throughout development (starting on mid-, fore- then hind-brain), with the postflexion larvae having pigment on most of the head. Internal pigment on snout from late preflexion.

*Dorsal:* Melanophores along midline of tail and caudal peduncle, increasing in number and decreasing in space between as development progresses.

*Lateral:* Melanophores on gut in preflexion, becoming heavily pigmented by postflexion. A series of melanophores developing along midline of tail by late preflexion that extends forward throughout development and increases in number. Internal melanophores in series along notochord, ventrally from preflexion, and dorsally from flexion.

*Ventral*: Melanophores on midline of gut and tail during preflexion, with additional melanophores by postflexion.

*Caudal:* Preflexion and flexion larvae have a few melanophores under the notochord tip. Pigment present along base of lower and upper caudal fin rays, in flexion and postflexion respectively (Neira, *et al*., 1998).

**Material examined**

25 larvae, ~20 – 30 mm BL, from Bridge Marina in Tauranga harbour.

**Similarities**

Families with similar larvae include Arripidae, Centrolophidae, Girellidae, Leptobramidae, Microcanthidae, Mullidae, Pomatomidae and Scorpididae (Neira, *et al*., 1998).

**References**

Miskiewicz (1987).

Figure 33: Photo of a postflexion *G. tricuspidata*.

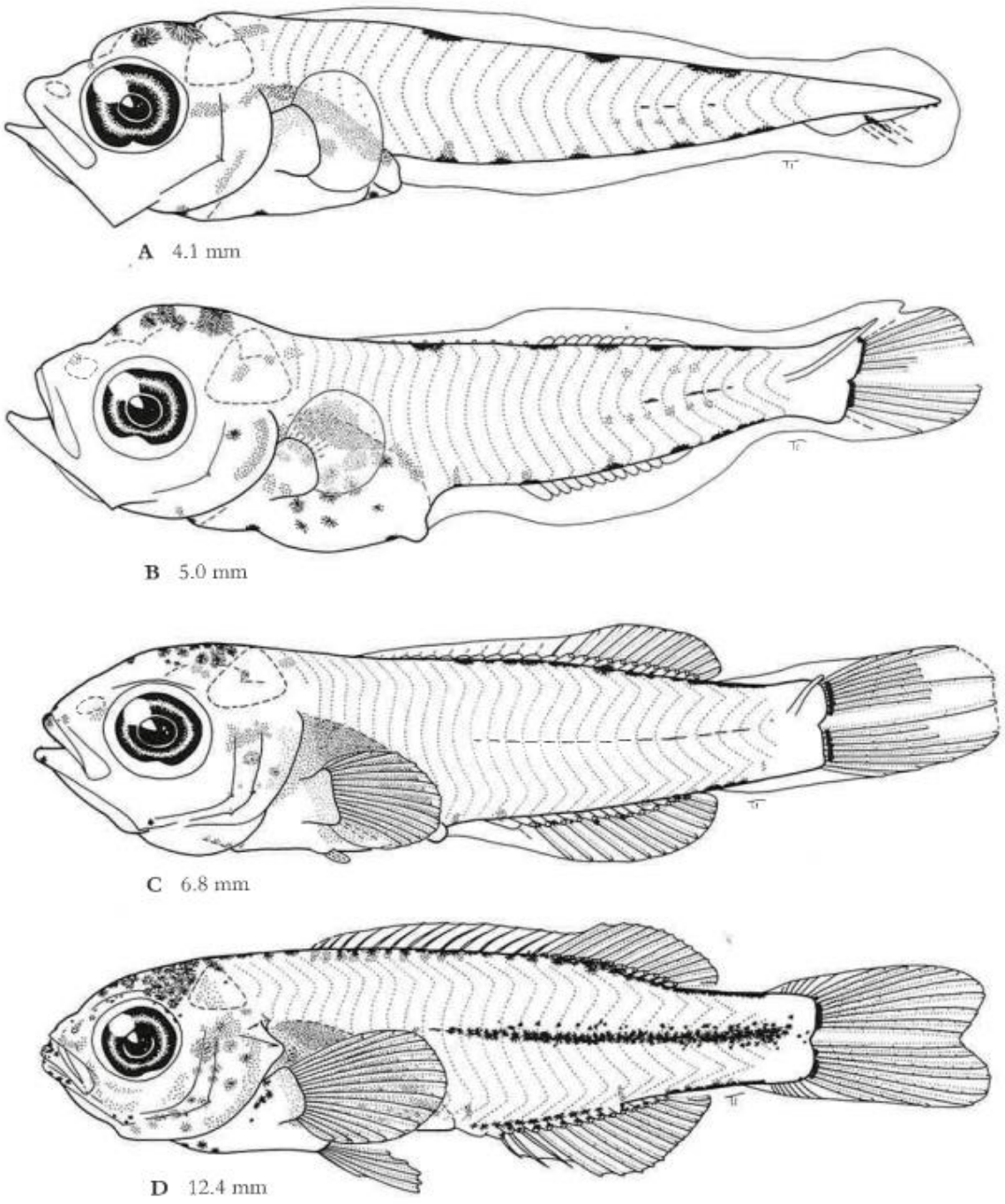


Figure 34: Larval development of *G. tricuspidata*. A - preflexion, B - late flexion, C - early postflexion, D - postflexion. From Neira, *et al*. (1998).

**Sparidae** *Chrysophrys auratus* (Forster, 1801) Snapper

Adapted from Neira, *et al*. (1998).

| D | A | $P_1$ | $P_2$ | C | V |
|---|---|---|---|---|---|
| XII, 9-10 | III, 8-9 | 15-16 | I, 5 | 17 | 24 |

**Diagnostic characters**

- 8-10 + 14-17 = 24-25 myomeres.
- Extensive head spination.
- Melanophore above nape is large and internal.
- Gut has 2 large melanophores ventrally.
- Notochord tip with 1-3 small melanophores beneath.

(Neira, *et al*., 1998).

**Description of larvae**

Morphology

Moderately deep body (BD 24-34%). Head moderate, becoming large by postflexion (HL 30-36%). Gut moderate (PAL 42-47%), becoming long by postflexion (PAL 53-59%). The gas bladder is small and found above the foregut. Scales start forming about 9.5 mm. Head spines that increase in number with growth (see Neira, *et al*. (1998) for full details of spines).

Size at

Notochord flexion: 5.0-6.6 mm

Settlement: ~12.0-13.3 mm

Pigmentation

*Head:* Internal pigment on hindbrain, 1 large melanophore internally over nape. Preflexion – 0-3 external melanophores above midbrain, postflexion – melanophores above midbrain increase in number.

*Dorsal:* Melanophores along dorsal-fin base from 9.2 mm.

*Lateral:* Broad vertical bars of pigment on trunk and tail. Internal pigment dorsally over hindgut and gas bladder.

*Ventral:* preflexion - 1 melanophore on isthmus, 2 large melanophores on gut, series of melanophores along tail midline. Postflexion – additional melanophores on gut, then absent in early juveniles. Extra melanophores along base of anal-fin and caudal peduncle midline from 7.7 mm.

*Caudal:* Preflexion – notochord tip has 1-3 melanophores underneath, postflexion – melanophores remain at base of caudal-fin (Neira, *et al*., 1998).

**Material examined**

Two larvae examined, ~13-17mm, from Tauranga harbour

**Similarities**

Preflexion stages show a superficial resemblance to tripterygiid larvae (Keith, 2000).

**References**

Cassie (1956); Crossland (1981a, 1981b); Miskiewicz (1987).

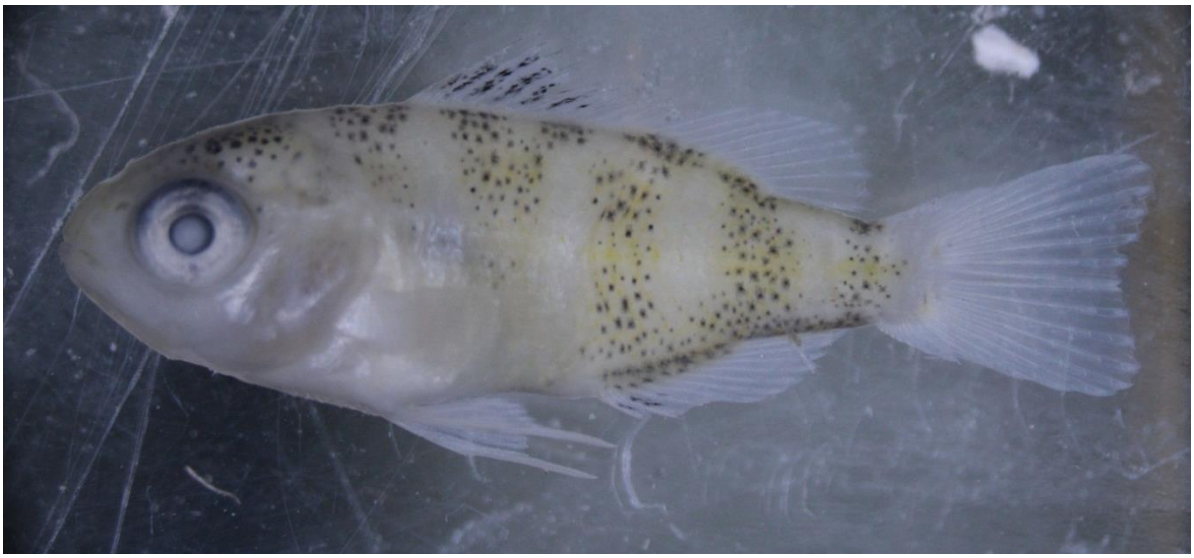

Figure 35: Photo of a presettlement *C. auratus*.

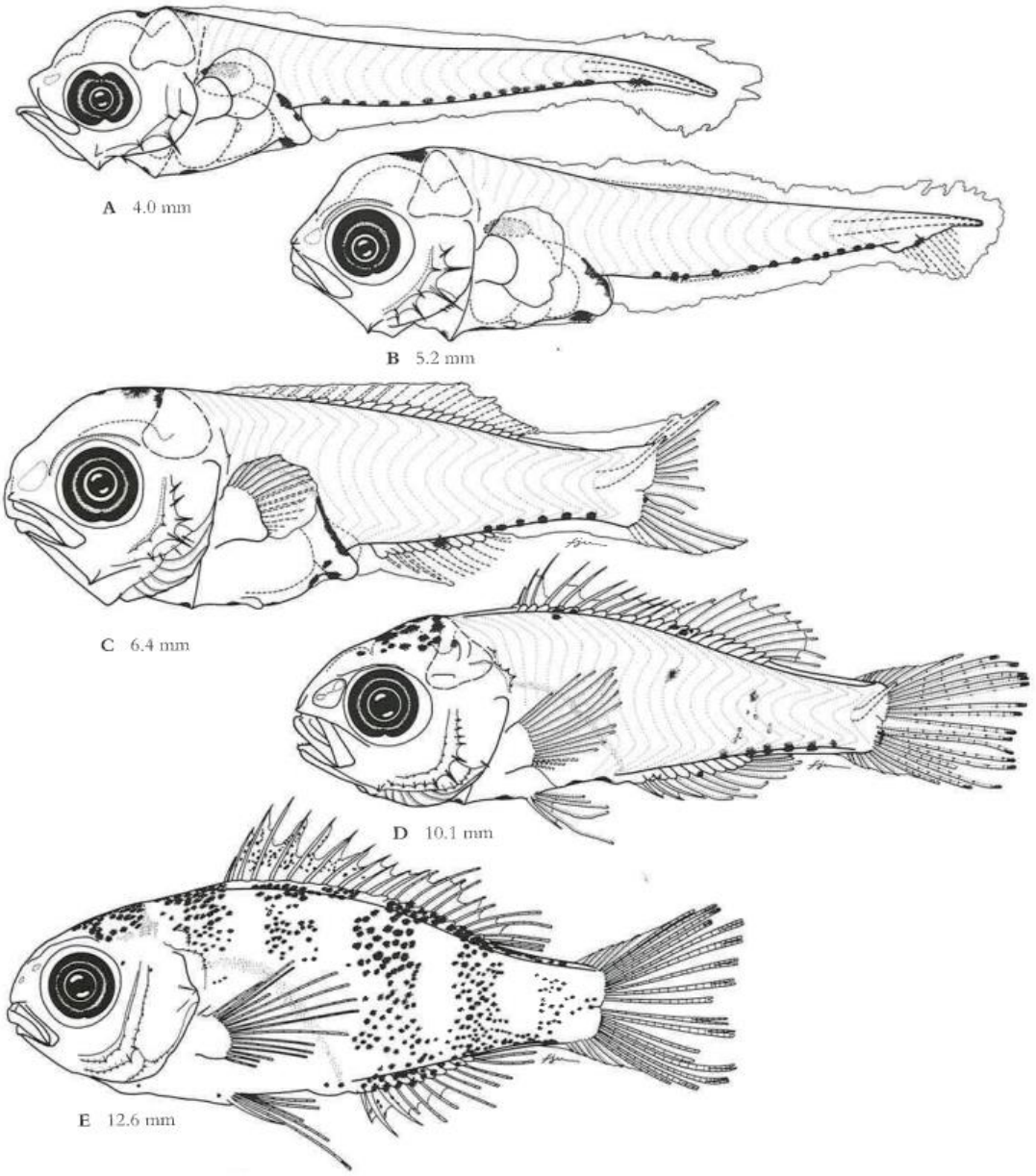


Figure 36: Development of *C*. *auratus*. A - preflexion, B - early flexion, C - late flexion, D - postflexion, E - early juvenile. From Neira, *et al*. (1998).

## Order TETRAODONTIFORMES

The order Tetraodonotiformes contains nine families, 101 genera and 357 species throughout the world. The family Monacanthidae, the filefishes, contains 32 genera and 102 species. They are identifiable by the presence of one or two dorsal spines, soft fin rays, small scales which can feel prickly to the touch, and a small mouth developed for nibbling (Nelson, 2006). There is one common species found in New Zealand, along with two species that are found occasionally from subtropical waters (Paul, 2000).

**Families and species included in this guide**

MONACANTHIDAE
*Meuschenia scaber*

**Monacanthidae** *Meuschenia scaber* (Forster, 1801) Leatherjacket

Adapted from Elder (1966) and Paulin, *et al*. (1989).

| D | A | $P_1$ | $P_2$ | C | V |
|---|---|---|---|---|---|
| II, 33-35 | 31-36 | 12 | - | 12 | - |

**Diagnostic characters**

- Distinguishing dorsal spine
- Pigment near the tail in a band
- Easily identifiable mini versions of the adult

(Crossland, 1981b).

**Description of larvae**

Morphology

Deep body. Dorsal spine bud is present on preflexion larvae at a size of about 3.5 mm. The characteristic dorsal spine is present at 4.5 mm. Scales develop to bear the dorsal spine. Dorsal and anal fins develop about 6 mm, caudal fin rays develop about 6.5 mm (Keith, 2000).

Size at

Notochord flexion: 6.5 mm

Settlement: 12 – 35 mm

Pigmentation

*Head:* Melanophores over midbrain and opercular margins on preflexion. Pigmentation increased on head in postflexion, becoming heavier.

*Lateral:* Melanophores above gut at preflexion, increasing by postflexion. Denser and more patches of pigmentation form by settlement.

*Caudal:* Melanophores scattered on caudal peduncle in postflexion (Elder, 1966).

**Material examined**

1 larva, 7 mm, from Bridge Marina in Tauranga Harbour.

**References**

Frentzos (1980); Kingsford & Milicich (1987); Dolphin (1997);.

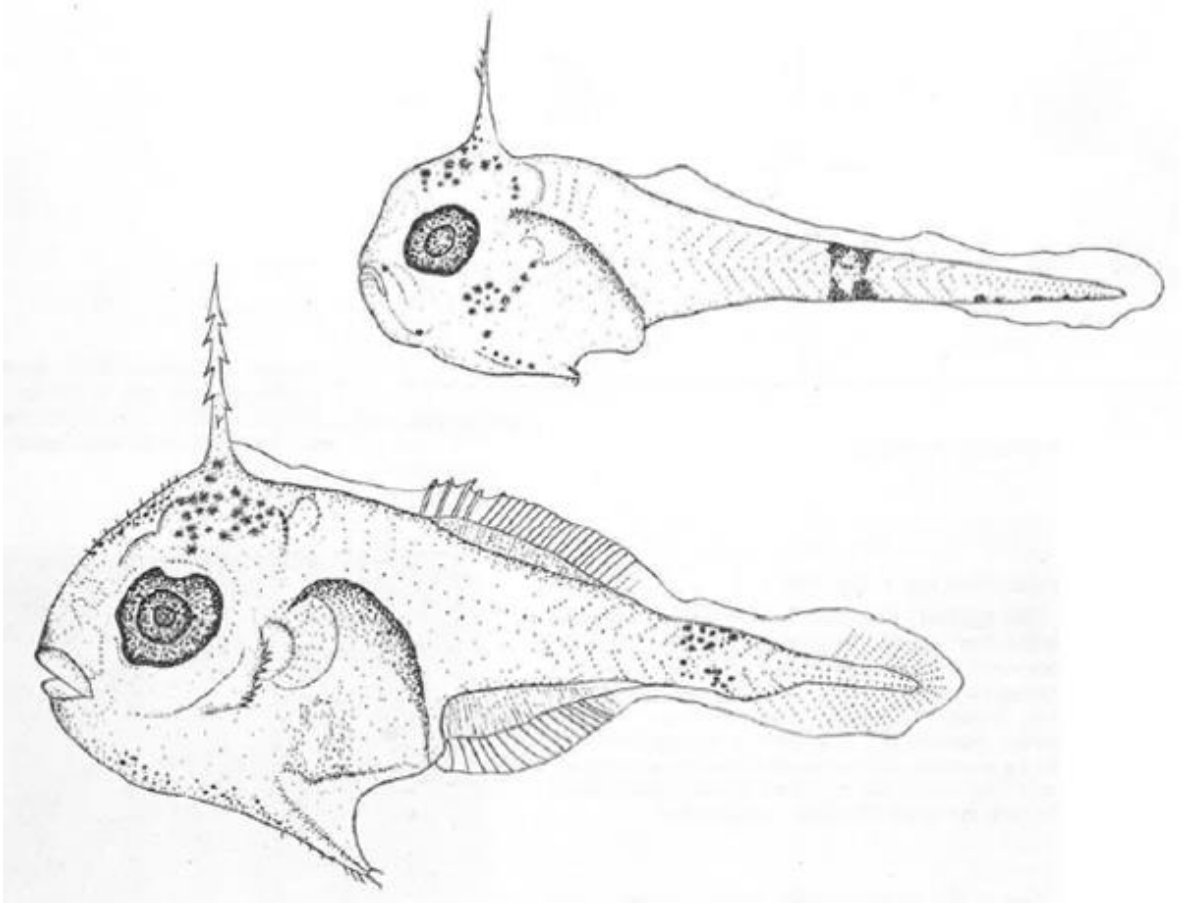

Figure 37: Larval *M. scaber* at lengths of 4.5 and 6.7 mm. From Crossland (1981b).

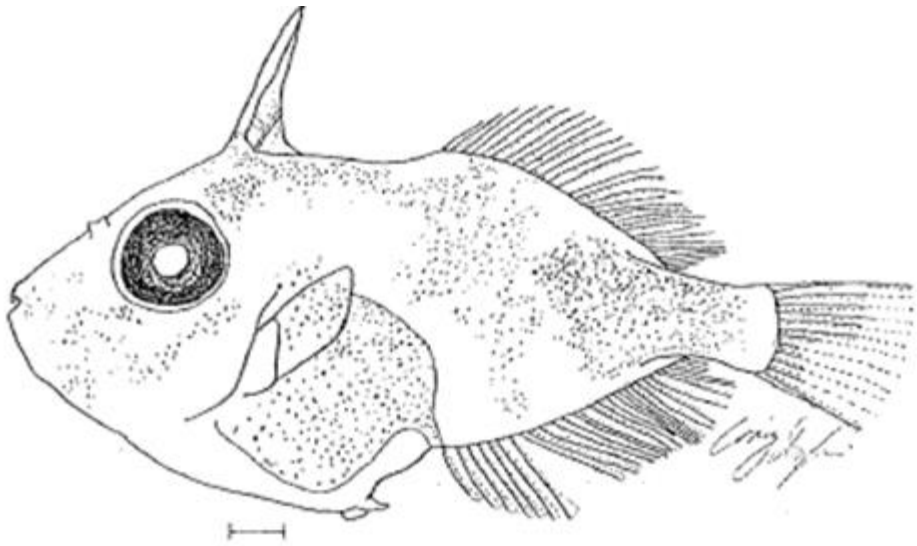

Figure 38: Prejuvenile *M. scaber*, length of 16.6 mm. From Dolphin (1997).

# 3 Chapter three - DISCUSSION

## 3.1 Species not included

A number of the larval fish taxa caught during sampling in Tauranga Harbour haven't been described in this guide, for reasons described below. This list also includes species where other members of the same genus were mentioned.

- *Conger verreaux*
- *Retropinna retropinna*
- Myctophidae
- *Trachurus murphyi*
- *Pseudolabrus celidotus*
- Labridae
- *Odax pullus*
- Creediidae
- Percophidae
- Uranoscopidae
- Leptoscopidae
- Tripterygiidae
- Blenniidae
- Gobiidae
- Syngnathidae
- Gobiosocidae
- Centrolophidae
- Pleuronectidae

A single *Conger verreaux* (Figure 39) was caught during sampling, but was not included in this guide due to time constraints and insufficient information.

The smelt, *Retropinna retropinna,* would have been included if there was sufficient time, as it was caught on a number of occasions, and there is sufficient information about the larval stages in literature. It is similar to larvae in the family Clupeidae, but has a fleshy adipose fin.

Figure 39: Photo of the *Conger verreaux* caught in Jan 2014.

A single specimen from the family Myctophidae (Figure 40) was caught during this study, however as it is not a common species, not well studied even in the adult life stage, and with about 100 species found in New Zealand waters, it was not possible to identify further.

Figure 40: The specimen from the family Myctophidae.

The mackerel *Trachurus murphyi* was not included as there was insufficient information available, however three other species in the same genus were included.
There are 16 species found in New Zealand in the family Labridae (Paul, 2000), and with the exception of the spotty *Pseudolabrus celidotus*, there was not enough information available to easily identify the other labrids caught, and insufficient time to look for further resources. No *Odax pullus* were caught during this survey, however it would have been included if there was enough time.

There are four species of Creediidae found in New Zealand, with two being quite common, but rarely seen due to their habits and small size (Paul, 2000). These were not included due to insufficient time (Figure 41). A similar family is the Percophidae, the opalfish. A few specimens from this family, possibly *Hemerocoetes monopterygius* were caught in this study, but not included due to lack of adequate literature.

Figure 41: Photo of a Creediid, possibly *Limnichthys renaldhi*.

The stargazers from the families Uranoscopidae and Leptoscopidae both have three species found in New Zealand (Paul, 2000). *Genyagnus monopterygius* and *Leptoscopus macropygus* were both caught during this study, but were not described due to time constraints (Figure 42).

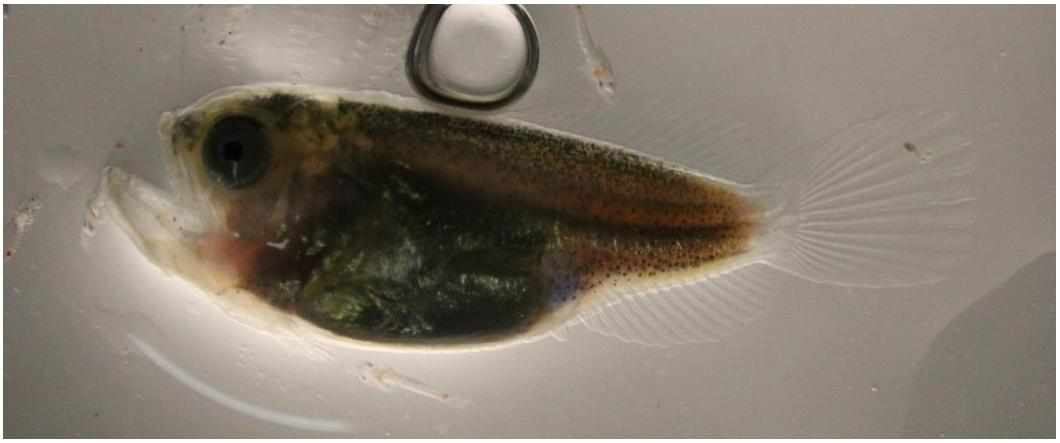

Figure 42: A stargazer from the family Uranoscopidae, possibly *Genyagnus monopterygius*.

There are about 20 species of Tripterygiidae found in New Zealand, which are easily distinguished as a family by three dorsal fins (Paul, 2000). A large number of triplefins were caught; however there is a large gap in the literature with only a few species described at in the larval stages (Figure 43).

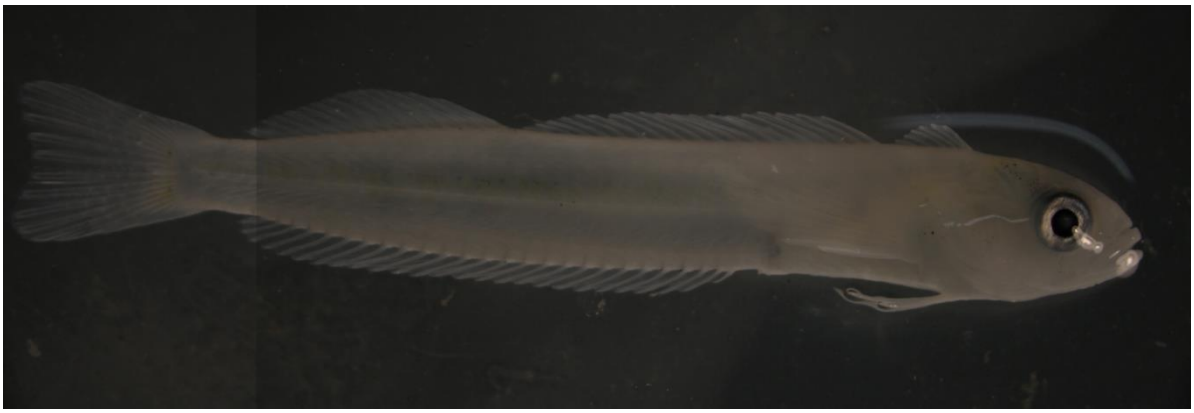

Figure 43: Photo of an unidentified triplefin.

One species from the family Blenniidae was caught, *Omobranchus anolius*, however there was insufficient time and literature available to include it in this guide. There are at least three species in the family Blenniidae found in New Zealand (Paul, 2000).

At least two species from the family Gobiidae were caught, but the literature available for identification is lacking. There are several species found in New Zealand (Paul, 2000)
A large number of larval and juvenile pipefish were caught throughout the study; however they were not identified to species, and just recorded as 'pipefish'. Other species from the family Syngnathidae were also caught (Figure 44). There are several species found in New Zealand (Paul, 2000).

Figure 44: Photo of a Syngnathidae.

There are ten species in the family Gobiesocidae found in New Zealand (Paul, 2000), and a number of larval and juveniles were captured during this study (Figure 45), however little is known about the larval stages of these species, and they were not included. They are fairly easily identifiable as a family, as the pelvic and pectoral fins begin the modification to form a sucking disc from a small size.

Figure 45: Postflexion clingfish, ventral view.

Juveniles of the Centrolophidae family were caught on several occasions during this study, usually found in the tentacles of jellyfish (Figure 46). It is thought they were the blue warehou *Seriolella brama* or bluenose *Hyperoglyphe antarctica*. There are about ten centrolophids in New Zealand (Paul, 2000).

Figure 46: Centrolophid that was found within the tentacles of a jellyfish.

There are two species in the family Bothidae, the left-eyed flounders, and ten in the family Pleuronectidae, the right-eyed flounders (Paul, 2000). A small number of flatfish were caught, however there was insufficient time and information to distinguish between the different species, however they were all right-eyed flounders, so in the family Pleuronectidae.

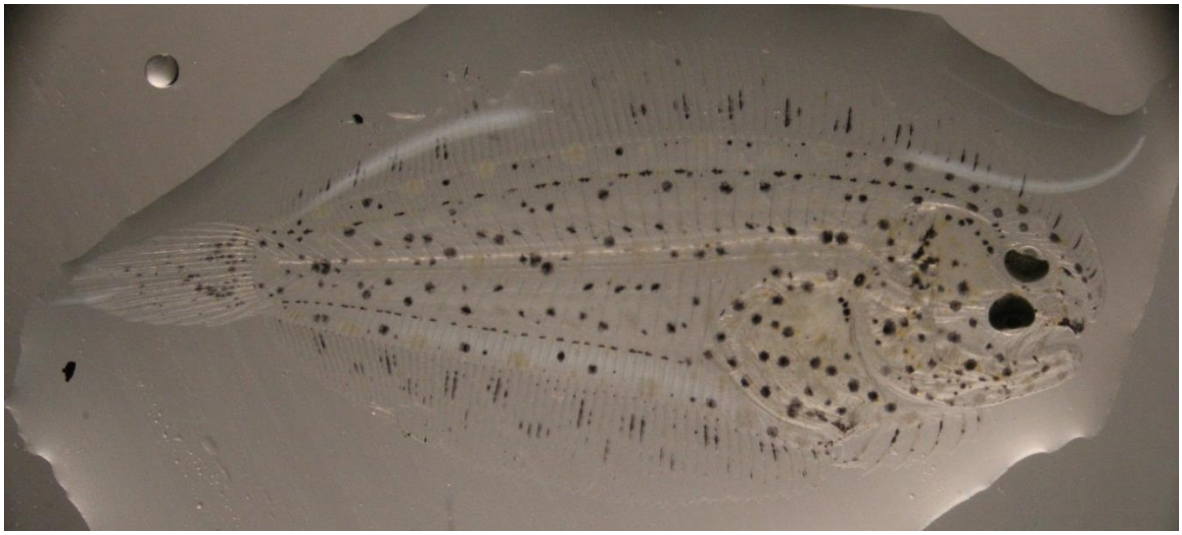

Figure 47: Pleuronectid with more advanced pigment than the one pictured as the frontispiece.

## 3.2 Discussion

It was not possible to include all of the fish species that were caught in Tauranga Harbour in this guide due to the lack of information on their early life stages. The unpublished theses listed in the introduction are early studies, having been completed between 14 and 48 years ago. Some classifications and species names have changed, for example the Parore is now found in the family Kyphosidae instead of Girellidae, and the leatherjacket is now *Meuschenia scaber* instead of *Parika scaber* (WoRMS Editorial Board, 2014). These theses were useful for the base identification of many species caught, which could then be searched for in other literature. The publications that were most useful were Leis and Carson-Ewart (2004); Neira, *et al*. (1998) and Moser, *et al*. (1984). These publications had descriptions for species that are found in New Zealand, as well as for the regions on which the publication were focused (Indo-Pacific, Australia, and worldwide).

A number of the species that were not included in this guide are small reef fish with no current commercial value to New Zealand. As a result, the literature available for the description of their larval stages is poor and lacks information that is commonly available for larger fish species. Common examples of this are the families Tripterygiidae, Gobiidae and Blenniidae, where in total there are approximately 30 species, however less than ten have been described. Even though these fish currently hold no commercial value, it would be beneficial to know

about their larval stages from a conservation and biodiversity perspective. It is hard to quantify biodiversity if species cannot be identified.

Another family not well described are the Myctophidae, for which there is little information for either adult or larval stages, due to being a rarely encountered deepwater fish. The species found in the order Clupeiformes were fairly well represented in literature, however, the main references for the family Clupeidae are over 40 years old (Baker, 1972, 1973) and it has been found that there are two species of *Sprattus* in New Zealand, where it was previously thought to be only one species (Dolphin, 1997). Published literature is lacking for the identification of many fish species in New Zealand, both larval and adult stages.

Some species mentioned in this guide are commercially important to New Zealand's fisheries. Being able to identify these larval fish can aid in research which can be applied for fisheries management, ecology studies, and other larval fish science in the Bay of Plenty region, and New Zealand wide. The presence of larval and juvenile fish can be an indicator of ecosystem health (Ramos *et al*., 2012). Important nursery habitats may be recognised by surveying the presence of juvenile fish (Beck *et al*., 2001). It is therefore imperative that the early life history stages are described for commercially fished species which lack this information.

This identification guide is the crucial first step in a research project examining the larval fish found in estuaries in the Bay of Plenty, a region of New Zealand previously unstudied in terms of larval fish ecology. The guide provides information that will be valuable for future research. Where the guide does not provide an account for a species recorded or likely to be found in Tauranga Harbour or the Bay of Plenty, the reader is directed to the best available literature.

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