Ecology of freshwater fish in the littoral zone of Lake Waikere, Kai Iwi Lakes, Northland, New Zealand: for the conservation of the dune lakes galaxias (*Galaxias* sp.)

Michael Alister Pingram

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Summary

It is widely accepted that introduced fish are responsible for the decline of native aquatic fauna worldwide. *Gambusia* and rainbow trout are considered to be amongst the most detrimental introduced species worldwide, including New Zealand. A native fish impacted by both species is the dune lake galaxias (hereon DLG) which is restricted to two lakes in Northland, New Zealand. DLG has been in decline since the introduction of exotic fish species in the 1960s and is now extinct in one of the Kai Iwi Lakes. DLG is presently considered to be a high priority for conservation. Rainbow trout are known to prey on DLG and decline subsequent to trout introduction has been recorded. However, recent studies have indicated that interactions with *Gambusia* are also likely to be important in the decline of DLG. This thesis aimed to provide a greater understanding of the ecology of fish species in the Kai Iwi Lakes, with the goal of aiding the setting and implementation of appropriate management strategies for the conservation of DLG. The abundance and distribution of three fish species (*Gambusia*, common bully and DLG) in littoral habitats were investigated using both passive and active sampling techniques. Results indicate that *Gambusia* are almost completely restricted to shallow vegetated habitats and peak in density during summer. DLG were observed shoaling in deeper waters around the edges of littoral vegetation during the day, while individual fish were frequently and regularly observed in un-vegetated stretches of the littoral zone at night. The diet of trout, *Gambusia* and DLG were examined as potential indicators of the impact of introduced species on DLG. Results indicate that both predation by trout and competition between *Gambusia* and DLG exist. Results also suggest that *Gambusia* may reduce both available food and littoral refuge habitat for DLG. The timing and location of DLG spawning in the Kai Iwi Lakes are currently uncertain. DLG were collected and daily growth increments on their otoliths were counted to back-calculate hatch date. Results suggest that spawning of DLG occurs from summer to early winter. A peak in hatch dates was observed for June 2004, suggesting that spawning may have peaked in May. Exotic fish species have almost certainly played a role in the decline of DLG in the Kai Iwi Lakes. Further research is necessary to assess whether *Gambusia* control or exclusion may be possible from key areas of littoral habitat that are important for DLG. Furthermore, regular and ongoing monitoring of DLG populations is essential to identifying any decline or recovery of DLG in the Kai Iwi Lakes. This can be achieved using inexpensive and accurate night time visual surveys of un-vegetated stretches of the littoral zone. This will provide information, in the form of a relative index, pertaining to seasonal and yearly variation in the abundance of DLG. Ideally the information gathered in this thesis will aid in halting the decline of the DLG and dwarf inanga in Northland, so that in the long-term populations of these species may be improved.

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Table of contents

List of figures

List of tables

Chapter 1.0: General introduction

1.1 Landlocked galaxiids

Members of the Galaxiidae family of fishes are found to occur naturally throughout the southern hemisphere, including New Zealand (McDowall 1990). There are presently at least 20 recognised species of freshwater galaxiid in New Zealand (McDowall 2000). One of the most widespread around New Zealand and the Southern Hemisphere is the inanga (*Galaxias maculatus*) (McDowall 1990). The inanga is typically a diadromous species, although landlocked and freshwater limited populations occur throughout its range (McDowall 1972), including those recorded by McDowall (1967) and Pollard (1971). Landlocked galaxiids were first reported from lakes on the west coast of Northland as early as 1949 (Cunningham et al. 1953). However, it was not until McDowall (1967) that galaxiids in some of those lakes were formally identified and described. Dwarf inanga (*Galaxias gracilis* McDowall 1967) were described from Lake Rototuna on the North Kaipara head and were considered to be a new species probably derived from the inanga (McDowall 1967). The separate taxonomic status of the dwarf inanga from inanga is based on morphological differences arising from evolving in completely landlocked, freshwater environments. The dwarf inanga is likely to have evolved from several founding populations of inanga which have become landlocked in the dune lakes of Northland over geological time (Ling et al. 2001). For a more complete description of dwarf inanga see McDowall (1967), and more recently McDowall (1990), McDowall & Rowe (1996) and McDowall (2000).

Since its description over 35 years ago, dwarf inanga has been recorded from a further 12 dune lakes, all within an 80km stretch of coastline (Rowe and Chisnall 1997a). It is presently rare in 5 lakes, extinct in 3 others (Rowe and Chisnall 1997a) and remains abundant in just four lakes (McDowall and Rowe 1996). It is currently found naturally in Lakes Taharoa and Waikere (Kai Iwi Lakes, Northland), and Lakes Waingata, Rototuna, Kanono, Rotokawau, Humuhumu, Rotopouua, and Kahuparere (Pouto Peninsula, North Kaipara Head) (Figure 1.1) and has been introduced as a forage food for trout in Lake Ototoa (South Kaipara Head) (Thompson 1989, Rowe and Chisnall 1997a, McDowall 2000). As a result of its restricted geographical occurrence and documented decline (McDowall and Rowe 1996), combined with a lack of contemporary gene-flow (Ling et al. 2001), the dwarf inanga is currently a priority for conservation (McDowall and Rowe 1996, Kerr 2001, Ling et al. 2001).

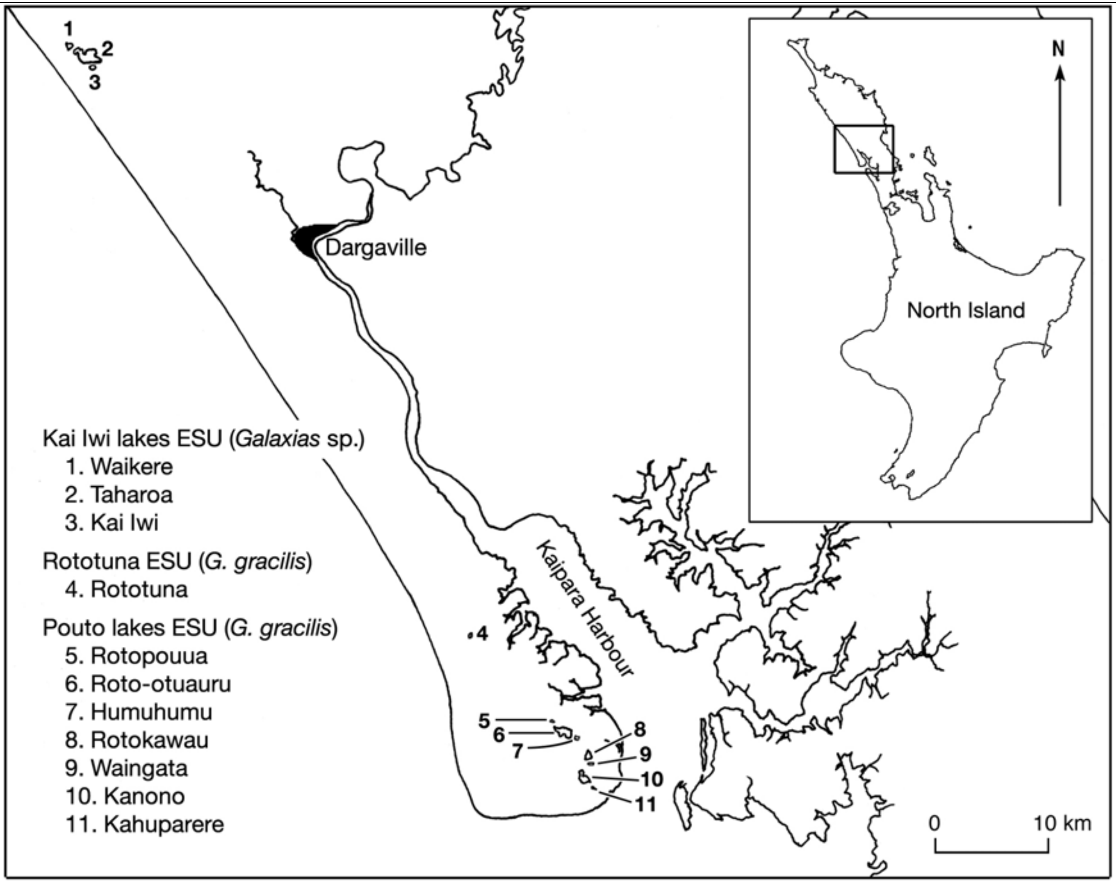

Figure 1.1. Distribution of dune lakes galaxias and dwarf inanga evolutionary significant units (ESU). Drawn by Ken Miller and based on data in Gleeson *et al.* (1999) and Ling *et al.* (2001).

1.2 The dune lakes galaxias

1.2.1 Conservation status

Dwarf inanga were originally considered to be New Zealand's only endemic species of completely lake dwelling freshwater fish (Rowe and Chisnall 1997a). Recent genetic research has revealed three distinct evolutionary significant units (ESU) of dwarf inanga, those in the southern Pouto Lakes on the North Kaipara Head, those in Lake Rototuna and those in the Kai Iwi Lakes (Gleeson et al. 1999, Ling et al. 2001) (Figure 1.1). The separation suggests three different founding events, possibly relating to the geological formation of the lake groups, with the Kai Iwi Lakes being the oldest (Ling et al. 2001). It has been recommended that the three ESU be managed separately, as the classification of ESU indicates deep phylogenetic subdivisions within the species due to a long period of isolation (Gleeson et al. 1999, Ling et al. 2001). The Kai Iwi Lakes ESU has been determined as being the most genetically distinct of the three ESU and is currently considered to be a separate species by the Department of Conservation (Hitchmough 2002, Allibone and Barrier 2004). It has subsequently received the title of "dune lakes galaxias", hereon DLG (*Galaxias* sp.) (Figure 1.2), in the Department of Conservations threat classification system (Hitchmough 2002, Allibone and Barrier 2004). The ESU present on the Pouto Peninsula retain the title of "dwarf inanga" (Hitchmough 2002). DLG is currently considered to be nationally vulnerable by the Department of Conservation (Allibone and Barrier 2004). DLG is further considered to be chronically threatened and conservation dependent by the Department of Conservation, using its threat classification system based on threat of extinction (Hitchmough 2002, Molloy et al. 2002). This status is based on a range contraction of DLG as a result of a documented extinction from Lake Kai Iwi and ongoing decline in Lakes Waikere and Taharoa since 1985 (Kerr 2001, B. David Unpubl. Data. 2004).

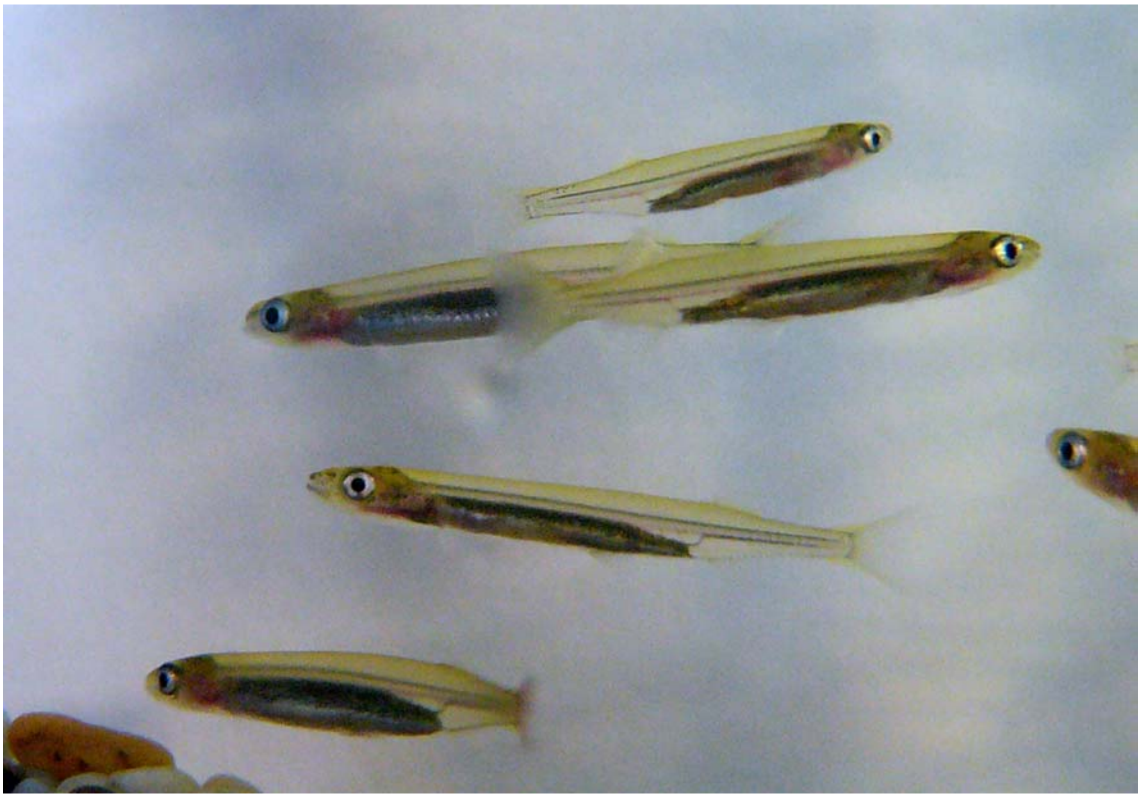

Figure 1.2. Dune lakes galaxias.

1.2.2 Introduced threats

The introduction of plant and animal species by humans to new areas contributes significantly to the decline of species' populations and biodiversity worldwide (Lodge 1993, Mack et al. 2000). Only habitat loss is believed to be a more significant factor (Everett 2000). The introduction by humans of species to novel ecosystems beyond natural barriers and ranges threatens native species worldwide, particularly where the latter exist in small and isolated populations (Begon et al. 1996). Exotic fishes have been deliberately introduced globally to establish recreational, commercial and ornamental fisheries and as biological control agents. Exotic species, including fish, are considered responsible for the major alteration of the biodiversity, structure and function of many freshwater communities (Kolar and Lodge 2000, Rahel 2002, Simon and Townsend 2003). Consequently, these species have been the target of much research by resource, conservation and restoration managers and scientists (Sakai et al. 2001). Furthermore, the impact of introduced species on freshwater communities may be exacerbated where more than one exotic species is present (Bryan et al. 2002). Current threats to dwarf inanga and DLG populations include the invasion of waterways by exotic flora and fauna, and declining water quality (McDowall and Rowe 1996, Rowe and Chisnall 1997a, b).

Rainbow trout (*Oncorhynchus mykiss*) and mosquitofish, hereon *Gambusia* (*Gambusia affinis*) are considered amongst the world's worst invasive species (Lowe et al. 2001). Both have been deliberately introduced to many freshwater systems, including in New Zealand where they threaten native biodiversity. Rainbow trout have been liberated widely to establish recreational fisheries and are considered to have several negative impacts on native freshwater fish species (directly and indirectly) (McDowall 2003). *Gambusia* spp. (*G. affinis* and *G. holbrooki*) have been widely used as a biological control method for mosquito borne diseases (e.g. malaria) with mixed success and acclaim (Rupp 1996). Indeed, *Gambusia* are known to destroy naturally occurring predators of mosquitoes and their larvae (Bence 1988, Rupp 1996). Consequently it is widely reported that the value of *Gambusia* for controlling mosquito larvae is somewhat exaggerated (Rupp 1996). Indeed as Rupp (1996) ironically points out, "*If Gambusia is so effective a predator, how is it there are so many mosquitoes in areas which are its native habitat?*"

1.2.3 The decline of the dune lakes galaxias

Rainbow trout and *Gambusia* have been implicated in the documented decline of DLG in the Kai Iwi Lakes (Rowe and Chisnall 1997a, b, McDowall 2000). While naturalised populations of rainbow trout exist elsewhere, the Kai Iwi Lakes have no suitable spawning grounds, so their presence in the lakes is maintained by stocking. *Gambusia,* however have managed to establish self sustaining populations in the Kai Iwi Lakes, making them the greater concern for the long-term management of native species. The decline of DLG is possibly due to inter-specific interactions between DLG and introduced fishes (i.e. competition and predation) (Rowe and Chisnall 1997a, b, Rowe et al. 1999). Early reports suggest that DLG was abundant in the Kai Iwi Lakes prior to trout stocking (Cudby and Ewing 1968). Following the stocking of rainbow trout into Lake Taharoa in 1968 (Cudby et al. 1969) and Lake Waikere in 1969 (Cudby 1970), a decline in the abundance of DLG in the lakes and trout stomachs was observed (Cudby 1970, Allen et al. 1971). *Gambusia* were illegally introduced as a potential forage food for trout in the 1960s (McDowall 2000). Results of a trout removal study in Lake Waikere suggested that although trout removal had a positive effect on the number of juvenile DLG present in the pelagic zone of the lake, it appeared to have little effect on adult recruitment (Rowe et al. 1999). Observations made during the autumn of 1998 indicated that *Gambusia* may be responsible for mortality and injury (in the form of fin nipping) to large numbers of DLG, particularly around areas of littoral vegetation where *Gambusia* occurred in high densities (Rowe et al. 1999). Consequently, *Gambusia* are currently considered to be the most significant threat to DLG in the Kai Iwi Lakes.

1.2.4 ***Gambusia***

Gambusia (Figure 1.3) were introduced to New Zealand for mosquito control purposes via Hawaii in the 1930s and have since become widespread throughout the northern half of the North Island (McDowall 2000, Ling 2004). At present *Gambusia* are listed as an unwanted organism in New Zealand under the Biosecurity Act (1993) and have been implicated in the decline and/or extinction of native species worldwide (Rupp 1996). Studies in North America by Lydeard and Belk (1993) found that all investigated densities of *G. affinis* had negative impacts on the native fish species studied. Negative impacts on native species as a result of competition, predation and inter-specific aggression by introduced *Gambusia* species. are known to affect the growth, survival and reproduction of native and threatened freshwater species. Examples of freshwater fish species impacted by *Gambusia* spp. include: in Australia the pacific blue-eye (*Pseudomugil signifier*) (Howe et al. 1997), western pygmy perch (*Edelia vittata*), nightfish (*Bostockia porosa*) and the western minnow (*Galaxias occidentalis*) (Morgan et al. 2004); in North America the endangered sonoran topminnow (*Poeciliopsis occidentalis*) (Meffe et al. 1983) and the least chub (*Iotichthys phlegethontis*) (Mills et al. 2004); and in Europe, Spanish toothcarp (*Aphanius iberus*), Valencia toothcarp (*Valencia hispanica*) (Rincon et al. 2002) and the Greek toothcarp (*Valencia letoureuxi*) (Economidis et al. 2000). *Gambusia* spp. are also implicated in the decline of several amphibian species from North America (Gamradt and Kats 1996, Goodsell and Kats 1999, Lawler et al. 1999), Australia (Komak and Crossland 2000, Hamer et al. 2002) and Europe (Denoel et al. 2005). *Gambusia* spp. may also threaten unique freshwater invertebrates such as dragonflies (Rowe 1987) and shrimps (Leyse et al. 2003). Predation by *Gambusia* spp. on grazing invertebrates may also indirectly affect water quality (i.e. temperature, pH and clarity) by reducing predation pressure on phytoplankton (Hulbert et al. 1972, Hulbert and Mulla 1981, Margaritora et al. 2001). Consequently, it is probable that *Gambusia* impact on important life history stages (e.g. reproduction) of DLG. The existence of a prospering population of *Gambusia* in the Kai Iwi Lakes is therefore, particularly disturbing.

Figure 1.3. *Gambusia affinis*, female (left) and male (right).

1.3 Objectives

Information about the ecology of freshwater fish in the Kai Iwi Lakes is vital to the recovery and conservation management of the DLG, particularly in Lake Waikere. Of particular importance is information regarding the distribution and abundance of fish species in habitats believed to be important to DLG conservation (including DLG), in particular the littoral zone. Furthermore, basic information regarding the diet and reproduction of important species is also essential. The greater aim of this thesis was to provide information to assist those making management decisions for the conservation of DLG in the Kai Iwi Lakes, so that these decisions may be better informed and effective. A more detailed breakdown of the content of this thesis this is as follows:

Chapter One began by providing a general introduction to the conservation status of the DLG and current threats to its survival.

Chapter Two investigates seasonal and diel distributions and abundances of native and exotic fish in the littoral zone of Lake Waikere. A combination of active and passive sampling techniques were employed to provide information on the fish species utilising the littoral zone of Lake Waikere.

Chapter Three quantifies the potential extent of predation and competition by exotic species on DLG in regard to diet. The composition of the diet is examined in DLG, *Gambusia* and rainbow trout from Lake Waikere.

Chapter Four employs a recognised aging technique of fish to accurately determine the time of year in which DLG spawn. Conclusions should aid in the identification of spawning events and habitats in Lake Waikere.

Chapter Five provides a summary and synthesis of the conclusions of previous chapters. Recommendations based on the information gathered in this thesis will be made in regard to the future direction of research and management goals for the conservation of DLG in the Kai Iwi Lakes.

Chapter 2.0: The diel and seasonal distribution and abundance of fish in the littoral zone of Lake Waikere, Kai Iwi Lakes, Northland, New Zealand.

A calm morning on Lake Waikere, perfect weather for sampling.

2.1 Abstract

The dune lakes galaxias is a threatened fish species restricted to two freshwater dune lakes on the west coast of Northland New Zealand. The littoral zone is considered to be an important habitat for this threatened species; however, it is also occupied by *Gambusia*, an exotic species which is implicated in the decline of this and other species worldwide. The distribution and abundance of fishes in relation to habitat is often determined by a combination of biotic and abiotic factors. Using a combination of passive trapping and active visual techniques, it was sought to better describe the patterns in fish abundance and distribution in the littoral zone of Lake Waikere. The relative abundances and distributions of three species of fish (*Gambusia*, common bully, dune lakes galaxias) and one species of crustacean (koura) in littoral habitats were investigated. Results indicated that *Gambusia* were restricted to shallow, vegetated littoral habitat and reach highest densities during late summer. DLG shoal in deeper waters and around the edges of reed beds during the day, while individual fish were frequently observed in un-vegetated areas of littoral habitat at night. Common bully occupy both vegetated and un-vegetated habitat in the littoral zone and appear to reach highest densities in these habitats during spring. A subsequent decrease in common bully density in shallow vegetated habitat coincided with a marked increase in *Gambusia* in the same habitat. Koura activity in the littoral zone was strictly nocturnal and was usually associated with areas of littoral vegetation. High densities of *Gambusia* can be expected to have a negative impact on other species utilising the littoral zone. In combination with trout, *Gambusia* are likely to be responsible for the observed decline in DLG in the Kai Iwi Lakes. Future management of DLG, particularly in Lake Waikere, should involve regular monitoring of these fish in the littoral zone. Potential control of *Gambusia* can be focused on patchily occurring areas of emergent littoral vegetation at certain times of year. Competitive exclusion by *Gambusia* may prevent DLG from effectively utilising areas of habitat in the littoral zone that provide refuge from predators, i.e. emergent littoral vegetation. Consequently this may accentuate rainbow trout and avian predation on DLG, while also threatening potentially valuable spawning locations for DLG.

2.2 Introduction

2.2.1 The littoral zone

Lakes are complex ecosystems made up of several distinct habitats including pelagic, littoral, benthic and riparian zones (Keast 1978, Schindler and Scheuerell 2002). Fish play an important role in determining the species composition, structure and dynamics of aquatic communities, both within and between habitat types (Brooks and Dodson 1965, Wellborn et al. 1996, Schindler and Scheuerell 2002). While many studies of freshwater ecosystems have focussed on the pelagic zones of lakes, less is known of littoral habitats, especially those containing little or no standing vegetation (Schindler and Scheuerell 2002). The littoral zone provides a mosaic of habitats, varying in wave action, turbidity, turbulence, temperature, substrate, vegetation density and various abiotic structures that create a contiguous zone of different microhabitats (Chick and McIvor 1994, Lewin et al. 2004).

2.2.2 Fish habitat use

The distribution and abundance of fishes in relation to habitat are often determined by a combination of biotic and abiotic factors. Biotic factors include trade-offs between the availability of food (Schindler et al. 1997, Jackson et al. 2001, Stoffels and Closs 2002, Shoup et al. 2003, Kahilainen et al. 2004), predation risk (Werner et al. 1983, Werner and Hall 1988, Lima and Dill 1990, Jacobsen and Berg 1998, Holker et al. 2002, Shoup et al. 2003, Kahilainen et al. 2004) and competition with coexisting organisms for optimal foraging habitat (Jackson et al. 2001). Abiotic factors include water quality (e.g. temperature and dissolved oxygen) and the physical structure of habitats (i.e. fetch and macrophytes) (Matthews 1998). Habitat selection occurs so that physiological stress is minimised and foraging and reproductive success is optimised (Huntingford 1993, Beauchamp et al. 1999, Jackson et al. 2001, Meredith et al. 2003).

Consequently, the spatial heterogeneity of the littoral habitat and factors involved in fish habitat selection result in patchy fish distribution and abundance (Keast 1978, Benson and Magnuson 1992, Chick and McIvor 1994, Weaver et al. 1997). Furthermore, fish respond to variation in environmental conditions by altering their activity and habitat selection in regard to season (Gilinsky 1984, Rossier 1995, Paukert and Willis 2002, David and Closs 2003, Meredith et al. 2003, Balcombe and Closs 2004, Kahilainen et al. 2004). Fish also respond to diel patterns and variation in their environment by altering their habitat selection and behaviour (Helfman 1981, Copp and Jurajda 1993, Arrington and Winemiller 2003, David and Closs 2003, Balcombe and Closs 2004, Lewin et al. 2004). The costs and benefits of different habitats for fish can vary according to the time of day, particularly in regard to trade offs between foraging potential and predation, often resulting in a marked shift between habitats (Naud and Magnan 1988, Piet and Guruge 1997, Jacobsen and Berg 1998, Beauchamp et al. 1999, Metcalfe et al. 1999, Shoup et al. 2003, Kahilainen et al. 2004).

2.2.3 Macro-fauna of the Kai Iwi Lakes

The Kai Iwi Lakes contain a relatively depauperate fish fauna, with only five species of freshwater fish present. Native fish species present in the lakes include DLG, common bully (*Gobiomorphus cotidianus*), short-fin eel (*Anguilla australis*) and long-fin eel (*Anguilla dieffenbachii*). Exotic fish present include the rainbow trout, which is stocked annually, and *Gambusia*. The native crustacea, koura (*Paranephrops planifrons*) and the freshwater crab (*Amarnius lacustris*) are also present in the lakes. The introduced Australian gold and green bell frog (*Litoria aurea*) is also present in the domain.

The littoral zone has been recognised as being important in the life-history of DLG (Rowe and Chisnall 1996, Rowe 1998). *Gambusia* also occupy this zone in the Kai Iwi Lakes and have been observed to impact on DLG in and around littoral habitats at various times of the year (Rowe et al. 1999). An improved understanding of *Gambusia* distribution and seasonal abundance is therefore crucial to understanding the potential impact of this introduced species on the DLG. *Gambusia* are known to prefer shallow littoral habitats that are characterised by prolific emergent aquatic macrophytes (Casterlin and Reynolds 1977, McDowall 2000, Ozturk and Ikiz 2004). *Gambusia* are documented to reach highest densities during summer in Lake Waikere (Rowe et al. 1999) and elsewhere (Barney and Anson 1921). Common bully have historically always been present in Lake Waikere and also utilise areas of littoral habitat. Therefore, common bully are likely to interact with DLG and *Gambusia* through competition for resources and predation (pers. obs. 2004). Common bully occupy a variety of freshwater habitats throughout New Zealand, including the littoral zones of lakes, where fish are often readily visible (McDowall 2000). Common bully occupy benthic habitats and are a somewhat cryptic and fecund species, allowing them to persist despite predation by trout. Koura is commonly found in lakes and streams of the North Island and is considered to be an important processor of terrestrial and aquatic detritus (Parkyn et al. 2002). Trout and eel species were not included in the present study because they were very rarely, if ever, recorded in the littoral zone of the sites surveyed, and although they utilise a range of habitats within the lakes, the littoral zone was the focus of the present study.

2.2.4 Aims

This study set out to investigate the habitat, diel and seasonal patterns of distribution and abundance of *Gambusia*, common bully, DLG and koura in Lake Waikere. It was expected that DLG abundance and distribution in the littoral zone of lake Waikere would vary in relation to season, possibly as a result of variables including water temperature, food availability and aggression from *Gambusia* (Rowe et al. 1999). *Gambusia* are known to prefer vegetated littoral habitats and were expected to exhibit a similar habitat distribution in Lake Waikere. As *Gambusia* reproduction is influenced by seasonal factors (Haynes and Cashner 1995), i.e. temperature and day length (Koya and Kamiya 2000), it was expected that *Gambusia* abundance would fluctuate in regard to season. Furthermore, the distribution of DLG in vegetated and un-vegetated littoral habitats could reflect competitive exclusion of DLG by *Gambusia* in the littoral zone of Lake Waikere. As common bully are known to spawn several times during the year in Northland (McDowall 1990), it was expected that common bully abundance in littoral habitats would fluctuate seasonally. Furthermore, high densities of Gambusia were expected to influence the relative abundance and distribution of common bully in the littoral zone.

2.3 Methods

2.3.1 Study site

2.3.1.1 Location

The Kai Iwi Lakes are located approximately 30 kilometres north of Dargaville on the west coast of Northland, New Zealand. The Kai Iwi Lakes are dune lakes and are thought to have been formed during the mid-Holocene period (c.10 000 years old) (Lowe and Green 1987). Three lakes make up the Kai Iwi Lakes group; Kai Iwi, Waikere and Taharoa. All three are fed by rain and subsurface springs from the surrounding catchment which comprises a mixture of exotic and native vegetation and some agriculture. Apart from a small seasonally flowing channel connecting Lakes Taharoa and Kai Iwi, there are no permanent stream inlets or outlets present. The lakes are unique in Northland for their clarity, with secchi disc readings in all three lakes varying seasonally between c.5 and c.11 metres (Rowe and Chisnall 1997b, K.Hartle Unpubl. Data. 2003). The Kai Iwi Lakes are also free of exotic macrophytes and contain rare native species, including the DLG and the aquatic plant *Hydatella inconspicua*. The natural ecology of the lakes has been altered through human activity, including the introduction of exotic fish species and the development of the surrounding landscape for agriculture, forestry and some habitation. Historically the Kai Iwi Lakes provided an important cultural and food resource for local iwi. Presently the lakes are located within the boundaries of the Taharoa Domain and are administered by a body consisting of local government, Fish and Game and local iwi. The lakes are an important recreational area for Northland and provide opportunities for water sports, e.g. waterskiing, swimming and trout fishing.

2.3.1.2 Lake characteristics

The lakes vary in maximum depth and surface area with Kai Iwi being the smallest (c.14m and c.33ha respectively), Lake Waikere is similar in surface area although considerably deeper than Kai Iwi (c.28m and c.35ha) (Figure 2.4). Taharoa is the largest of the three lakes (c.35m and c.237ha) (Rowe et al. 1999). Lake Kai Iwi is distinct from the other two lakes in that over 80% of its littoral habitat is made up of emergent macrophytes, while vegetated habitats make up only c.25% of the littoral zone of Lakes Taharoa and

Waikere. The littoral vegetation in Lake Waikere consists of *Leptocarpus similis*, *Baumea arthropylla* and *Eleocharis sphacelata* (Rowe et al. 1999). The lakes are between 70 and 80 metres above sea level and c.3km from the west coast.

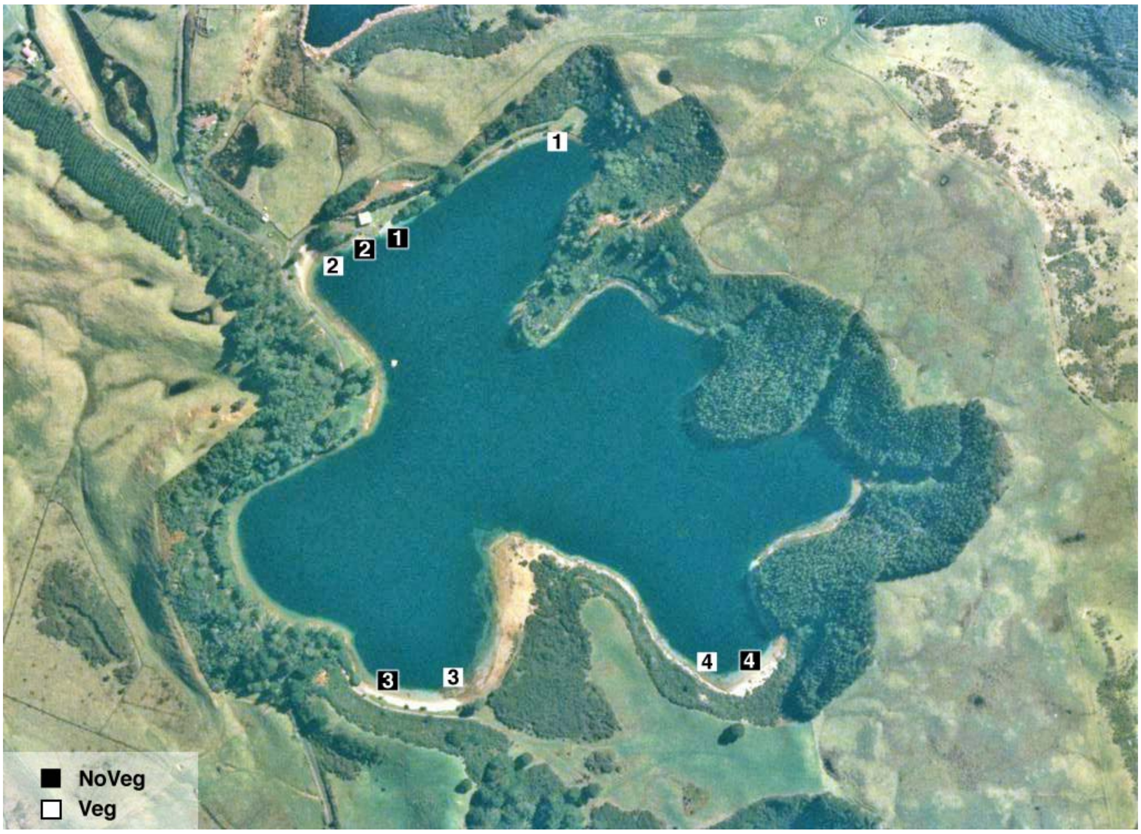

Figure 2.4. Aerial photo showing the shape of Lake Waikere. Also displayed are the approximate positions of the four vegetated (Veg) and un-vegetated (NoVeg) sampling locations listed in Table 2.1.

2.3.2 Sampling techniques

This study set out to investigate the habitat, diel and seasonal patterns of distribution and abundance of *Gambusia*, common bully, DLG and koura in Lake Waikere. Two different methods of sampling were employed. A passive trapping technique was complemented by an active visual detection technique. Trials indicated that un-baited minnow traps were effective at capturing both *Gambusia* and common bully in areas where they were present. However, minnow traps were unsuitable for sampling DLG. Visual surveys of the littoral zone were used to assess littoral habitat use by DLG (and subsequently koura).

2.3.2.1 Passive trapping catch per unit effort estimates

A passive minnow trapping technique, was selected to sample *Gambusia* and common bully in the littoral zone of Lake Waikere. Minnow traps have been used elsewhere to survey littoral fish communities (Balcombe and Closs 2004) and allow a simple, inexpensive and easily replicable method (Layman and Smith 2001). Concerns have been raised over the effectiveness and inherent bias of passive sampling techniques for investigating fish distributions under certain conditions (Rozas and Minello 1997, Layman and Smith 2001). However, passive sampling techniques, particularly minnow traps, have been widely and successfully used to study a range of freshwater fish, including *Gambusia* (Botsford et al. 1987, Bence 1988, Blaustein 1989) and common bully (Ludgate and Closs 2003). Furthermore, trials in 2003 indicated that minnow traps were effective at capturing both *Gambusia* and common bully in Lake Waikere. The traps used were collapsible minnow traps (c.400x250x250mm), made of soft mesh (5mm), with 50mm diameter apertures.

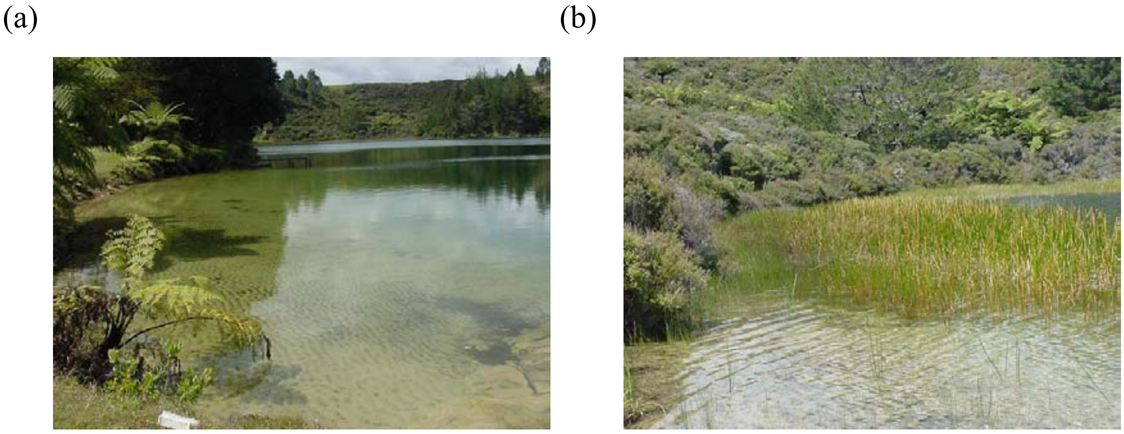

Figure 2.5. Typical (a) un-vegetated (NoVeg) and (b) vegetated (Veg) sampling locations.

To investigate seasonal changes in the relative abundance and distribution of fish between vegetated (hereon Veg) and un-vegetated (hereon NoVeg) littoral habitats, sampling was undertaken in November 2003, March, June, August, November 2004 and January 2005. To provide sufficient replication fish were sampled using minnow traps at six of the locations listed in Figure 2.4 and Table 2.1 representing both NoVeg (Figure 2.5(a)) and Veg (Figure 2.5(b)). Three sites of emergent standing aquatic vegetation (sites Veg1, 2 & 3) and three with no standing vegetation (sites NoVeg1, 2 & 3) were selected for the trapping method (see

Figure 2.4 for approximate locations of sampling sites). Traps were spaced at approximately two metre intervals to allow at least 20m of contiguous habitat to be sampled. Sampling locations therefore, had to represent a distinct portion of contiguous habitat type, that was longer than the minimum length of a trapping transect (i.e. >20m of shoreline). Several methods for the random selection of the sampling locations were considered. However, due to logistical constraints, sampling locations were chosen so that there was sufficient access, to enable efficient setting of minnow traps. To minimise the effect of weather between habitat types, sites were chosen so that a Veg and NoVeg site could be, and were, sampled almost simultaneously.

Table 2.1. Physical characteristics of sampling locations (displayed in Figure 2.4), including approximate area of littoral vegetation (m^2), maximum water depth of vegetated area (m) and stem densities (per m^2) of *Baumea arthropylla* (A), and *Eleocharis sphacelata* (B), showing that the two habitat types, un-vegetated (NoVeg) and vegetated (Veg) sampling locations, used were distinctly different. Sites used for each sampling technique are represented by a tick, while those not used for a particular sampling technique are represented by a cross. In total three Veg and three NoVeg were used for each sampling technique.

Site	Surveyed using trapping technique	Surveyed using visual technique	Veg area	Max. Veg depth	Stem density at 0.5m depth		Stem density at 1.5m depth	
					A	B	A	B
NoVeg1	✓	✓	NA	NA	0	0	0	0
NoVeg2	✓	✗	NA	NA	0	0	0	0
NoVeg3	✓	✓	NA	NA	0	0	0	0
NoVeg4	✗	✓	NA	NA	0	0	0	0
Veg1	✓	✗	367	2.49	52.3	6	25.1	14.7
Veg2	✓	✓	450	1.41	41.7	2.3	7	1.3
Veg3	✓	✓	1343	1.89	17.4	1.4	8	10.1
Veg4	✗	✓	542	1.86	2.3	1.7	3.4	7.2

To investigate the effect of water depth within habitat type, un-baited minnow traps were set at two transects positioned parallel to the shoreline at each sampling location. The first transect was placed at a depth of 1-1.5 metres (1.5m), the second transect was placed at a depth of 0-0.5 metres (0.5m) (so that both entrances to the trap were submerged). Traps laid on the 1.5m depth transect were attached to buoys which were tied to indicate a set depth of 1.5m. 10 traps were set along each of the two depth transects within each sampling location (i.e. 20 per site). Each minnow trap was set for at least 30 minutes and the length of time each trap was in the water was recorded. A Veg and a NoVeg sampling location were always set within 10 minutes of each other as a pair (e.g. NoVeg1 and Veg1). Up to 40 traps could therefore be in the water at any one time. Traps at 1.5m depth were placed first within each site and care was taken when retrieving them not to disturb traps on the 0.5m transect line, which were still active. Each of the three Veg and NoVeg sites was trapped once on each sampling occasion (same day). To minimise the effect of time of day between sites, the order in which the sites were trapped was randomly selected on each sampling occasion. Replication was further increased by sampling at each location 4 times in each month that sampling occurred. A monthly mean for each habitat and depth combination was then calculated based on the data of ten traps, in each of three sites, four times a month (120 traps).

To measure the relative abundance of fish, counts of common bully and *Gambusia* were recorded from each minnow trap. In addition to the count data, biomass of the *Gambusia* catch was measured using a set of field scales (accuracy to 0.1g). The biomass of the *Gambusia* catch was used as another measure of *Gambusia* abundance. Catch per unit effort (CPUE) and biomass per unit effort (BPUE) were later calculated for each trap to reconcile and standardise the count and biomass measurements with trapping time across traps. Common bully were temporarily contained in a bucket of lake water following capture. In order not to influence traps still set, common bully were not released until all the traps from the site in which they were captured had been processed. Captured *Gambusia* were immediately euthanised using an overdose of 2-phenoxyethanol (1mg/l) following the guidelines set by the ethics approval document. The removal of *Gambusia* from the sampled population was considered acceptable because it would have been illegal to return *Gambusia* to the lake under the Biosecurity Act 1993 and because of their potential negative impact on a threatened native fish. The removal of *Gambusia* from the study lake was considered unlikely to affect later sampling events due to the large number of observed fish, the high fecundity of female *Gambusia*, and the ability of fish to move into sampled sites from adjacent, un-sampled habitat.

To highlight the well-defined physical differences between Veg and NoVeg sampling locations characteristics including horizontal width, perpendicular depth and maximum water depth were recorded during October 2004. The stem density of each Veg sampling location was surveyed using 0.5m^2 quadrates along two transects, one at 0.5m and 1.5m depths, each quadrate was placed with eyes shut at 2m intervals. As indicated in Table 2.1, NoVeg sites contained no aquatic vegetation, while Veg sites ranged from being very dense in the case of Veg1 to a moderately dense but still distinct area of Veg habitat in Veg. To further investigate physical characteristics of littoral habitats affecting fish distribution and abundance, water temperature was measured 20cm below the water's surface at each transect during each trapping occasion.

2.3.2.2 Visual estimates of fish densities.

Despite regularly observing shoals of DLG in the littoral zone during trials of minnow trapping, very few DLG were caught in minnow traps, regardless of trap location. Therefore, to obtain reasonable and reliable quantitative information on the distribution of DLG in littoral habitats of Lake Waikere an alternative sampling approach was required. I sought to compare diurnal and nocturnal use of both Veg and NoVeg littoral habitats in Lake Waikere using visual observations. The use of visual observations to determine various aspects of fish behaviour has been widely used (e.g. Keast (1978), Bachman (1984), Hankin and Reeves (1988), Bryan *et al.* (2002) and David *et al.* (2002)). An advantage of visual observations is that while being non-invasive to the fish habitat, it can enable the abundance, distribution and behaviour of fish to be estimated without physical contact. Furthermore, DLG caught in minnow traps and nets often struggled to survive the stress related with being caught and handled (pers. obs.)), consequently trapping and netting techniques were not considered appropriate for regular monitoring of this threatened species.

Trials indicated that four important freshwater species could be regularly observed in littoral habitats. Furthermore, we wished to trial an inexpensive, reliable and easily replicable technique for use as a potential tool for future monitoring of DLG. Two methods of visual observation to investigate the distribution of fish in the littoral habitat of Lake Waikere were trialled. Visual counts from the lake's edge and snorkel counts in the water were directly compared (counts from the same transects were compared). Of these two techniques, visual counts made from the bank were deemed to be the more reliable, time efficient and versatile method to investigate changes in seasonal and diel abundance and distribution of fish in the littoral zone.

To reduce the effect of environmental variables relating to water clarity and visibility, surveys were conducted during fine and preferably still weather whenever possible. Despite creating a bias to calm weather, this was considered to increase the strength of comparisons between surveys, by reducing the chance for observed differences between sampling occasions being due to differing weather conditions. Furthermore, fish are known to abandon the littoral zone when wave action exceeds 25cm, by moving markedly off shore and downward (Matthews 1998). Consequently, both day and night surveys were carried out along six stretches of littoral habitat (three Veg and three NoVeg, Table 2.1), on up to four occasions each month for May 2004 through to January 2005. To minimise the effect of weather between habitat types, sites were chosen so that a Veg and NoVeg site could be surveyed consecutively within a short space of time. Survey data were then categorised into season for statistical analysis. As in the trapping method, six sampling locations were used during each survey. However, two of the sites used in the trapping study were unsuitable for visual surveys due to terrestrial impediments along the shoreline. Consequently, to maintain the level of replication another one Veg and one NoVeg site were chosen for use in the visual survey. The length of surveyed shoreline ranged from c.43-71m (mean of c.57m) between sites and, visually surveyed areas made up approximately 325.m of the lake shoreline. To estimate relative fish density per m^2 of littoral habitat, the distance of shoreline of each sampled stretch was measured and fish observed within two metres of the edge were counted. The start location and direction of each survey was randomly chosen on each occasion. On each sampling occasion, visual surveys were carried out during the early-mid afternoon (Day) and at least 1 hour following dark the subsequent night (Night). Day surveys were carried out using a pair of polarised sunglasses and night surveys using a Lightforce® 60 watt spotlight connected to a 12v 6.5 Ah battery. Visual counts were made by walking quietly and carefully along the selected shoreline. Only fish observed in the survey area at the time the survey were counted, fish entering the area already covered by the survey (i.e. behind the observer) were not included, however fish observed leaving the area being surveyed were included as they were observed in the area prior to moving. Survey results were counts of both juvenile and adult fish.

2.3.2.3 Summary of replication and temperature

Minnow traps were set on a total of 23 occasions, spanning 14 months, although due to poor weather and logistical constraints replication was not even for all months. Abundance estimates are therefore, based on the mean of 120 traps (10 traps at three locations of each habitat and depth, four times in a month) for all sampled months, except January 2005 when only 90 were set in each habitat and depth combination. Night and day visual surveys of each of the shoreline at each of the 6 sites were carried out on 13 occasions during the study period. Due to poor weather, no night survey was successfully conducted in May and logistical difficulties prevented surveys from taking place in July.

2.3.3 Statistical analysis

2.3.3.1 Data checking and transformations

Trap data were standardised by converting count data to an hourly catch per unit effort (CPUE) and biomass per unit effort (BPUE) trapping count data. Visual count data was standardised to a relative density per m^2. Each study design was structured with a parametric multi-factorial ANOVA analysis in mind. However, parametric statistical analyses require that the data meet certain assumptions. The first, that of normality of the data and second (more important), that of homogeneity of variances (Quinn and Keough 2002). Due to a high proportion of zero values in the data, all data sets violated these assumptions despite applying (unsuccessfully) a range of accepted transformations (including $\text{Log}_{10}X+1$, $^2\surd+0.5$, $^3\surd$, $^4\surd$). As a result conventional means of parametric statistical analysis were deemed inappropriate to investigate the data. A statistical test that makes fewer assumptions about the data was required. Although non-parametric statistical analyses equivalent to a two-way ANOVA are available, the multi-factorial design would have to be compromised.

2.3.3.2 Logistic Regression

A logistic regression was used to examine the relative importance of each variable to fish distributions. A logistic regression was chosen as it is able to test the predictive and functional power of independent categorical and continuous variables, with few assumptions

(Quinn and Keough 2002). Logistic regression must be used on binary data, the coding of which is laid out in Table 2.2. Consequently, density and CPUE data were transformed to presence or absence categories (for each trap in the case of the trapping and each stretch in the visual data). Analyses were carried out using a stepwise binary logistic regression procedure in SPSS (Version 10.0). SPSS reports the percentage of dependent variables correctly classified (as present or absent) by the set of independent variables. Pseudo R square statistics (Cox & Snell and Nagelkerke) indicate the amount of variation that can be attributed to the set of independent variables. SPSS conducts two goodness-of-fit tests for the model created by the independent variables (i.e. Omnibus test of model co-efficients and Hosmer & Lemeshow statistic). The final output includes B, Wald and Odds ratio (Exp(B)) values. The Wald value (if significant at an $\alpha=0.05$ level) indicates the importance of an independent variable to the model. B value indicates the direction and magnitude of the relationship between a particular independent and the dependent variable (compared against the reference category of that variable). The Exp(B) reflects the odds ratio (increase if $\text{Exp(B)}>1$ or decrease if $\text{Exp(B)}<1$), of the dependent being “1” (i.e. present), when the independent variable increases by one unit (Pallant 2005).

Table 2.2. Logistic regression coding variables, 0 values indicate the reference category to which all others are compared, in this case the first occurring category in the data set was used.

Variable	Levels	Coding
Fish species	Present	1
(Dependent)	Absent	0
Habitat	NoVeg	0
	Veg	1
Depth	0.5m	0
	1.5m	1
Time	Day	0
	Night	1
Month	Nov 03	0
(Trapping study)	Mar 04	1
	Jun 04	2
	Aug 04	3
	Nov 04	4
	Jan 05	5
Season	Spring	0
(Visual study)	Summer	1
	Autumn	2
	Winter	3
Temperature	Continuous	
Gambusia CPUE	Continuous	

2.4 Results

2.4.1 Dune lakes galaxias

2.4.1.1 Habitat and Diel distribution

Active visual density estimates

Over the entire length of the study just 15 DLG were recovered from the traps in the trapping study, consequently DLG trapping data was not analysed further. 1314 DLG were recorded during visual surveys, 1079 (82.1%) at night, of these 751 (69.6%) were in NoVeg habitat. Both adult and juvenile DLG were observed with greater regularity during night surveys of the littoral zone (Figure 2.6). Daytime observations were usually of fish in tight knit shoals or schools, while night time observations were of fish appearing to act as individuals with no shoaling behaviour observed. Daytime observations of DLG tended to be associated with the edges of Veg habitat. Shoals were observed infrequently and were usually made up of moderate to large numbers of fish, hence the high standard error observed in Figure 2.6(a).

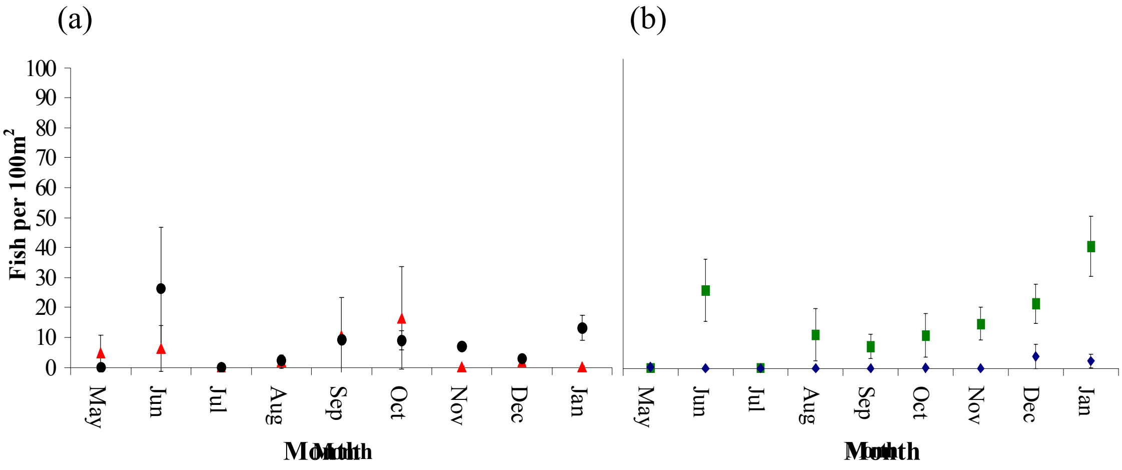

Figure 2.6. Mean relative densities per $100m^2$ of DLG, ≥c.30mm, observed in visually surveyed littoral habitat (n= three sites surveyed once for May, June, August and September; three sites surveyed twice for November, December and January; and three sites surveyed three times for October; no surveys were conducted in July). (a) Veg habitat; red triangles (▲) represent day and black circles (●) represent night densities. (b) NoVeg habitat; blue diamonds (◆) represent day and green squares (■) represent night densities. Error bars represent one standard error of the mean.

The logistic regression for the presence or absence of DLG correctly classified 88.2% of cases. According to the logistic regression output in Table 2.3, the most significant independent predictor category is time. The odds ratios (Exp(B)) produced by the analysis predicted that the chance of encountering a DLG during a night survey increased c.218 times when compared to a daytime survey, regardless of habitat. Habitat was almost a significant predictor (p=0.06). However, the suggestion that it is up to three times more likely to encounter a DLG in a Veg habitat conflicts with the density data which recorded more DLG in NoVeg habitat (particularly at night).

Table 2.3. Logistic regression of DLG visual survey. DLG presence/absence dependent variable. Independent variables were 'Time', 'Habitat' and 'Season' categorical variables. The model correctly classified 88.2% of cases (Homer & Lemeshow test, X^2=3.96, d.f.=8, p=0.861; Omnibus test of model co-efficients, X^2=11.46, d.f.=4, p=0.00) and pseudo R^2 statistics accounted for over 50% of observed variation (Cox & Snell R^2 = 54% and Nagelkerke R^2 = 73%). Significant independent variables are in **bold**.

Variable	B	S.E.	Wald	d.f.	p	Exp(B)	95% C.I. for Exp(B)	
							-	+
Time	**5.38**	**0.86**	**39.48**	**1**	**0.00**	**217.61**	**40.59**	**1166.57**
Habitat	**1.13**	**0.60**	**3.53**	**1**	**0.06**	**3.09**	**0.95**	**10.05**
Season			4.59	2	0.10			
Season(1)	-0.53	0.83	0.41	1	0.52	0.59	0.12	3.00
Season(2)	0.85	0.83	1.05	1	0.31	2.3	0.46	11.77
Constant	-2.11	0.81	6.69	1	0.01	0.12		

2.4.2.1 Seasonal abundance

Active visual density estimates

Highest night time densities were recorded during January 2005 and appeared to increase steadily from late winter/early spring (Sep 04) (Figure 2.6(b)). Highest daytime densities were observed from Veg habitats during early spring (September and October 2004), although high error rates are associated with these means (Figure 2.6(a)). The logistic regression (Table 2.3) indicated that season was not a significant predictor of encountering a DLG during surveys of the littoral zone, regardless of time of day.

2.4.2 *Gambusia*

2.4.2.1 Habitat and diel distribution

Passive trapping catch per unit effort estimates

During the trapping study 8321 *Gambusia*, weighing a total of 3.6kg, were caught. Overall 99.7% of the total *Gambusia* CPUE (8302 fish) was recorded from Veg habitats and only 19 fish (0.3% of CPUE) from NoVeg habitats. Within Veg habitats, 95.9% of total *Gambusia* CPUE (7993 fish) was caught at a 0.5m depth and 4.1% (309 fish) at a 1.5m depth. The preference of *Gambusia* for shallow, vegetated littoral habitat is clearly illustrated in figures 2.7(a)&(b). *Gambusia* CPUE and BPUE were appreciable at 1.5m depth in vegetated habitat only when high values were recorded at 0.5m depth. The preference for Veg habitat is particularly evident in figures 2.7(a)-(d), as graphically the CPUE and BPUE of *Gambusia* in NoVeg habitats appears to be effectively nil.

Mean temperature recorded at time of trapping was highest in January 2005 and lowest in August 2004. Temperature in shallow Veg transects was usually greater than elsewhere and the difference between 1.5m and 0.5m depth tended to be greatest in Veg zones. During spring and summer the mean water temperature of shallow Veg habitat was between 1 and 1.7°C warmer than shallow NoVeg habitat. However, during winter the mean difference was less than 0.4°C.

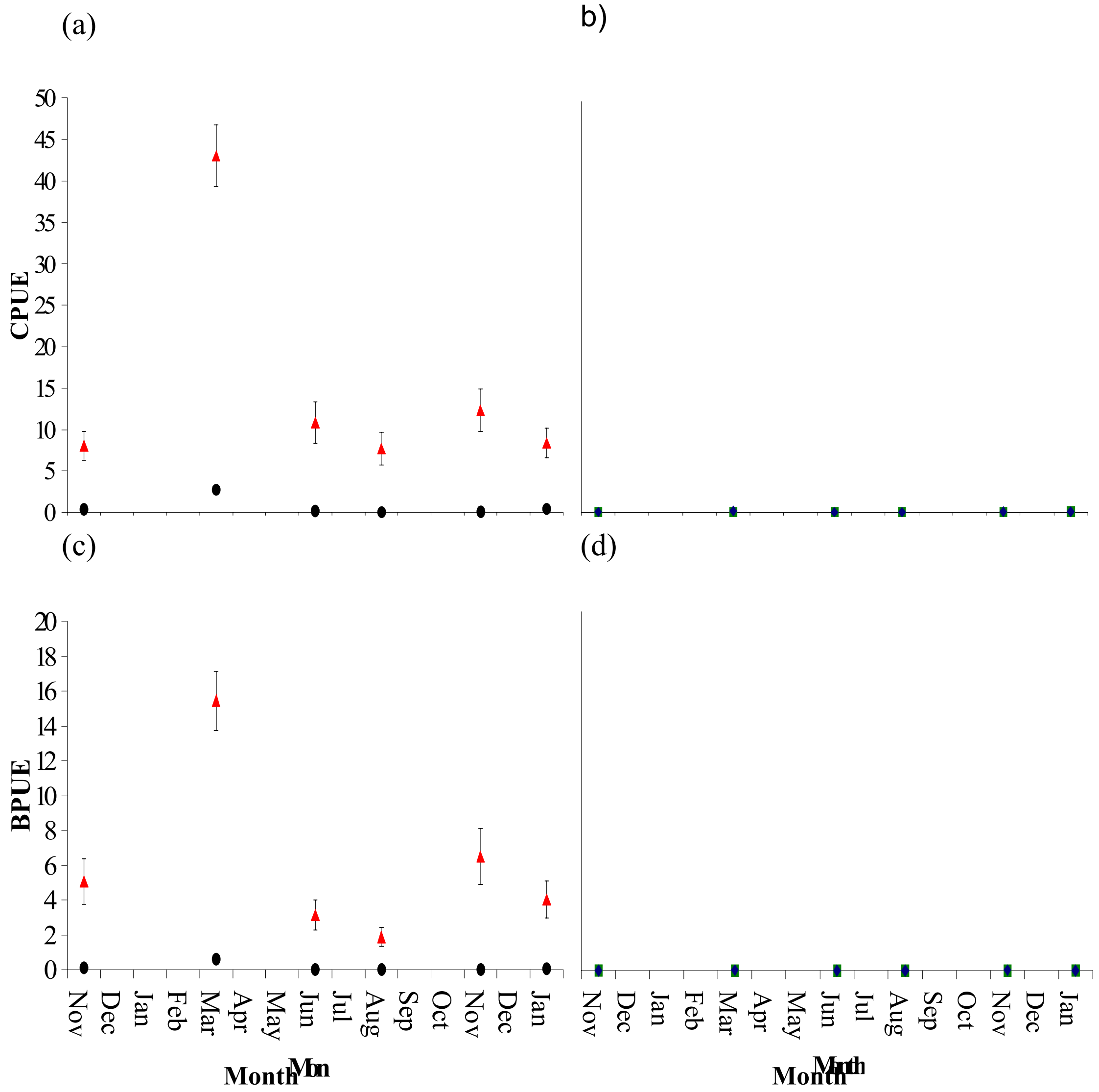

Figure 2.7. Mean *Gambusia* catch per unit effort (CPUE), fish per hour per trap, and biomass per unit effort (BPUE), fish biomass per hour per trap, relative abundances from trapping study (n=120 traps, except for January 2005 where n=90 traps). (a) Veg habitat; red triangles (▲) represent CPUE at 0.5m depth and black circles (●) represent CPUE. at a 1.5m depth. (b) NoVeg habitat; blue diamonds (◆) represent CPUE at 0.5m depth and green squares (■) represent CPUE at a 1.5m depth. (c) Veg habitat; red triangles (▲) represent 0.5m BPUE and black circles (●) represent BPUE at a 1.5m depth. (d) NoVeg habitat; blue diamonds (◆) represent BPUE at 0.5m depth and green squares (■) represent BPUE at a 1.5m depth. Error bars represent one standard error of the mean.

Habitat and depth represent significant predictors of the presence or absence of *Gambusia* ($p<0.05$). (Table 2.4) Positive B values provided in Table 2.4 indicate the direction of the relationship between independent and dependent variables (positive value indicates that an increase in the independent variable will result in an increased probability of the dependent equalling 1, negative values indicate a decreased probability of it equalling 1). From the odds ratios produced by the analysis it is possible to conclude (despite the large confidence intervals) that there is c.120 times greater chance of encountering a *Gambusia* in a Veg habitat and c.10 times less chance of it being at a 1.5m depth than a 0.5m depth. Furthermore, goodness of fit tests (Table 2.4) show that the categorical variables in the trapping study had a strong predictive ability for the presence of *Gambusia* and the set of variables was able to correctly classify 86.5% of cases. Pseudo R square values indicate that between 33.6% and 54.9% of the variability can be attributed to the set of independent variables.

Table 2.4. Logistic regression of *Gambusia* trapping data. *Gambusia* presence/absence dependent variable. Independent variables were 'Depth', 'Habitat', 'Month', 'Temperature' and 'Depth*Habitat interaction' categorical variables. Temperature and Depth*Habitat were removed by the stepwise procedure. The model correctly classified 86.5% of cases (Homer & Lemeshow test, X^2=6.847, d.f.=8, p=0.553; Omnibus test of model co-efficients, X^2=114.63, d.f.=7, p=0.00) and pseudo R^2 statistics accounted for 34 and 55% of observed variation (Cox & Snell R^2 = 34% and Nagelkerke R^2 = 55%). Significant independent variables are in **bold**.

Variable	B	S.E.	Wald	d.f.	p	Exp(B)	95% C.I. for Exp(B)	
							-	+
Habitat	**4.79**	**0.30**	**247.83**	**1**	**0.00**	**120.00**	**66.12**	**217.79**
Depth	**-2.304**	**0.151**	**233.51**	**1**	**0.00**	**0.10**	**0.07**	**0.13**
Month			**158.19**	**5**	**0.00**			
Month(1)	1.66	0.22	58.283	1	0.00	5.26	3.43	8.05
Month(2)	-0.75	0.23	10.50	1	0.00	0.48	0.30	0.75
Month(3)	-0.99	0.23	18.55	1	0.00	0.37	0.24	0.58
Month(4)	-0.33	0.22	2.29	1	0.13	0.72	0.47	1.10
Month(5)	0.11	0.23	0.24	1	0.62	1.12	0.71	1.76
Constant	-6.74	0.36	342.01	1	0.00	0.00		

Active visual density estimates

As in the trapping data, *Gambusia* were observed almost entirely in Veg habitats during daytime surveys (Figure 2.8). *Gambusia* were usually observed as loose knit shoals of 5-200+ fish during the day and as single relatively inactive and unresponsive fish at night.

Although a preference for Veg habitat still existed at night, single fish were regularly observed at low densities in NoVeg habitats at night, although this is hard to detect in Figure 2.8(b). The observation of *Gambusia* regularly at night in NoVeg sites is interesting, particularly as they are almost never observed in the shallows of NoVeg sites during the day.

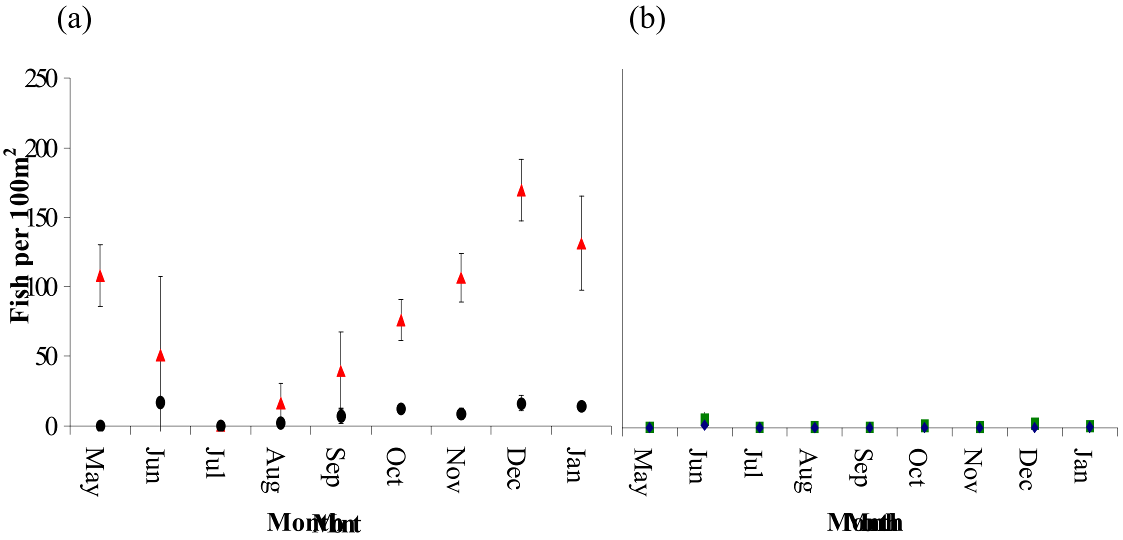

Figure 2.8. Mean relative densities per $100m^2$ of *Gambusia*, ≥c.25mm, observed in visually surveyed littoral habitat (n= three sites surveyed once for May, June, August and September; three sites surveyed twice for November, December and January; and three sites surveyed three times for October; no surveys were conducted in July). (a) Veg habitat; red triangles (▲) represent day and black circles (●) represent night densities. (b) NoVeg habitat; blue diamonds (◆) represent day and green squares (■) represent night densities. Error bars represent one standard error of the mean.

Habitat was a significant predictor of *Gambusia* presence, with a strong preference for Veg habitat again demonstrated for *Gambusia* ($p<0.05$) (Table 2.5). *Gambusia* were c.184 times more likely to be encountered in a Veg than a NoVeg habitat. Interestingly, the time variable was significant, so that the chance of encountering a *Gambusia* regardless of habitat increased at night, despite being observed at lower densities (Figure 2.5). Furthermore, goodness of fit tests show that the categorical variables in the trapping study had a strong predictive ability for the presence of *Gambusia* and the set of variables was able to correctly classify 87.5% of cases. Pseudo R square values indicate that between 51% and 70% of the variability can be attributed to the set of independent variables.

Table 2.5. Logistic regression of *Gambusia* visual survey. *Gambusia* presence/absence dependent variable. Independent variables were 'Time', 'Habitat' and 'Season' categorical variables. The model correctly classified 87.5% of cases (Homer & Lemeshow test, X^2=9.59, d.f.=8, p=0.295; Omnibus test of model coefficients, X^2=101.86, d.f.=4, p=0.00) and pseudo R^2 statistics accounted for over 50% of observed variation (Cox & Snell R^2 = 51% and Nagelkerke R^2 = 70%). Significant independent variables are in **bold**.

Variable	B	S.E.	Wald	d.f.	p	Exp(B)	95% C.I. for Exp(B)	
							-	+
Time	**2.88**	**0.71**	**16.61**	**1**	**0.00**	**17.74**	**4.45**	**70.72**
Habitat	**5.22**	**0.87**	**35.98**	**1**	**0.00**	**184.49**	**33.54**	**1014.90**
Season			4.34	2	0.11			
Season(1)	-1.34	0.81	2.73	1	0.10	0.26	0.05	1.29
Season(2)	-0.24	0.85	0.08	1	0.78	0.79	0.15	4.15
Constant	-1.86	0.83	5.00	1	0.025	0.16		

2.4.2.2 Seasonal abundance

Passive trapping catch per unit effort estimates

Gambusia reached highest recorded CPUE of 43 fish per hour (Figure 2.7(a)) and a BPUE of 15.5g per hour (Figure 2.7(b)) during the late summer (March 2004) in Veg habitat at 0.5m depth. Lowest CPUE (7.7 fish per hour) and BPUE (1.9g) in Veg habitat were recorded during August 2004 (winter). Little difference appears to exist for CPUE and BPUE in regards to months other than March 2004. Regardless of season and depth CPUE, of *Gambusia* in NoVeg habitats never exceeded 0.05 fish per hour.

The logistic regression of trapping data indicated that month was a significant predictor of *Gambusia* presence ($p<0.05$). All months expect for November 2004 and January 2005 predicted a significant difference from November 2003, the reference month (Table 2.4). Furthermore, when compared to November 2003 odds ratios suggest that the chance of encountering a *Gambusia* in March 2004 increased while it decreased in June and August 2004. An insignificant Wald statistic was obtained for November 2004 and January 2005 suggesting that the chance of *Gambusia* being present was not significantly different to November 2003. The results of both visual density and CPUE estimates appear to indicate that *Gambusia* prefer shallow vegetated littoral habitat, and reach highest abundance during late summer.

Active visual density estimates

Seasonally, daytime visual densities in Veg habitats ranged from a low of 16 fish per 100m2 during winter (August) to a high of 170 fish per 100m2 in summer (December). A pulse of juvenile *Gambusia* was observed for the first time in December 2004. The number of larger (trappable) fish would be expected to increase during summer as water temperatures and hours of sunlight increase and juveniles mature. Although the highest observed density was recorded during December 2004 (Figure 2.8(a)), no late summer and autumn observations were made. Daytime density and CPUE estimates for *Gambusia* were the highest observed of any fish species during the study period. The logistic regression of the visual data indicates that season was an insignificant predictor of the chance of encountering a *Gambusia* in a visual count. This is possible as *Gambusia* were observed throughout the visual study, despite changing in density, and the logistical regression used only presence/absence data (Table 2.5).

2.4.3 Common bully

2.4.3.1 Habitat and diel distribution

Passive trapping catch per unit effort estimates

During the trapping study 3422 common bully were caught. Overall 62.9% of common bully CPUE (2367 fish) were caught in Veg habitat. Unlike *Gambusia*, the CPUE of common bully distribution was not restricted to a particular habitat or depth (Figure 2.9(a)&(b)) However, greater bully CPUE was typically obtained from Veg habitats throughout the study. The logistic regression of trapping data indicated that habitat and depth were significant predictors of common bully presence or absence ($p<0.05$). Odds ratios indicate that a common bully is c.2.5 times more likely to be observed in a Veg habitat than in a NoVeg habitat and is c.1.3 times more likely to be observed at a 1.5m depth (Table 2.6).

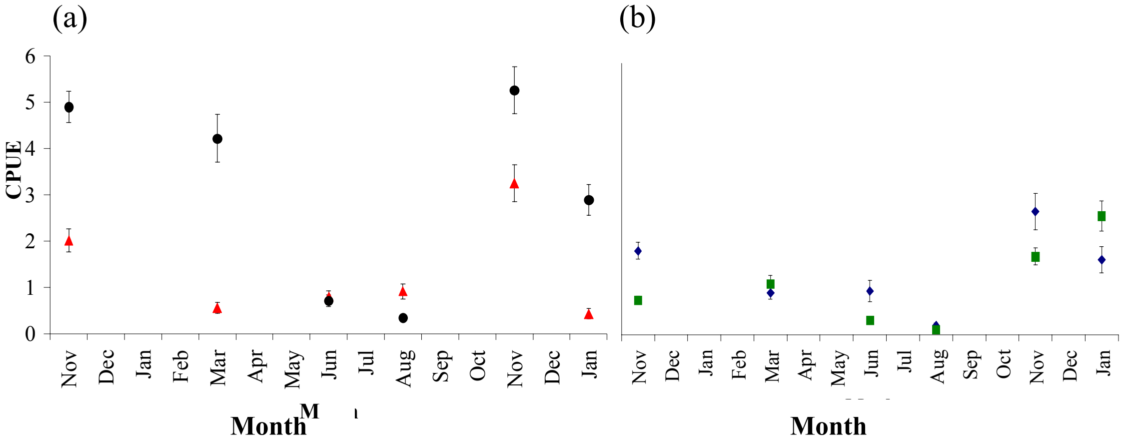

Figure 2.9. Mean common bully CPUE relative abundances from trapping study (n=120 traps, except for January 2005 where n=90 traps). (a) Veg habitat; red triangles (▲) represent CPUE at 0.5m depth and black circles (●) represent CPUE at 1.5 m depth. (b) NoVeg habitat; blue diamonds (◆) represent CPUE at 0.5m depth and green squares (■) represent CPUE at 1.5 m depth.

Table 2.6. Logistic regression of common bully trapping data. Common bully presence/absence dependent variable. Independent variables were 'Depth', 'Habitat', 'Month' and 'Depth*Habitat interaction' categorical variables. Depth*Habitat was removed by the stepwise procedure. The model correctly classified 69.4% of cases (Homer & Lemeshow test, X^2=11.82, d.f.=8, p=0.16; Omnibus test of model co-efficients, X^2=617.76, d.f.=9, p=0.00) and pseudo R^2 statistics accounted for 18 and 23% of observed variation (Cox & Snell R^2 = 18% and Nagelkerke R^2 = 23%). Significant independent variables are in **bold**.

Variable	B	S.E.	Wald	d.f.	p	Exp(B)	95% C.I. for Exp(B)	
							-	+
Habitat	**0.93**	**0.10**	**94.66**	**1**	**0.00**	**2.54**	**2.1**	**3.06**
Depth	**0.238**	**0.91**	**6.89**	**1**	**0.01**	**1.27**	**1.06**	**1.52**
Month			**216.91**	**5**	**0.00**			
Month(1)	-0.82	0.15	31.75	1	0.00	0.44	0.33	0.59
Month(2)	-2.43	0.26	90.95	1	0.00	0.09	0.05	0.15
Month(3)	-3.21	0.30	118.14	1	0.00	0.04	0.02	0.07
Month(4)	-0.12	0.14	0.72	1	0.40	0.89	0.67	1.17
Month(5)	-0.61	0.18	10.89	1	0.01	0.55	0.38	0.78
Constant	0.74	0.12	40.73	1	0.00	2.10		

Active visual density estimates

In general (apart from a few early surveys with low replication), few common bully were observed during day surveys (Figure 10(a)&(b)). The observed density of common bully in the littoral zone appeared to increase significantly at night in both habitats, especially in un-vegetated areas of the littoral zone. Large standard error bars show that estimates of common bully density in the littoral zone could be variable between sampling occasions, within each month.

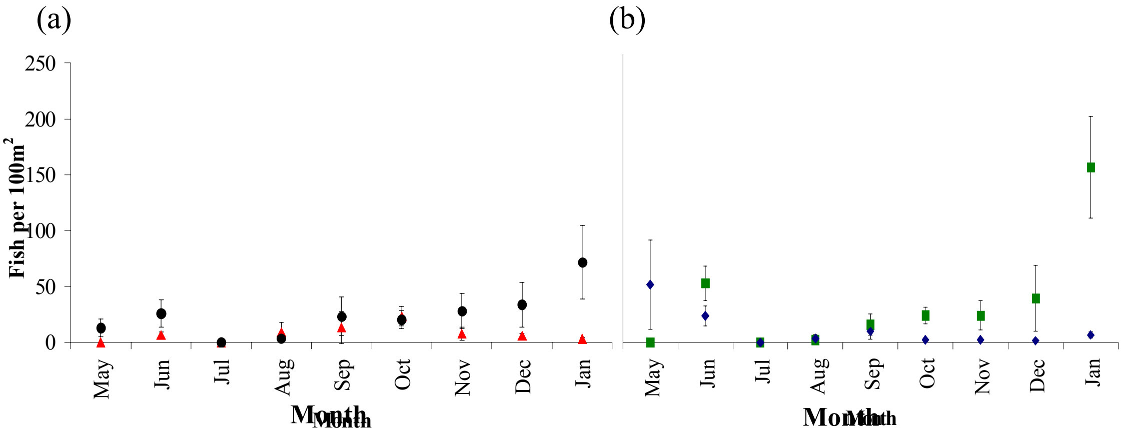

Figure 2.10. Mean relative densities per 100m^2 of common bully, ≥c.25mm, observed in visually surveyed littoral habitat (n= three sites surveyed once for May, June, August and September; three sites surveyed twice for November, December and January; and three sites surveyed three times for October; no surveys were conducted in July). (a) Veg habitat; red triangles (▲) represent day and black circles (●) represent night densities. (b) NoVeg habitat; blue diamonds (◆) represent day and green squares (■) represent night densities. Error bars represent one standard error of the mean.

The logistic regression of visual observations demonstrated that the only independent variable that had a significant ($p<0.05$) predictive ability of common bully presence/absence was time (Table 2.7). Odds ratios indicate that the chance of encountering a common bully was c.23.1 times more likely during a night survey than a day survey (regardless of habitat). Habitat was almost a significant predictor ($p=0.06$), indicating that common bully are probably more likely to be observed in Veg habitats.

Table 2.7. Logistic regression of common bully visual survey. common bully presence/absence dependent variable. Independent variables were 'Time, 'Habitat' and 'Season' categorical variables. The model correctly classified 86.5% of cases (Homer & Lemeshow test, X^2=1.46, d.f.=8, p=0.99; Omnibus test of model co-efficients, X^2=28.75, d.f.=4, p=0.00) and pseudo R^2 statistics accounted for 18 and 35% of observed variation (Cox & Snell R^2 = 18% and Nagelkerke R^2 = 35%). Significant independent variables are in **bold**.

Variable	B	S.E.	Wald	d.f.	p	Exp(B)	95% C.I. for Exp(B)	
							-	+
Time	**3.14**	**1.06**	**8.83**	**1**	**0.00**	**23.14**	**2.92**	**183.71**
Habitat	1.16	0.61	3.66	1	0.06	3.18	0.97	10.41
Season			0.09	2	0.96			
Season(1)	-8.39	30.33	0.08	1	0.78	0.00	0.00	1.49×10^{22}
Season(2)	-8.46	30.33	0.08	1	0.78	0.00	0.00	1.39×10^{22}
Constant	8.93	30.33	0.09	1	0.77	7565.25		

2.4.3.2 Seasonal abundance

Passive trapping catch per unit effort estimates

Lowest CPUE estimates of common bully abundance were recorded from all habitats during winter (June and August 2004) (Figure 2.9(a)&(b)). All habitats recorded an increase in CPUE during spring (November 2004). common bully CPUE was highest during November 2003 and 2004 (spring) and the highest CPUE in spring was recorded from the 1.5m traps in Veg habitats. Notably, in Veg habitats a marked decrease was observed between spring and summer (both years) at 0.5m depth (Figure 2.9(a)). Conversely, the observed density and CPUE of *Gambusia* increased over the same time frame in shallow Veg habitats (figures 2.7(a)&2.8(a)). Month was a significant predictor of bully presence/absence in minnow traps (p<0.05). Odds ratios obtained in Table 2.6 indicate that when compared to November 2003, the chance of capturing a common bully is significantly lower in all months except November 2004. November 2003 and 2004 estimates were not significantly different from each other. Both logistic regression and graphical data analysis suggest that highest common bully abundance is observed during spring.

The observed density of common bully appeared to change little over the course of the study period. However, common bully density at night observed between spring and early summer surveys appeared to be steadily increasing in both Veg and NoVeg habitats (Figure 2.10). Season was not a significant predictor of observing a common bully during visual surveys of the near littoral zone (Table 2.7). Although not used in density estimates, a pulse of larval bullies was observed in spring (Nov & Dec 04).

2.4.4 Koura

Koura were also recorded regularly from the littoral zone of Lake Waikere during visual surveys. Koura were only observed at night and as a result the axis of Figure 2.11 are different to previous figures. Greater densities of koura were observed in Veg habitat. The density of koura varied over the study period, with lowest densities in littoral zone being recorded during winter (August-October 2004). Few koura were observed in NoVeg zones. The high standard error observed in June 2004 was probably due to the small sample size of surveys in this month.

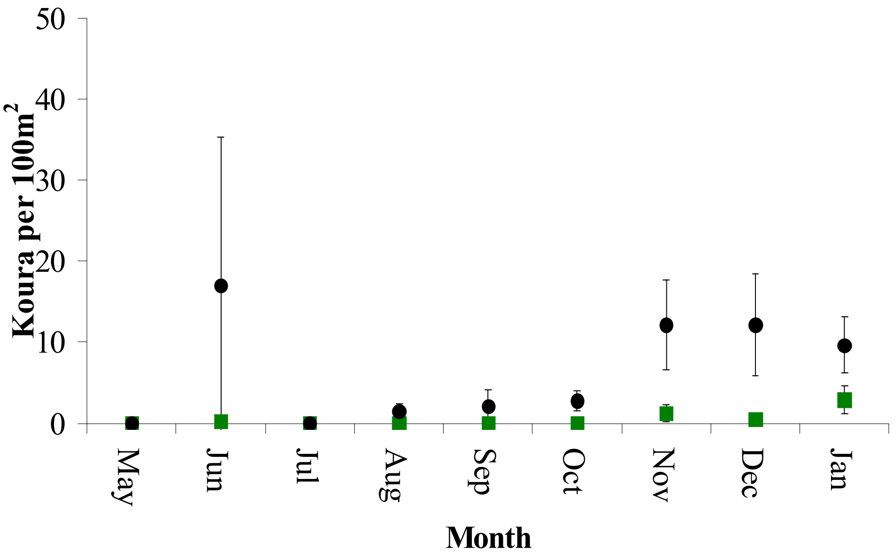

Figure 2.11. Mean relative densities per 100m^2 of koura, observed in visually surveyed littoral habitat (n= three sites surveyed once for May, June, August and September; three sites surveyed twice for November, December and January; and three sites surveyed three times for October; no surveys were conducted in July). Black circles (●) represent night densities in Veg habitat, green squares (■) represent night densities in NoVeg habitat. Error bars represent one standard error of the mean.

2.5 Discussion

2.5.1 Dune lakes galaxias

2.5.1.1 Habitat distribution

The estimated density of DLG in the littoral zone appeared to be most consistently reliable at night and in stretches of un-vegetated habitat. DLG were rarely observed in Veg habitats when *Gambusia* catch per unit effort and density were high during the day. Rowe *et al.* (1999) also observed that DLG and *Gambusia* were not simultaneously present in vegetated habitats. Un-vegetated habitats appear to be an important habitat for the nocturnal behaviour of DLG. Furthermore, while DLG were usually observed as shoals during the day (Figure 2.12), DLG were present as individuals at night with no indication of shoaling behaviour being observed at night. The littoral habitat is known to be important to adult DLG for both food and reproduction (Rowe 1998). DLG and dwarf inanga are known to occupy deeper water during the day and migrate to the littoral zone at night (Rowe and Chisnall 1996, Rowe 1998).

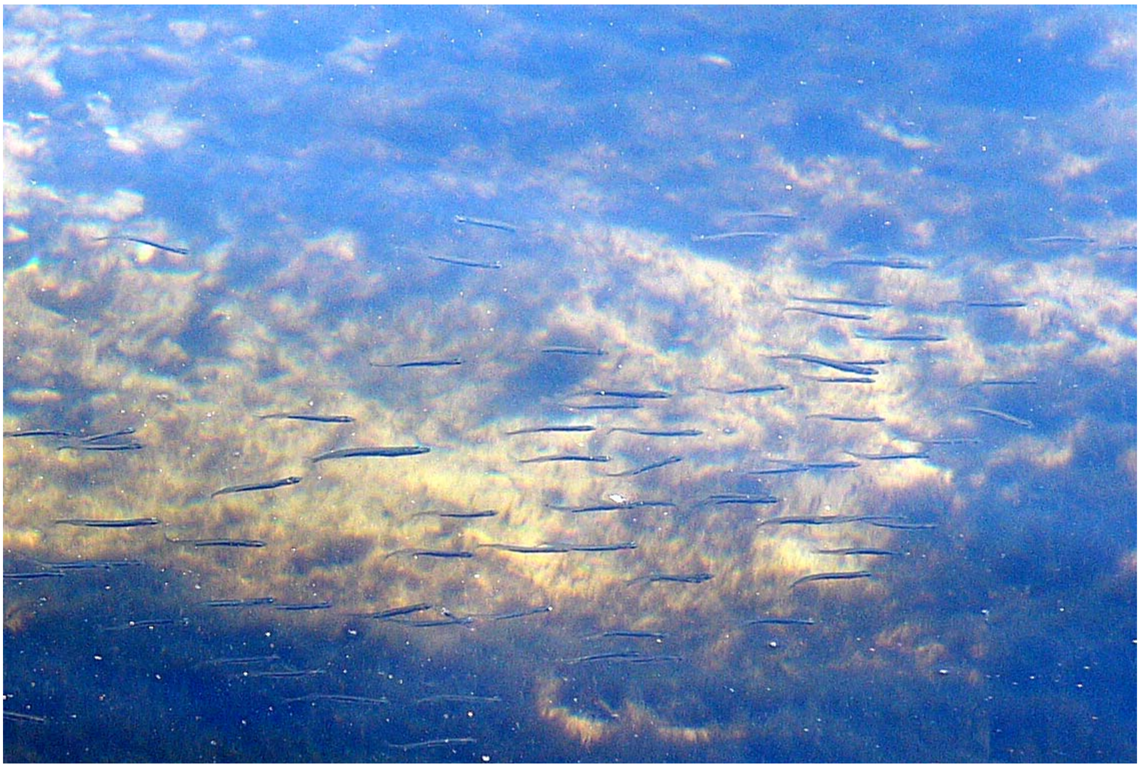

Figure 2.12. A shoal of DLG observed in the littoral zone of Lake Waikere during the day.

2.5.1.2 Seasonal abundance

DLG densities in un-vegetated littoral habitat indicated that lowest densities of DLG using the littoral zone at night occur during late winter. A steady increase up to the end of the study period in January 2005 was then observed. Similarly Rowe *et al.* (1999) recorded an increase in the CPUE of adult DLG from winter to summer in Lake Waikere. DLG were almost never caught in minnow traps, while the visual method trialled for quantifying DLG use of the littoral zone appears to have potential, particularly at night. Visual counts of DLG in un-vegetated habitat at night appear to provide a useful, simple, accurate and inexpensive method for regular and frequent monitoring of the DLG population in Lake Waikere. Monitoring using the visual counts would need to be restricted to windless nights; however, it may be possible to expand the scope of the method to differentiate between adult and juvenile size classes. Furthermore, some test of observer effect would be required before multiple staff members could be involved in collecting monitoring data for visual density estimates.

2.5.2 *Gambusia*

2.5.2.1 Habitat Distribution

Both trapping and visual methods, regardless of season, show that the distribution of *Gambusia* in Lake Waikere is almost entirely restricted to shallow vegetated areas of the littoral zone. The observed distribution of *Gambusia* in Lake Waikere was also supported by the logistic regression and confirmed the findings of Rowe *et al.* (1999). *Gambusia* are known to exhibit an active preference for littoral vegetation, particularly that which provides lateral concealment, calm water and darker substrates (Casterlin and Reynolds 1977). Shelter from avian predators is also an important asset of littoral vegetation for fish (Matthews 1998) and avian predation is known to influence *Gambusia* population structure (Britton and Moser 1982). Fish abundance in minnow traps only represents of fish greater than the mesh size of 5mm, therefore accurate investigation regarding gender and length distributions of species is not possible (Blaustein 1989, Rozas and Minello 1997)

2.5.2.2 Seasonal Abundance

The relative abundance of *Gambusia* in Lake Waikere during the study period was highest in late summer (March 2004) in shallow (0.5m) vegetated habitat and lowest during winter (August 2004). Visual densities from May 2004 to January 2005 indicate that a similar trend would occur beyond the study period. This result concurs with previously observed high densities during late summer in Lake Waikere (Rowe et al. 1999). *Gambusia* abundance is known to fluctuate according to season within its natural range (Barney and Anson 1921). A pulse of juvenile fish was observed during spring and a rapid increase in population size is known to occur as soon as conditions are suitable for reproduction. *Gambusia* reproduction is closely tied to water temperature and females are capable of storing sperm over winter (Krumholz 1948). Ovarian development and pregnancy are initiated by a rise in water temperature above 14 and then 18 degrees in spring respectively (Koya and Kamiya 2000). Lower temperatures and shorter day length initiate a cessation of reproduction in late summer (Koya and Kamiya 2000), although in warmer regions such as Hawaii *Gambusia* are known to reproduce year round (Haynes and Cashner 1995). Cold and age-induced mortality (*Gambusia* being a short lived species) result in a decline in population size during winter as smaller and less fit individuals senesce (Haynes and Cashner 1995). Using Lake Taharoa as a control site, previous studies have attributed the very high densities of *Gambusia* in Lake Waikere during late summer to the absence (removal) of predatory fish (Rowe et al. 1999). Results presented here suggest that high densities of *Gambusia* during summer occur in the presence of trout and eels in Lake Waikere and that the variation in relative *Gambusia* abundance between lakes Taharoa and Waikere may be influenced by a suite of factors (i.e. not only predatory fish).

2.5.3 Common bully

2.5.3.1 Habitat Distribution

Common bully occupied both vegetated and un-vegetated littoral habitats in Lake Waikere. The trapping method appears to indicate a preference for the deeper water (1.5m) of vegetated habitats during the day by common bully. Common bully were more likely to be observed in the near littoral zone at night rather than day, although they were regularly trapped in both vegetated and un-vegetated habitats. The tendency for common bully to occupy vegetated habitats, deeper water (during the day) and be more frequently observed in the littoral zone at night may be a result of trade-offs between predation, foraging potential, competition with *Gambusia* and environmental conditions. Alternatively, it could be a result of potential sampling bias associated with passive sampling methods (Rozas and Minello 1997, Layman and Smith 2001). Common bully are known to occupy the littoral zone of oligotrophic New Zealand lakes from depths of 0.5-25m (Rowe et al. 2001) and common bully have been shown to increase in abundance with increasing distance from shore in some South Island lakes (Rowe et al. 2003). The relative abundance of common bully in Lake Waikere also reflects this as 1.5m depth transects were markedly further from the shoreline than 0.5m transects regardless of season. Common bully are considered to be a particularly adaptable species, capable of occupying a variety of habitats and withstanding habitat deterioration and predation from both piscivores and birds (McDowall 1990, Rowe 1999). However, populations may be reduced in those lakes containing self-sustaining eel populations (Rowe 1999), although the eel population in Lake Waikere is not currently considered to be self sustaining (Rowe et al. 1999).

2.5.3.2 Seasonal Abundance

Seasonal variation of catch per unit effort and visual density estimates existed for common bully in the littoral zone of Lake Waikere. Catch per unit effort and visual densities were highest during spring, before decreasing during winter in both habitat types. The highest chance of encountering a common bully in minnow traps was during spring of both years (November 2004 and 2005) and common bully are usually considered common place in the littoral zones of Northland lakes during summer (Rowe 1999). This pattern was not observed in the visual data which recorded a steady increase in nocturnal bully density in the littoral zone. Seasonal variation may be explained by the life history of common bully. Common bully are known to spawn several times a year in North Island lakes, including July and August (McDowall 1990), which may explain the observed pulse in larval bullies in littoral habitats during spring. Interestingly, a marked decrease in common bully catch per unit effort from shallow vegetated habitat was associated with increasing *Gambusia* catch per unit effort. Increasing water temperature was also was also predicted to decrease the chance of common bully occurring in the logistic regression analysis and may also play a role in their distribution.

2.5.4 Koura

Koura were never caught or observed during daytime trapping or visual surveys and appear to show a preference for vegetated habitats. Observed densities in the littoral zone were lowest during winter before increasing through spring and early summer. Given that in North Island streams koura recruitment and highest densities occur over summer (Parkyn et al. 2002) and given the findings of Rowe *et al.* (1999) that koura abundance was greater in autumn than spring, it is expected that the abundance of koura in the littoral zone at night will continue to increase through summer and autumn.

2.5.5 Implications for Conservation

The relative abundance and distribution of fish species in the littoral zone of Lake Waikere appears to respond to differences in habitat, and changes in season and time of day. Littoral vegetation in Lake Waikere is important for all three species of small fish in Lake Waikere as refuge from predators, including trout, shag and kingfisher, which were regularly observed operating in the littoral zone during the day (pers. obs. 2004). Consequently, the increased abundance of DLG and common bully observed in the littoral zone at night could be a response to the lower risk of predation from visual predators that are effective during the day (Jacobsen and Berg 1998). Of the four species frequently observed in the littoral zone one, *Gambusia* appear to be strictly littoral in their distribution and show a significant preference for vegetated patches of the littoral zone. The high relative abundance and density of *Gambusia* in shallow areas of vegetated littoral habitat during summer may directly reduce the density of native fish in this habitat (as may have occurred in common bully). This may be a result of direct inter-specific competition and aggression by *Gambusia* with native fish for resources in shallow vegetated littoral habitat (e.g. food, space and predator refuge). An important finding of this study is that *Gambusia* numbers increased in vegetated littoral habitat in summer irrespective of the presence of rainbow trout in the lake. *Gambusia* are known to have a voracious nature and are known to predate on fish and anuran eggs and larvae elsewhere (Rupp 1996, McCullough 1998, Komak and Crossland 2000)). DLG are believed to spawn in littoral habitats (Rowe 1998) and landlocked inanga are known to use littoral vegetation (Pollard 1971). Therefore, if spawning coincided with periods of high *Gambusia* abundance in vegetated littoral habitat then a severe impact on DLG recruitment and fecundity could be expected.

DLG were often observed shoaling in or around the edges of littoral vegetation during the day, and such habitat is likely to be valuable as predator refuge. High densities of *Gambusia* may therefore reduce the value of refuge for DLG, i.e. a DLG may escape a predator only to be set upon by *Gambusia*, and attacks by *Gambusia* on DLG are known to occur (Rowe 1998, Rowe et al. 1999), thereby, making DLG more vulnerable to piscivore and avian predation; DLG regularly occur in trout diet (see chapter three). Exclusion from habitats that provide food resources and refuge (e.g. littoral macrophytes (Persson and Crowder 1998)) via competitive exclusion (Jackson et al. 2001) may negatively affect predation risk and foraging trade-offs for fish (Werner et al. 1983, Lima and Dill 1990, Shoup et al. 2003). Consequently, the decline of DLG in the Kai Iwi Lakes may be the result of an interaction between or a cumulative effect of both trout and *Gambusia*. The uniformity of the littoral zone of Lake Kai Iwi (i.e. over 80% vegetated) may have increased the severity of the negative effects of *Gambusia* on DLG, potentially preventing DLG from withstanding trout predation and leading to its subsequent extinction from the lake. The persistence of DLG in Lakes Taharoa and Waikere therefore, could be due to the patchy occurrence of littoral vegetation (i.e. not a completely vegetated or un-vegetated shoreline).

This study demonstrated that minnow trapping is a suitable method for monitoring both *Gambusia* and common bully in Lake Waikere, but is unsuitable for DLG. A visual count of fish in stretches of littoral habitat, particularly at night, is a useful method to estimate fish density, particularly DLG, in Lake Waikere. The visual method requires less time and lower logistical requirements than even minnow trapping. The method appears to be capable of detecting changes in DLG abundance between seasons in the near littoral zone of Lake Waikere. By collecting more detailed information (i.e. size class), the method may prove useful for monitoring DLG recruitment between years as both adult and juvenile fish were observed in areas of un-vegetated littoral habitat. Visual counts were also an effective method for monitoring common bully in the near littoral zone of Lake Waikere. This research highlights the potential impacts of exotic species on a unique species of threatened freshwater fish. Future research could well be most beneficial by focussing on controlling or excluding *Gambusia* from selected vegetated areas of littoral habitat, to which it is almost completely restricted in its distribution. This would complement previous research that removed trout from the lake, and given the early success of the introduction of dwarf inanga to Lake Ototoa (Thompson 1989), DLG might be expected to survive the presence of trout and absence of *Gambusia*. Detailed habitat mapping of the littoral zone of the Kai Iwi Lakes would also aid in identifying important areas where G*ambusia* may severely impact on DLG and areas for conservation attention and management.

Chapter 3.0: *Gambusia* (*Gambusia affinis*), dune lake galaxias (*Galaxias* sp.) and rainbow trout (*Oncorhynchus mykiss*) diet in Lake Waikere, Kai Iwi Lakes, Northland, New Zealand.

A Lake Waikere rainbow.

3.1 Abstract

Inter-specific interactions (competition and predation) influence the population structure and resource use within freshwater fish communities. Competition for food resources between native and introduced species of fish can occur, and may result in changes in the abundance of or resource use by native fish species. Diet analysis was carried out to further contribute to the understanding of the interactions within the fish community of Lake Waikere, with particular regard to examining competition and predation pressure on dune lakes galaxias by the exotic species present. *Gambusia* and DLG diet overlap was investigated in regard to competition with dune lakes galaxias. The diet of rainbow trout was investigated in regard to predation on dune lakes galaxias. The diet of *Gambusia* were also compared between season and fish size class. Dietary overlap between *Gambusia* and dune lakes galaxias and trout predation on dune lakes galaxias were also investigated. *Gambusia* diet varied between summer and winter and this is likely to be a result of changing availability of food items and possibly population structure in regard to fish size. Dietary overlap was evident for dune lakes galaxias and *Gambusia,* the diet of both species being dominated by cladocera and aquatic arachnids and terrestrial invertebrates, suggesting that competition for food resources between *Gambusia* and DLG could exist. Dune lakes galaxias made up a substantial part of the diet of sampled rainbow trout in the Kai Iwi Lakes, as did common bully. These results may have been even higher due to amount of unidentifiable fish remains. Both predation by rainbow trout and competition with *Gambusia* for food resources are likely to have a significant effect on the dune lakes galaxias population in Lake Waikere. Furthermore, a combination of predation and competition by more than one introduced species could increase the negative impact of each individual exotic species on DLG.

3.2 Introduction

Predation by exotic species and competition for food resources between native and exotic fish has been demonstrated to result in changes in the abundance and resource use of native species (Douglas et al. 1994). The examination of diet is one method used to examine inter-specific interactions within freshwater fish communities, particularly with regard to competition (Glova and Sagar 1991, Hodgson et al. 1997, Schindler et al. 1997) and predation (Hodgson et al. 1997). Where overlap of food resource use exists, the extent of overlap can vary over time and in many freshwater systems fish foraging will converge to the common use of temporally abundant food items (Matthews 1998). Responses to inter-specific competition and predation notably include the adjustment of fish foraging behaviour (Bryan et al. 2002), especially with regard to spatial and temporal distribution (Jacobsen and Berg 1998, Jackson et al. 2001, Holker et al. 2002). As discussed in Chapter 2, a variety of biotic factors can influence the habitat selection of fish. Biotic factors including inter-specific competition and predation will influence the structure and resource use within freshwater fish communities. Therefore, the diet of fish is often a reflection of a combination of available prey items, foraging behaviour and interactions with other fish (Hodgson et al. 1997, Holker et al. 2002, Paukert and Willis 2002). The diets of DLG, *Gambusia* and rainbow trout were investigated to provide further information on inter-specific interactions, particularly competition and predation of fishes in Lake Waikere. Diet analysis will contribute to a better overall understanding of the impact of exotic fish species on DLG in Lake Waikere.

Exotic species in Lake Waikere are likely to exert both competition (*Gambusia*) and predation (rainbow trout) pressure on DLG. *Gambusia* are known to consume large quantities of a variety of organisms throughout the water column in the littoral zone, from the water's surface and the substrate (McDowall 1990, Mansfield and McArdle 1998). The diet of a species closely related to DLG (dwarf inanga) has been studied in Lake Kanono, where cladocera and aquatic mites (particularly for smaller fish), as well as terrestrial insects and aquatic insect larvae, were found to be important prey items for dwarf inanga (Rowe and Chisnall 1996). It was predicted therefore, that a direct comparison of *Gambusia* and DLG diet would show and help to quantify dietary competition between the two species. I sought to quantify and compare the diet of *Gambusia* between size classes and season, while also comparing the diet of DLG and *Gambusia* to investigate potential competition for food resources and dietary overlap.

The diet of rainbow trout in the lakes is of particular interest as they are stocked into these lakes as a popular angling resource and some dietary records for trout date back to the years immediately subsequent to their initial stocking. Rainbow trout are known to impact on native fishes through predation and competition (Bryan et al. 2002, McDowall 2003). Trout predation on DLG is well documented (e.g. Cudby *et al.* (1969), Allen *et al.* (1971), Rowe *et al.* (1999) and Troup (2003)) and I expected this research to have similar results. However, given the restricted distribution of *Gambusia* to shallow areas of littoral vegetation (see Chapter Two), I did not expect *Gambusia* to feature significantly in the diet of trout in Lake Waikere.

3.3 Method

3.3.1 Sampling of DLG and *Gambusia*

To compare the diet of *Gambusia* across seasons and size classes approximately 100 randomly selected *Gambusia* from Lake Waikere were collected during March, June, August, November 2004, and January 2005 and were caught in the traps used in Chapter 2. Approximately ten DLG were collected each month from August 2004 to January 2005. DLG were primarily caught using a dip net and spotlight after dark. For comparison with DLG a sub-sample of ten *Gambusia* were randomly taken from each of the August, November and January samples. All fish were euthanized using an immediate overdose of 2-phenoxyethanol (1mg/l) and were then stored in 70% ethanol. Fish were later dissected under a 0-40x microscope and the stomach contents recorded. Prior to dissection, the gender, weight and standard length of fish were measured and recorded. The left and right sagital otoliths were removed from DLG samples prior to analysis of their stomach contents for analysis in Chapter 4.

3.3.2 Sampling of rainbow trout

Rainbow trout are known to utilise a variety of lake habitats year round, including the shallow littoral zone, depending on the availability of food resources and water temperature (McDowall 1990). An annual trout fishing contest takes place at the Kai Iwi Lakes, so the opportunity was taken to sample the gut contents of rainbow trout in the Kai Iwi Lakes. The 2004 contest took place on the 14th and 15th of August. Anglers were offered the chance to have their fish gutted and cleaned in exchange for the fish stomachs. Fish were caught using a variety of techniques, including fly fishing, spinning and trolling. A total of 82 fish were caught during the August 2004 competition from two of the three Kai Iwi Lakes, 61 from Lake Taharoa and 21 from Lake Waikere. The weight, length, gender, age, method of catch and origin of caught trout was recorded at the contest weigh-in station. The trout stomachs were placed on ice before being placed in a deep-freeze until the time of dissection. The stomachs were dissected and contents recorded using a 0-50x dissecting microscope. All fish from Lake Waikere and 21 from Taharoa had the contents of the stomach identified and counted. Identifiable DLG present in the stomach contents were measured to the nearest millimetre.

3.3.3 Data Analysis

For the numerical analysis and description of the stomach contents of DLG, *Gambusia* and rainbow trout in Lake Waikere, the occurrence method was used to calculate the percentage diet composition of each food item (as dry weight was not feasible in the time available). The occurrence method has been previously used for another New Zealand study of *Gambusia* diet by Mansfield and McArdle (1998). The occurrence of each food type is expressed as a percentage of the total number of occurrences of all food types or alternatively the percentage of fish in which a particular food item occurred (Hynes 1950). *Gambusia* diet was compared between summer (March 2004) and winter (June 2004), as well as between size classes of *Gambusia* collected during March 2004 and June 2004. The results of Mansfield and McArdle (1998) also suggested that all large fish were female, so sex was not used for analysis. The size classes used for comparison were that used by Mansfield & McArdle (1998) and consisted of ≤ 15mm, 15-25mm, ≥25mm. To compare the diets of DLG and *Gambusia*, samples from months where diet information of both species was available were pooled for each species. Samples from August and November 2004 and January 2005 were therefore used to investigate DLG and *Gambusia* diet overlap. Empty stomachs were removed from the data set for comparisons between groups.

To reduce the effects of outliers, a $\mathrm{Log}_{10}X+1$ transformation was applied to all DLG and *Gambusia* diet data. A multi-dimensional scaling (MDS) ordination plot was used to graphically present and analyse diet overlap. To construct the ordination plot a similarity matrix was calculated using a Bray-Curtis coefficient (as zero values indicate absence of information rather than a measurement value). An analysis of similarity (ANOSIM) to test if the diet contents of groups were statistically different was then performed ($\alpha=0.05$). A SIMPER analysis was then performed on the original data ($\mathrm{Log}_{10}X+1$ transformation) to discern which prey species was the most divergent (i.e. most responsible for dissimilarity) between groups of interest (e.g. species) and to provide a measure of dissimilarity/similarity. All procedures for diet analysis were carried out in Primer 5©.

3.4 Results

3.4.1 Dune lakes galaxias

3.4.1.1 Overall diet composition

The diet of DLG was dominated by cladocera (53.6%) and terrestrial invertebrates (30.7%) (Table 3.8(a)). With regard to the percentage occurrence of fish containing a particular food item, the frequency of cladocera in the diet reduced slightly to 48.1% and for terrestrial invertebrates increased slightly to 43.4 % (Table 3.8(b)). Other food items recorded in DLG stomachs included molluscs, hyrdacarina, aquatic dipteran larvae, copepods and ostracods.

Table 3.8(a). Percent occurrence of total number of food items for DLG by month

	Aug	Sep	Oct	Nov	Dec	Jan	Overall
N (fish sampled)	11	10	15	10	10	15	71
Mean fish length (mm)	37	35	26	30	29	43	33
Cladocera	88.4	87.0	36.5	0.0	63.6	45.8	53.6
Terrestrial	2.5	3.9	49.2	76.5	35.7	16.5	30.7
Hydracarina	4.4	1.2	0.0	0.0	0.7	36.5	7.1
Diptera larvae	0.0	3.1	11.1	17.7	0.0	0.2	5.4
Ostracoda	4.4	4.3	3.2	0.0	0.0	1.0	2.1
Copopoda	0.0	0.0	0.0	5.9	0.0	0.0	1.0
Mollusca	0.3	0.0	0.0	0.0	0.0	0.0	0.1

Table 3.8(b). Percent occurrence of prey item type in the total number of fish for DLG by month.

	Aug	Sep	Oct	Nov	Dec	Jan	Overall
N (fish sampled)	11	10	15	10	10	15	71
Cladocera	81.8	60.0	66.7	0.0	40.0	40.0	48.1
Terrestrial	27.3	30.0	40.0	50.0	60.0	53.3	43.4
Ostracoda	18.2	30.0	13.3	0.0	0.0	26.7	14.7
Hydracarina	18.2	30.0	0.0	0.0	10.0	26.7	14.1
Diptera	0.0	30.0	13.3	10.0	0.0	6.7	10.0
Copepoda	0.0	0.0	0.0	10.0	0.0	0.0	1.7
Mollusca	9.1	0.0	0.0	0.0	0.0	0.0	1.5

3.4.2 *Gambusia*

3.4.2.1 Overall diet composition

Overall *Gambusia* dietary composition was dominated by cladocera spp. (56.7% of all food items), aquatic hydracarina (23.3%) and terrestrial invertebrates (14.8 %) in Table 3.9(a). However, in terms of percentage of fish consuming a food type, terrestrial insects were more frequent (consumed by 36.7% of fish), while cladocera (46.7%) and hydracarina (26.0%) maintained similar percentages (Table 3.9(b)). Other food items included aquatic dipteran, odonate and coleopteran larvae, crustacea (other than cladocera) and copepods. Other fish, molluscs, collembola and nematodes occurred in less than one percent of fish stomachs examined and fish and molluscs only in the sample of fish from May 2004.

Table 3.9(a). Percent occurrence of total number of food items for *Gambusia* by month and size class (size class refers only to fish collected in March and June 2004). Size class 1 is fish 15 - 25mm in standard length and size class 2 is fish 25mm or greater in standard length. The overall percentage relates to fish collected in all months.

	Mar	Jun	Aug	Nov	Jan	Size Class 1	Size Class 2	Overall
N (fish sampled)	140	124	10	10	10	151	113	
Cladocera	26.2	90.4	74.3	92.5	0.0	59.0	48.4	56.7
Hydracarina	54.2	3.8	0.0	3.0	55.6	29.8	31.9	23.3
Terrestrial	4.8	2.9	20.0	1.6	44.4	3.2	8.4	14.8
Crustacea	9.0	1.4	0.0	2.7	0.0	4.9	6.3	2.6
Diptera	0.3	0.5	5.7	0.2	0.0	0.4	0.7	1.3
Copopoda	4.4	0.9	0.0	0.0	0.0	2.4	2.7	1.1
Mollusca	0.7	0.0	0.0	0.0	0.0	0.1	1.1	0.1
Coleoptera	0.1	0.1	0.0	0.0	0.0	0.1	0.2	0.0
Odonata	0.1	0.0	0.0	0.0	0.0	0.0	0.2	0.0
Collembola	0.0	0.1	0.0	0.0	0.0	0.1	0.0	0.0
Nematoda	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
Pisces	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.0

Table 3.9(b). Percent occurrence of prey item type in the total number of fish for *Gambusia* by Month and size class (size class refers only to fish collected in March and June 2004). Size class 1 is fish 15 - 25mm in standard length and size class 2 is fish 25mm or greater in standard length. The overall percentage relates to fish collected in all months.

	Mar	Jun	Aug	Nov	Jan	Size Class 1	Size Class 2	Overall
N (fish sampled)	140	124	10	10	10	151	113	
Cladocera	57.1	76.2	50.0	50.0	0.0	92.9	62.8	46.7
Terrestrial	37.1	36.5	30.0	40.0	40.0	57.5	38.1	36.7
Hydracarina	53.0	27.0	0.0	40.0	10.0	39.8	46.9	26.0
Crustacea	20.7	13.5	0.0	10.0	0.0	31.9	8.8	8.8
Diptera	5.0	9.5	10.0	10.0	0.0	6.2	10.6	6.9
Copopoda	15.0	10.3	0.0	0.0	0.0	18.6	11.5	5.1
Coleoptera	2.1	1.6	0.0	0.0	0.0	0.9	0.9	0.8
Odonata	2.9	0.0	0.0	0.0	0.0	1.8	2.7	0.6
Collembola	0.7	2.4	0.0	0.0	0.0	0.9	2.7	0.6
Mollusca	1.4	0.0	0.0	0.0	0.0	2.7	0.9	0.3
Pisces	1.4	0.0	0.0	0.00	0.00	1.8	0.0	0.3
Nematoda	0.7	0.8	0.0	0.0	0.0	0.0	1.8	0.3

3.4.2.2 Comparison of *Gambusia* diet between season

ANOSIM analysis suggested that the diet of *Gambusia* between summer (March 2004) and winter (June 04) could be considered significantly different ($p<0.05$). The diet of *Gambusia* in winter was more closely clustered than that of summer (Figure 3.13). Diet of *Gambusia* between summer and winter, although significantly different, did exhibit some overlap, evident in the ordination plot (Figure 3.13). SIMPER analysis showed that the diets between summer (March 2004) and winter (June 2004) were 67.0% dissimilar. The average abundance of cladocera and hydracarina were most responsible for the dissimilarity in dietary composition between months.

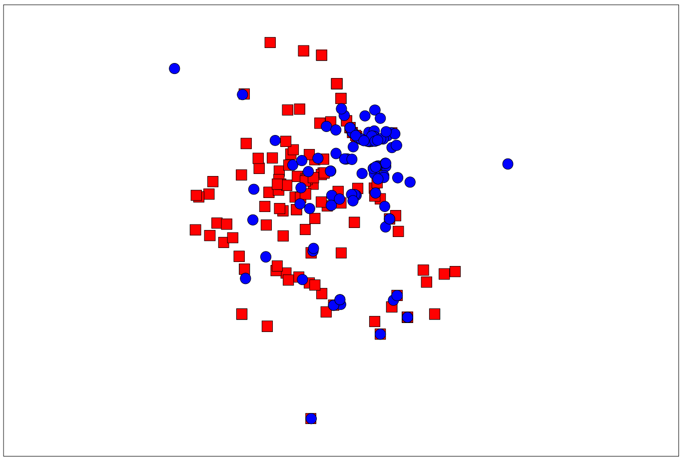

Figure 3.13. Multi-dimensional scaling (MDS) ordination plot comparing the diet of *Gambusia* during summer (March 2004) and winter (June 2004). (one-way ANOSIM, R=0.135, p<0.001). Red squares represent fish sampled during March 2004 and blue circles represent fish sampled during June 2004.

3.4.2.3 Comparison of *Gambusia* diet between size class

ANOSIM analysis suggested that the diets of the two tested size classes (15<25mm and ≥25mm) cannot be considered significantly different (p=0.06). Dietary overlap clearly exists between both size classes, although the diet of smaller fish appears to be more closely clustered together in the ordination plot (Figure 3.14). Although the difference between size classes was not quite significantly different, using a SIMPER analysis, the average abundance of cladocera in fish stomachs was considered to be most responsible for any observed dissimilarity in dietary composition between the two analysed size classes.

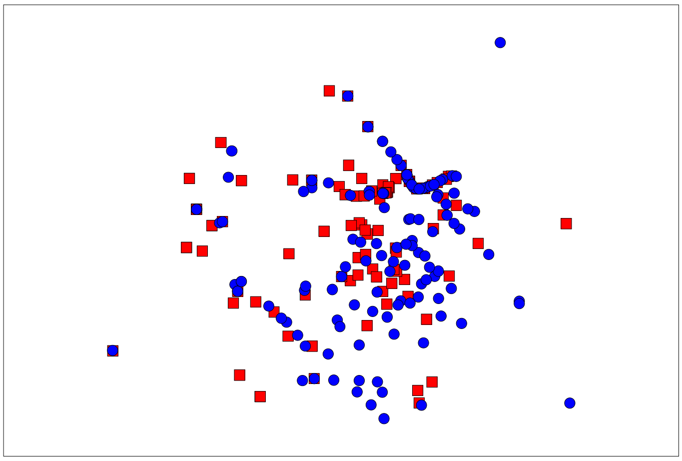

Figure 3.14. Multi-dimensional scaling (MDS) ordination plot comparing the diet of *Gambusia* between size classes (one-way ANOSIM, R=0.018, p=0.06). Red squares represent fish >25mm in length and blue circles represent fish 15<25mm in length.

3.4.3 Comparison of DLG and *Gambusia* diet

ANOSIM analysis suggested that there was no statistically significant difference (p=0.33) between the pooled diets of *Gambusia* and DLG during August, November 2004 and January 2005. As is illustrated in Figure 3.15, there is substantial overlap between the stomach contents of each species. A SIMPER analysis suggested that both between and within species dissimilarity was c.70%, perhaps as an artefact of small monthly sample size and low taxonomic resolution of the diet analysis. These results suggest that significant dietary overlap exists between *Gambusia* and DLG in Lake Waikere.

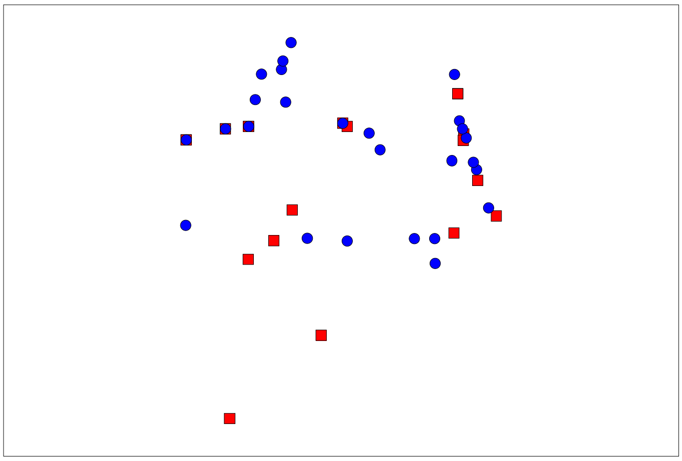

Figure 3.15. Multi-dimensional scaling (MDS) ordination plot comparing the diet of *Gambusia* and DLG (one-way ANOSIM, R=0.006, p=0.33). Red squares represent *Gambusia* and blue circles represent DLG.

3.4.4 Rainbow trout

3.4.4.1 Overall diet composition

Invertebrate larvae, including those of damselfly and dragonfly, but particularly chironomid larvae, were important food items for the sampled rainbow trout from Lake Waikere (Table 3.10). In Lake Taharoa, insect larvae were far less frequent in sampled fish stomachs. Small fish also made up an important part of the diet of trout in the Kai Iwi Lakes and were present in 76% of fish from Lake Waikere and 58% in Lake Taharoa (the largest proportion of which were unidentifiable remains). Overall, 19 identifiable DLG were recovered from trout stomachs, occurring in nearly a quarter (22%) of all trout stomachs (28.6% in Waikere). The average length of recovered DLG was 38.7mm. The diet of trout between the two lakes appeared to vary most in regard to the chironomid larvae and koura, with koura occurring in 58% of fish stomachs from Lake Taharoa but in less than 10% of fish from Lake Waikere. Other important diet items included common bully, terrestrial insects and freshwater snails, beetles and crabs. Most fish caught from Lake Waikere also contained empty chironomid larvae cases. Fish stomachs also frequently contained algae/weed and a range of terrestrial objects including sticks, plastic and cigarette butts.

Table 3.10. Percent occurrence of prey item type in the total number of fish for rainbow trout overall and by lake.

	Lake Waikere	Lake Taharoa	Overall
N (fish sampled)	21	19	40
mean fish length (mm)	470	440	455
chironomid larvae	81.0	0.0	42.5
unidentifiable fish remains	47.6	26.3	37.5
koura	9.5	57.9	32.5
common bully	23.8	31.6	27.5
dune lakes galaxias	28.6	15.8	22.5
damselfly larvae	38.1	0.0	20.0
dragonfly larvae	38.1	0.0	20.0
unidentifiable terrestrial insect	19.1	5.3	12.5
freshwater snail	23.8	0.0	12.5
freshwater crab	0.0	10.5	5.0
aquatic beetle	4.8	5.3	5.0
algae/weed	66.7	63.2	65.0
terrestrial object	52.4	36.8	45.0
empty chironomid cases	76.2	0.0	40.0

3.5 Discussion

3.5.1 Dune lakes galaxias

This study suggests that the diet of DLG is likely to be very similar to that of its closest relative, dwarf inanga. Overall the cladocera and terrestrial insects made up the largest components of the diet of DLG sampled during the study period. The closely related (and also landlocked) dwarf inanga diet was examined in Lake Kanono and revealed a similar prevalence of cladocera and terrestrial insects in the diet of fish up to 60mm in length, although larger fish contained more terrestrial insects and aquatic larvae than did smaller fish (Rowe and Chisnall 1996). However, no DLG over 60mm in length were sampled for stomach contents in this study, as the collection of fish was primarily for otolith analysis.

3.5.2 *Gambusia*

Cladocera are probably the most important prey item for *Gambusia* sampled in Lake Waikere, regardless of season. Although terrestrial insects make up a small percentage of prey items, they occur regularly in fish stomachs. Consequently they can be considered an important part of the diet, particularly as they are usually larger prey items and may account for a greater part of the biomass consumed by *Gambusia*. Hydracarina made up a significant part of the diet during late summer when they occurred in over 50 percent of fish stomachs examined. However, they declined in frequency during winter and cladocera frequency increased. Other studies in New Zealand have found that *Gambusia* feed on a wide variety of items including, crustacea, arthropods, aquatic arachnids, mollusca and ostrocoda, aquatic insect larvae in the water column, terrestrial insects from the water's surface and at times other fish, including con-specifics (Hayes and Rutledge 1991, Mansfield and McArdle 1998). *Gambusia* are known to be especially effective predators of cladocera (Bence 1988), while also being opportunistic generalist predators (Mansfield and McArdle 1998). Such effective predation of grazing zooplankton by *Gambusia* spp., particularly during summer (Hulbert and Mulla 1981), has been demonstrated to increase algal growth and reduce water quality (Hulbert et al. 1972, Margaritora et al. 2001).

Gambusia diet varied between summer (March) and winter (June) as was clear in the clustering in Figure 3.13; the diet of *Gambusia* in June exhibited a greater similarity between fish than March. The diet between months was approximately 66% different, the contribution of arachnids and cladocera being the most important to the observed dissimilarity. Differences in diet between months are likely to represent changes in the relative abundance of prey items in the littoral zone, as fish exploit temporally abundant prey items (Mansfield and McArdle 1998, Matthews 1998).

Unlike the study of *Gambusia* diet by Mansfield and McArdle (1998), the present study lacked the smallest fish size class (<15mm) for analysis due to the mesh size of minnow traps used to collect specimens. Despite this, a near significant difference between the two size classes was observed. Although not statistically significant, an analysis of similarity indicated that the diets of the two collected size classes were approximately 64% dissimilar. This was largely due to an increase in the consumption of terrestrial insects by larger fish and a preference for smaller items (particularly hydracarina) by smaller fish. The finding that larger fish take a greater proportion of available larger prey items was recorded by Mansfield and McArdle (1998). An increase in the size of prey is commonly associated with an increase in the size of the fish, and this may occur during the development of fish from larvae to adult (Persson and Crowder 1998). Differences in prey selection by different sized fish can be related to the ontogenetic anatomical (i.e. gape size) and ecological characteristics of fish (i.e. habitat use) (Schael et al. 1991, Sardina and Cazorla 2005).

3.5.3 Dune lakes galaxias vs. *Gambusia*

The comparison of DLG and *Gambusia* diet did not indicate a significant difference in diet between the two species across the study period. This indicates that some overlap and hence competition for food resources may be occurring in Lake Waikere. Diet overlap between similarly sized fish for food items, including cladocera and aquatic larvae, is known to occur elsewhere (Gisbert et al. 1996, Hodgson et al. 1997, Lewin et al. 2004). This is possible for DLG and *Gambusia* as both species utilise the littoral zone of Lake Waikere for feeding, especially in and around vegetated habitats. Furthermore, where diet overlap occurs, habitat partitioning may be important for the long-term co-existence of fish species (Wheeler and Allen 2003). Temporal movement of fish and prey items may also be important in facilitating the partitioning of resources (Matthews 1998). Vegetated habitats also offer cover from predation and higher densities of invertebrates, making them important for both species in regard to trade-offs associated with foraging, i.e. prey abundance (Schindler et al. 1997, Kahilainen et al. 2004) and predation (Werner et al. 1983, Shoup et al. 2003).

3.5.4 Rainbow trout

DLG occurred in approximately 25% of fish stomachs and given the amount of unidentifiable fish recovered, it is possible that this percentage is indeed greater. DLG also appeared to form a significant part of trout diet in the Kai Iwi Lakes during 1993 (Rowe et al. 1999) and 2003 (Troup 2003) analyses of trout diet. Given the well-documented nature of trout predation on DLG (Cudby and Ewing 1968, Allen et al. 1971, Rowe et al. 1999, Troup 2003), it is likely that DLG are an important part of trout diet year round. Furthermore, early studies have indicated that the DLG population declined following the first stocking of trout as a result of trout predation (Allen et al. 1971). Trout stomachs from the Kai Iwi Lakes showed a range of items being consumed during the August 2004 fishing contest. Significantly no *Gambusia* were recorded from rainbow trout stomachs gathered during the 2004 or 2003 fishing contests and to my knowledge *Gambusia* have not previously been recorded from rainbow trout gut contents in the Kai Iwi Lakes. The sample of rainbow trout was collected over a short period time and drawing accurate conclusions in regard to the full extent of trout predation on DLG and *Gambusia* is difficult. However, Rowe *et al.* (1999) and Troup (2003) found that rainbow trout predation was biased towards juvenile DLG less than 50mm in length and this ultimately could reduce recruitment of individuals to the reproductive cohort. Furthermore the removal of trout has been shown to increase juvenile recruitment of DLG (Rowe et al. 1999).

3.5.5 Implications for conservation

Both introduced species appear to have a potentially serious impact on the DLG through predation in the case of trout, and potential the for competition in the case of *Gambusia*. Although diet overlap may exist between *Gambusia* and DLG at times, the results presented in Chapter 2 suggest that competition is likely to occur for habitat as well. However, DLG were usually collected at night and may have been responding to temporal shifts in the spatial abundance of prey items, competition and predation risk, in regard to dietary selection and foraging behaviour. The decline or extinction of threatened species is often influenced by negative impacts from several competitors or predators rather than those from a single species (Bryan et al. 2002). The closely related dwarf inanga has been reported to be abundant in lakes where rainbow trout are present, in the absence of other introduced fish species (Rowe 1998). This suggests that the combination of trout predation and *Gambusia* competition for space and resources may be an important factor for the decline of DLG in the Kai Iwi Lakes.

An implication of this research is that competition with *Gambusia* for food items may limit the productivity of the DLG population. Trout predation on *Gambusia* was not observed, and I failed to come across any record of predation by rainbow trout on *Gambusia* in the Kai Iwi Lakes. Despite trout stomach samples being restricted to winter months, results in Chapter Two suggest that regardless of the time of year *Gambusia* are restricted to shallow vegetated areas of the littoral zone. Trout are therefore unlikely to be able to access the majority of *Gambusia* in Lake Waikere. Furthermore, the abundance of potential prey items (e.g. *Gambusia* for trout) in refuge habitats is more likely to be a result of the availability of resources within such habitats than predation (Closs et al. 1999). Consequently, trout predation is may not be the most important factor regulating *Gambusia* abundance in Lake Waikere.

Chapter 4.0: Using otoliths to estimate the spawning time of the dune lakes galaxias (*Galaxias* sp.) in Lake Waikere, Kai Iwi Lakes, Northland, New Zealand.

4.1 Abstract

The use of otoliths to investigate various aspects of fish populations is widespread in fisheries science. Otoliths can be used to determine hatch dates and spawning times. The exact timing and location of DLG spawning in the Kai Iwi Lakes is presently unclear. Using DLG otoliths and assuming that growth increments form on a daily basis, as is the case for the closely related inanga, I aimed to identify the spawning period of DLG in Lake Waikere. DLG were collected between August 2004 and January 2005, although samples from an entire year would have been preferable, however this was not possible due to the time restraints. By counting the daily increments of otoliths from sampled DLG, hatch dates ranging from January to August 2004 were estimated. This would suggest that DLG have a spawning period extending from summer to early winter, which is similar to inanga. Furthermore, a peak in hatch dates was found for June 2004 and consequently a peak in spawning events could have occurred in May 2004 for the sample of DLG collected in the study. Diadromous inanga spawn on littoral and marginal vegetation and the same is probably true for DLG. Consequently evidence for spawning (i.e. eggs, milt and newly hatched larvae) should be searched for during months identified as being within the likely spawning period of DLG. DLG are likely to spawn on or near vegetation in the littoral zone and these habitats should be examined for evidence of spawning using a combination of observations from the shoreline and within the water. The likely spawning period of DLG overlaps with periods of high seasonal abundances of *Gambusia* in vegetated littoral habitats. Therefore, an increased likelihood of attacks on adult DLG and predation on both DLG eggs and larvae by *Gambusia* in vegetated stretches of the littoral zone has the potential to be partly responsible for the documented decline of DLG in the Kai Iwi Lakes.

4.2 Introduction

Basic life history information is crucial to implementing effective conservation strategies for threatened species. Information pertaining to the age of fish can be used to calculate spawning period, productivity, mortality rate and growth rate, making it one of the most useful of biological variables (Campana 2001). Information regarding the location and timing of reproductive events is particularly important for the management of threatened species. Such information may allow timely and targeted management interventions for the conservation of threatened fish species. Fish produce several calcified structures that form periodic growth increments, including otoliths. Otoliths have been widely used for the age estimation of fish species important for commercial and conservation reasons (Campana and Thorrold 2001). Otoliths are $CaCO_3$ crystalline structures found in the brain cavity of fish, and are continuously formed throughout the life of a fish. Growth increments are formed during the deposition of $CaCO_3$ and those useful for age determination can be formed annually (Campana 2001, Egger et al. 2004) and daily (Campana and Neilson 1982, Lou and Moltschaniwskyj 1992, Campana 2001). Use of growth rings, particularly daily rings, to estimate fish age can be made through counting increments and making back calculations to key life history events (e.g. hatch dates and spawning time) (McDowall et al. 1994, McDowall and Kelly 1999, Light and Able 2003). As there is no turnover of the deposited crystalline material, otoliths are a permanent record of growth (Campana and Neilson 1985).

Ideally, growth increments should be validated to confirm that the visible increments are indeed laid down at the expected frequency over time. Validation techniques range from the raising of fish from hatching (McDowall et al. 1994) to chemical methods to mark the otoliths in live fish (Campana and Neilson 1982, Lou and Moltschaniwskyj 1992, Hernaman et al. 2000, Egger et al. 2004), before terminating fish after a known amount of time. The closely related and likely parent taxon of the DLG, *Galaxias maculatus* (Ling et al. 2001), has been demonstrated to produce growth increments at a daily frequency on its otoliths (McDowall et al. 1994). McDowall *et al.* (1994) assumed that other closely related galaxiids will do the same and therefore, for this study it is assumed that DLG form daily growth increments on their otoliths.

DLG is currently a threatened species restricted to the Kai Iwi Lakes. Quantitative information regarding the location and timing of spawning by DLG in these lakes is currently insufficient and more information is essential for protection of this species. To increase available information regarding the spawning time and habitat of DLG, I sought to use back calculations of daily increment counts from DLG otoliths to estimate spawning period. Closely related inanga usually spawn during late summer and autumn (McDowall 1990), with peak spawning time occurring during April and mid-May (McDowall et al. 1994) and spawning events are often linked with lunar cycles (i.e. tides). However, land-locked populations of inanga in Australia (Pollard 1971) and Chile (Barriga et al. 2002), are known to spawn during early spring and summer. It has been suggested that another closely related and lacustrine fish species, the dwarf inanga, also spawn during late-summer and autumn (McDowall 1990, Rowe and Chisnall 1996).

4.3 Methods

4.3.1 Age estimation of dune lakes galaxias

To provide a representative sample of fish otoliths for age estimation 70 DLG were collected between August 2004 and January 2005 (c.10 per month). Fish were caught using a dip net and spotlight at night from the littoral zone of Lake Waikere. Fish were euthanized immediately using an overdose of (1mg/l) of 2 phenoxyethanol; fish were then stored in 95 % ethanol. The weight and length of each fish was measured prior to storage in ethanol. The sagital otoliths of each fish were then extracted by dissecting open the brain case and removing the otoliths from the small depression located at the posterior end of the brain cavity. Following removal, otoliths were viewed under a dissecting microscope and if necessary cleaned in distilled water to remove any tissue still attached. Otoliths were then placed in a labelled vial to air-dry overnight prior to mounting, sanding and polishing. To view the growth increments in the otoliths one of each pair was positioned horizontally on a standard microscope slide and embedded in "Crystal bond™" thermoplastic resin. Each otolith was then polished by hand in aluminium oxide slurry (Diamond Edge) and then rinsed in distilled water. Following final polishing, counts of daily increments were made under 400x magnifications on a compound microscope.

Variation between counts of growth increments can be caused by the often variable distance between growth increments (i.e. they can be very close together) and some margin of error is considered to be unavoidable (McDowall et al. 1994). To compensate for the potential variation between counts of growth increments and provide a measure of central tendency, two observers each made three counts of growth increments, at three different locations on each otolith. This meant that an estimate of age could be inferred from an average of six counts of growth increments made across a single otolith. A paired t-test was performed to determine if the observed variation between counts of daily growth increments was a result of a difference between observers.

4.4 Results

4.4.1 Age estimation of dune lakes galaxias

A paired t-test ($\alpha=0.05$) indicated that there was no significant difference between the mean counts of the two observers ($p=0.65$). In total the daily growth increments of 65 otoliths were counted and age estimates were made from the mean of six counts. The mean length of fish in the sample was 33.3 mm and fish in the sample ranged from 25 mm to 49 mm in length. The mean otolith diameter was 0.59 mm and otoliths ranged from 0.39 mm and 0.92 mm in diameter. The mean estimated age of sampled fish was 170 days and the estimated age of fish in the sample ranged from 99 to 229 days old (the mean standard error of age estimates was 6.5 days). Estimated hatch dates of sampled fish ranged from 8 January to 3 August 2004, with a peak in abundance of estimated hatch dates during June and July 2004 (Figure 4.16). Allowing 20-30 days for embryonic development to hatching (McDowall et al. 1994), the peak spawning time of sampled fish could be expected to have been during May and June 2004 (Figure 4.16).

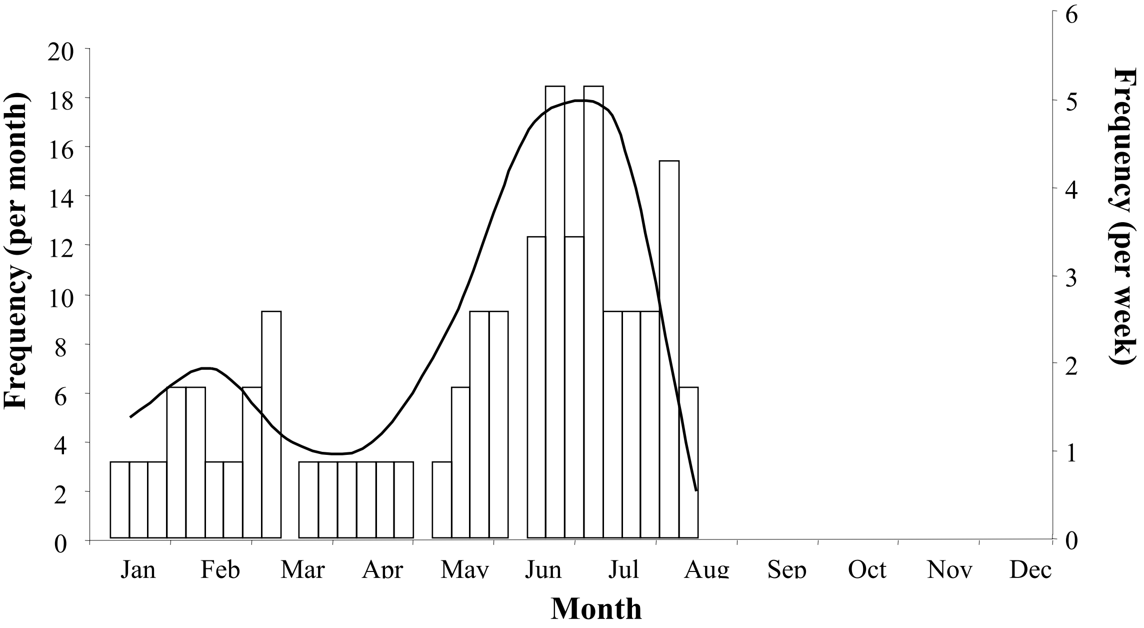

Figure 4.16. Frequency histogram of estimated hatch dates of 65 DLG. Bars represent weekly frequency of estimated hatch dates (left hand axis). The smoothed line represents monthly frequency of estimated hatch dates (right hand axis). Weeks and months are calculated for the 2004 calendar year from 1 January.

4.5 Discussion

4.5.1 Age estimation of dune lakes galaxias

Results indicate that DLG in Lake Waikere spawn over a period extending from summer to early winter (January through June.) A peak in estimated DLG hatch dates were observed in June and could have resulted from spawning events during May. This is consistent with inanga and other native diadromous galaxiids that are known to spawn over a broad period of time during autumn and winter (McDowall 1990, McDowall et al. 1994, McDowall and Kelly 1999). Inanga spawning is generally considered to peak during April and May, while hatch dates of inanga are known to range from mid March to early June (McDowall et al. 1994). Reproduction in freshwater fish is usually related to season; with reproduction often peaking in spring or summer when higher water temperatures may positively influence egg and larval development, survival, growth and the amount of food resources available to larval fish (Matthews 1998). However, several species commonly spawn during winter and autumn when water temperatures are lower, including galaxiids, salmonids and some darters (Matthews 1998). The seasonality of the spawning events of freshwater fish can be influenced by the physical tolerance of eggs and fish and by inter-specific interactions with other fish species (i.e. predation on eggs and larvae and competition for resources between larvae of different fish species) (Matthews 1998).

The results of this research indicate that a peak in DLG spawning occurs during autumn and early winter, and larval DLG have previously been recorded from Lake Waikere during September (Rowe et al. 1999). In the absence of introduced fish species (Rowe and Chisnall 1997b) however, spawning in populations of dwarf inanga is thought to occur during summer months (Rowe and Chisnall 1996). Furthermore, hatch dates in early winter release young fish into an environment where potential food items are likely to be scarce and the development and growth of larval and juvenile fish can be slower due to lower water temperatures (Matthews 1998). Reproduction in other land-locked galaxiids is also related to lunar cycles and periods of high rainfall (Pollard 1971, McDowall et al. 1994), and may be the case for the DLG. The observed monthly frequency of DLG hatch dates during the study may be a result of several factors; including a life history adapted to successfully producing young in cooler water temperatures, an ancestral link to inanga that also spawn during autumn and winter, or temporal limitation of the sampled fish (i.e. collection of fish did not span an entire year). Therefore, efforts to identify important spawning habitat and behaviour should be undertaken during and months either side of the spawning period predicted by the research presented in this thesis, with factors such as lunar events and high rainfall in mind.

4.5.2 Implications for conservation

Littoral vegetation is considered to be an important spawning substrate for both diadromous and non-diadromous inanga (Pollard 1971, McDowall 1990). The littoral zone is considered to be important for the spawning of both dwarf inanga and DLG (Rowe 1998). Consequently, littoral vegetation is likely to provide an important spawning substrate for DLG in the Kai Iwi Lakes. The observed spawning period of DLG from this sample suggests that spawning, to some extent overlaps with high *Gambusia* relative abundance during late summer (see Chapter 2). Therefore, given the length of the spawning period of inanga (McDowall et al. 1994), observations of dwarf inanga being sexually mature in summer months (Rowe and Chisnall 1996) and the estimated hatch dates of DLG presented in this thesis; it is likely that DLG reproduction overlaps with periods of high *Gambusia* relative abundance in vegetated littoral habitats in Lake Waikere. It is therefore possible that DLG reproductive success may be directly reduced by *Gambusia* through attacks on adults (Rowe et al. 1999) and potentially the consumption of eggs and larvae by *Gambusia* (McCullough 1998). Consequently, the impact of *Gambusia* on the decline of DLG may include a reduction in the reproductive success of DLG as well as competition for food and habitat related resources (see Chapters 2 and 3). Implications of this may be that the recruitment of individuals spawned or hatched during summer months, when more food may have been available, may be reduced by *Gambusia* (i.e. through attacks on spawning adults or predation on eggs and young) and is reflected in the peak of observed hatch dates. Alternatively, the peak in DLG spawning during May 2004 could indicate that the effect of *Gambusia* on DLG recruitment is minimal, although I considered this to be unlikely. The sample of DLG used in this research could potentially be limited by the temporal constraints of the study period. Further investigation may therefore be necessary to confirm the full extent of the potentially negative impacts of *Gambusia* on the reproductive success of DLG, at various stages in the life history of DLG (e.g. impacts on DLG adults, larvae and eggs).

Chapter 5.0: General discussion

5.1 Summary

The purpose of this thesis was to provide relevant information for the conservation and management of DLG in the Kai Iwi Lakes. This was particularly in regard to assessing the ecological impact of two exotic fish species, *Gambusia* and rainbow trout on DLG. This was investigated using studies of abundance and distribution and diet to identify areas of likely impact. The use of otoliths to calculate a likely spawning time of DLG may also shed some light on the potential impact of exotic species, *Gambusia* in particular. The relative distribution of four species in the littoral zone of Lake Waikere was demonstrated to be related habitat, particularly in regard to areas of emergent macrophytes. *Gambusia* in particular have a distribution that is restricted to areas of littoral vegetation and have the potential to exclude or reduce the value of such habitats to native fish species, especially DLG. Likely diet overlap between DLG and *Gambusia*, and predation by rainbow trout on DLG may have contributed to the decline of DLG in the Kai Iwi Lakes.

5.2 Exotic species impacts on DLG

The littoral zone provides a mosaic of habitats and makes up a contiguous zone of different microhabitats (Chick and McIvor 1994, Lewin et al. 2004). Areas of the littoral zone containing emergent macrophytes provide both a productive zone of invertebrate prey and protection from fish and avian predators for small fish (Persson and Crowder 1998). It is likely then, that littoral vegetation is an important habitat for foraging and refuge for DLG. While DLG are conspicuously absent from shallow areas of littoral vegetation (ascertained using a combination of sampling techniques), the distribution of *Gambusia* are almost completely restricted to that habitat. Consequently, *Gambusia* are known to be aggressive towards DLG in littoral habitats (Rowe 1998, Rowe et al. 1999) and have the potential to negatively affect DLG by excluding them from valuable areas of littoral vegetation. As a result, the available vegetated littoral habitat that DLG may utilise in Lake Waikere is reduced by aggression from *Gambusia*. Furthermore, *Gambusia* and DLG diet exhibited significant overlap suggesting that competition for food, as well as habitat, exists. *Gambusia* may therefore, out-compete DLG for both space and food resources in vegetated littoral habitat. Furthermore, if DLG were to spawn in littoral vegetation, then the risk of predation of DLG eggs and larvae by *Gambusia* could be increased, particularly as the spawning period of DLG appears to overlap with periods of high *Gambusia* abundance and reproduction (i.e. summer).

Predation by rainbow trout is also likely to have played a role in the decline of DLG in the Kai Iwi Lakes and DLG have been demonstrated to form a significant part of the trout diet on several occasions (including in this thesis). In Lake Ototoa, however, dwarf inanga were introduced in the 1980s as forage for the recreational trout fishery, and seemingly trout predation has not prevented this species from flourishing (Thompson 1989). Unfortunately Lake Ototoa is now also home to both perch (*Perca fluviatilis*) and *Gambusia*, so any potential contemporary comparisons are of limited value, especially as the dwarf inanga in that lake has since declined significantly. As previously mentioned, trout removal studies were not documented to increase the adult DLG population in Lake Waikere. Tentative conclusions could be drawn that trout predation on its own may be insufficient to lead to the decline and/or extinction of DLG in the Kai Iwi Lakes.

5.3 A combination of foes?

Although many studies involving native threatened species have focussed on the effect of a single exotic species, it is often a combination of interactions with multiple exotic species that leads to a greater negative impact on native species (Bryan et al. 2002). In the case of DLG in the Kai Iwi Lakes, it is possible that the individual effect of each exotic species is magnified by the other. This may be exacerbated by the restricted distribution of *Gambusia* to shallow areas of dense littoral vegetation and as a result *Gambusia* and trout may seldom interact. Trout may simply not be able to access the majority of *Gambusia* in Lake Waikere (as *Gambusia* are restricted to dense littoral vegetation) and hence the top predator in the system, in this case trout, are unable to exert much influence on the abundance of a prey item through predation (Closs et al. 1999), in this case *Gambusia*. However DLG, which utilise both pelagic and littoral habitats may be negatively impacted by both species at various parts of its life history, i.e. physical exclusion (through competition) and adult recruitment by trout (through predation). Although DLG were observed around the edges of vegetated habitats, the value of these as temporary refuge from trout predation may be reduced owing to high abundances of *Gambusia*. If this is the case, then the amount of potential refuge from introduced species for DLG would be significantly reduced (i.e. DLG may avoid trout predation only to be set upon by aggressive *Gambusia* or vice versa). The impact of competitive exclusion by *Gambusia* may force DLG to utilise areas of higher predation risk and increase the magnitude of trout and avian predation on DLG. Consequently, DLG may have declined due to the introduction of more than one exotic fish species with impacts on DLG, in this case rainbow trout and *Gambusia*, although the introduction of *Gambusia* may have had a greater detrimental effect. However, the characteristics of decline (e.g. speed and extent) resulting from biotic interactions with exotic species in each in the Kai Iwi Lakes is likely to be affected by the individual abiotic and biotic characteristics of each lake. *Gambusia* therefore, may be more responsible for DLG extinction in Lake Kai Iwi as they are known to reach exceptionally high densities in that lake (Rowe et al. 1999), probably as a result of the extent of littoral vegetation in Lake Kai Iwi, creating a near uniform littoral zone. The impact of *Gambusia* could therefore, be lessened in Lakes Waikere and Taharoa where littoral zone is a mosaic of vegetated and un-vegetated habitats. The prevalence of un-vegetated areas of littoral habitat may therefore, be important to the persistence of DLG in these lakes. *Gambusia* are likely to have had a critical impact on DLG through competition, aggression and reduced DLG reproductive success. Re-introduction to Lake Kai Iwi may therefore, not be a presently viable option for species recovery, but if interaction between trout and *Gambusia* was the main cause of DLG extinction (in Lake Kai Iwi), then re-introduction to Lake Kai Iwi may be successful as trout are no longer stocked to that lake. Potential movement of fish between Lakes Taharoa and Kai Iwi is a possibility that would require investigating, as it may also facilitate natural re-colonisation by DLG in the absence or control of *Gambusia*.

5.4 Where to from here?

As with much scientific work, this thesis raises more questions that need to be answered and hence opportunities for potential future research. Consequently, recommendations for management provide scope for adaptive management and further investigation of detailed areas of the ecology of both threatened and exotic species in the Kai Iwi Lakes.

5.4.1 Monitoring Techniques

Regular monitoring of the DLG population in the Kai Iwi Lakes is a top priority. Monthly surveys of the littoral zone using a spotlight at night should enable suitably experienced and trained observers to monitor population change in the littoral zone of both Lake Taharoa and Lake Waikere. Visual estimations can provide cost-effective, accurate and detailed information of fish abundance, distribution and habitat detail (Hankin and Reeves 1988). Results of monitoring efforts can be compared between years and may enable population recovery, equilibrium or decline to be identified. Furthermore, the collection of seasonal data would help to contribute to increasing knowledge in regard to the life history of DLG. To make observations more complete, distinction between small (juvenile) and large (adult) fish should be factored into survey data collection along with any observations of reproductive behaviour, i.e. aggregations of adult fish or signs that spawning has occurred e.g. milt, eggs or spent adult fish. Efforts to identify spawning habitats are a priority (Allibone and Barrier 2004) and should be undertaken through regular visual surveys, especially during autumn and early winter. If a decline is observed over a period of time (i.e. several years) and if spawning locations and evidence have been identified, collection of eggs and attempts at captive rearing may be a possibility. Dead fish should always be collected and preserved so that cause of death may be determined, as small populations are known to be susceptible to irregular environmental perturbations (Begon et al. 1996), i.e. outbreaks of disease or rare climatic events. Changes in the biotic community of DLG may make it more susceptible to changes in the abiotic environment, especially from disturbance in the surrounding catchment (e.g. vegetation removal or pollution). The introduction of other exotic species to the Kai Iwi Lakes is also a danger and appropriate measures should be taken to educate the public as to what to avoid, including signage at the lakes and through bodies such as the Taharoa Domain committee and the Fish and Game Council. Regular monitoring of DLG should allow incursion by new species of exotic aquatic flora and fauna to be identified quickly. Appropriate personnel should then be notified immediately to check the extent of incursions and take measures for control or eradication. Public participation should also be encouraged through signage and in co-operation with the Fish and Game Council, particularly in regard to identifying and halting the spread of exotic species and increasing public awareness of the uniqueness of the Kai Iwi Lakes and DLG.

5.4.2 Research Recommendations

Trials should be undertaken to ascertain whether *Gambusia* control is possible to reduce the peak abundance from occurring during late summer. Given the restricted distribution of *Gambusia* to certain habitats this may be feasible. Furthermore, studies to determine if *Gambusia* can be removed and excluded from areas of vegetated littoral habitat, and the effect this has on DLG recruitment, in the presence and absence of trout are worth investigating. This would all help to confirm the role each exotic species plays and better illustrate the cumulative effect on DLG in the Kai Iwi Lakes. The diet of trout in the Kai Iwi Lakes may vary seasonally and therefore the extent of trout predation on DLG and *Gambusia* may also vary seasonally. Diet investigations already underway should be extended to accommodate this. As manipulation of trout densities (to zero) appeared not to result in an increase of adult recruitment of DLG (Rowe et al. 1999), it is considered inadvisable to increase stocking beyond current reduced levels. However, if DLG were to decline (or continue to decline) markedly, it would be worth reducing the input of trout to the lakes, at least temporarily. Furthermore, the Kai Iwi Lakes are managed as a recreational area, and rainbow trout in the Kai Iwi Lakes are an important recreational fishery for many people. A more cynical view could be that the permanent removal of trout for the protection of DLG would be welcomed, or maintained. The translocation of DLG to new lakes as a means of protection is also a possibility (Allibone and Barrier 2004). However, this would need to be done with due care to extant flora and fauna and with the genetic integrity of DLG in mind. A re-introduction of DLG to Lake Kai Iwi is also a possibility and could be used to test whether DLG can survive (or re-establish) in the presence of *Gambusia* where trout predation is absent. Lake Kai Iwi however, differs in physical nature to the other two, especially in regard to its depth and littoral macrophytes; and the abundance of *Gambusia* in this lake may prevent successful re-establishment of a self-sustaining DLG population.

5.5 Final conclusions

In conclusion, exotic fish species have almost certainly played an important role in the decline of DLG in the Kai Iwi Lakes. It is likely that the impact of *Gambusia* is particularly significant. Further research to assess whether *Gambusia* control or exclusion may be possible from key areas of littoral habitat that are important for DLG is essential. Furthermore, regular and ongoing monitoring of DLG populations is essential to identifying any decline or recovery of DLG in the Kai Iwi Lakes. This can be achieved using the inexpensive and accurate night time spotlighting method investigated and developed for DLG in this thesis. Hopefully the information gathered in this thesis will ultimately assist in the recovery of the DLG (and other native galaxiids). Finally, the best way to protect populations of native fish (including DLG) is to prevent the further spread and establishment of exotic fish and plant species in New Zealand's waterways.

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