Conservation Biology of the Golden Galaxias

(*Galaxias auratus*) (Pisces: Galaxiidae)

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A thesis submitted for the degree of Doctor of Philosophy at the School of Zoology,

University of Tasmania, Hobart, Tasmania, Australia

2007
Declaration of Originality

This thesis does not contain any material which has been accepted for the award of any other degree or diploma in the University of Tasmania nor any other university or institution. The material this thesis contains is, to the best of my knowledge, original except where due acknowledgement is made.

Mr Scott A. Hardie
June 2007

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Statement of Co-authorship

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Summary

1. The golden galaxias (*Galaxias auratus* Johnston 1883) is a threatened, non-diadromous galaxiid that is endemic to lakes Crescent and Sorell in central Tasmania, Australia. Similar to the lacustrine habitats of other threatened galaxiids in this region, the Crescent-Sorell system has altered hydrology and contains alien fishes. The objective of this study was to examine crucial aspects of the biology and life history of *G. auratus* (including age, growth, population structure, reproductive biology and recruitment dynamics) in these impounded highland lakes that are likely to be influenced by hydrology and lake management. An investigation of population monitoring methods for this species was also conducted. This work aimed to assess the vulnerability of *G. auratus* populations, and gain insight into the ecological attributes of other threatened galaxiids, threats to this family and other similar small-sized lentic species.

2. Analysis of a 5-year, monthly record of population and spawning attributes of both populations, along with detailed environmental data, including water levels and water temperatures, showed water levels and the access they provide to spawning habitat strongly limit the reproduction and recruitment of *G. auratus* in Lake Crescent. Detailed life history attributes of this species support these conclusions and further illustrate the vulnerability of this species to hydrological manipulations.

3. Gonad development began in mid-summer and spawning was spread over late autumn – early spring, peaking in winter. Demersal adhesive eggs (~1.5 mm diameter) were found on cobble substrates (c. 20-250 mm diameter) in littoral areas (c. 0.2-0.6 m deep). Patterns in larval emergence and abundance were associated with the timing of inundation of spawning habitats. In Lake Crescent, seasonal abundances of larvae were strongly related to the
magnitude of water level rises during spawning and egg incubation (i.e. May-September). Despite the occurrence of larvae in pelagic habitats in both lakes during winter, they did not grow until spring; thus, coupling of water level and water temperature regimes is important for recruitment. *Galaxias auratus* reached up to 240 mm in length and ~10 years of age; however, most grew to <130 mm and the 0+, 1+ and 2+ year classes dominated the age structure of both populations. There were more >2+ fish in Lake Crescent where predatory introduced salmonids were less abundant than in Lake Sorell. Growth of these larger fish was slower due to limited access to complex littoral habitats in Lake Crescent.

4. In a translocated population, fyke netting at night was the most effective sampling method owing to increased activity at night and cover-seeking behaviour by this species. In the lakes, monthly catches of *G. auratus* increased substantially during spawning, suggesting that knowledge of the reproductive biology of target species can aid population monitoring programs for other galaxiids.

5. Water level fluctuations play a key role in the life cycle of *G. auratus* which relies on access to complex littoral habitats for spawning, feeding and refuge. Seasonal hydrological cycles (i.e. rises during late autumn – winter) and a minimum water level of 802.20 m AHD in Lake Crescent during autumn (above which littoral areas of cobble substrate are inundated) are critical to *G. auratus* populations. Because many lacustrine galaxiids use littoral habitats during several life stages, alterations to water levels and seasonal hydrological regimes may impact on their populations by restricting access to these habitats at critical times. To assist the management of other threatened galaxiid species, further studies should identify habitats that limit populations based on species biology and examine ecological traits that provide resilience to major perturbations.
Acknowledgements

Firstly, I would like to acknowledge the support given to me by my supervisors, Leon Barmuta and Robert White of the School of Zoology and Tasmanian Aquaculture and Fisheries Institute (TAFI), University of Tasmania (UTas). Leon administered this study and helped define its direction. His broad understanding of conservation biology and contemporary management strategies for threatened taxa were of great value to the project. Leon has a wealth of knowledge regarding the analysis of ecological data and his guidance (and unrelenting patience) in this area was much appreciated. Rob’s thoughts on the biology of this species and knowledge of the family Galaxiidae improved the final content of the thesis.

Given the varied components of this thesis and substantial amount of time spent in the field, I was fortunate to have received assistance from many people. I am especially indebted to the Tasmanian Inland Fisheries Service (IFS), where I initially began studying the golden galaxias. Kindly, IFS allowed me to use much of that information for this thesis and provided further logistical support on many occasions. J. Diggle provided guidance in early stages of the project. Field work, which was conducted in the variable and sometimes arduous conditions of the Tasmanian Central Plateau, could not have been undertaken without assistance from IFS staff including B. Mawbey, A. Uytendaal, K. Breheny and H. Mulcahy, T. Byard, R. Walker, A. MacDonald, D. Jarvis, C. Wisniewski, M. Schottmeier, P. Donkers, A. Taylor, R. Cordwell and S. Frijlink. Further assistance was also provided by B. Mawbey, K. Breheny and H. Mulcahy (processing of larval samples), A. Uytendaal (water temperature modelling), D. Hardie (preparation of location maps and aquatic macrophyte identification), A. Taylor (otolith preparation and sectioning) and S. Solman (general field assistance). Additionally, S. Tracey and G. Ewing (TAFI) provided guidance in the interpretation of
otolith incremental structure and S. Tracey also performed the secondary otolith readings. S. Wotherspoon (UTas) helped with growth modelling, M. Higgins and T. Wilson (Department of Primary Industries and Water (DPIW)) with microbiological and molecular genetic work, and C. Marshall (DPIW) with histopathological tests.

The following people are thanked for fruitful discussions and comments regarding different elements of the thesis: J. Jackson (IFS), S. Pyecroft (DPIW), T. Raadik (Arthur Rylah Institute, Melbourne), R. McDowall (National Institute of Water and Atmospheric Research, Christchurch, New Zealand), B. Mawbey (IFS), R. Stuart-Smith (UTas) and J. Patil (CSIRO, Hobart). I would like to thank my two examiners for their constructive comments and suggestions which helped strengthen the content of the thesis and will also assist me in preparing further associated publications. I am very grateful to the McShane family for their hospitality and access to their property at all hours of the day. Financial support was provided by the Natural Heritage Trust, Environment Australia (now Department of the Environment and Water Resources), Tasmanian State Government via IFS, and TAFI through a postgraduate scholarship. The Tasmanian Museum and Art Gallery, Hobart also provided logistical support.

I am very grateful to Brett Mawbey and Adam Uytendaal for memorable times spent on lakes Crescent and Sorell and for what they taught me. I thank my parents, Graham and Margaret, for giving me the freedom to pursue and develop my interest in the aquatic world during my childhood. Finally, I am especially thankful to my wife, Danielle, for her constant love and support throughout this study.
Dedication

I hope the knowledge gained from this volume of work helps raise awareness of the uniqueness and imperilled status of small-sized inconspicuous freshwater fishes. I believe the naive and careless views expressed in the following quote* regarding European fishes still hold true today in several sectors; to the detriment of many species which are of little or no commercial or recreational value.

‘There is also a little fish called a Stickleback: a fish without scales, but hath his body fenced with several prickles. I know not where he dwells in winter, nor what he is good for in summer, but only to make sport for boys and women-anglers, and to feed other fish that be fish of prey, as Trouts in particular, who will bite at him as at a Pink, and better, if your hook be rightly baited with him, for he may be so baited, as his tail turning like the sail of a wind-mill will make him turn more quick than any Pink or Minnow can. For note, that the nimble turning of that or the Minnow is the perfection of Minnow-fishing.’

* Taken from modern day reprint ‘Walton, I. (1995). The Complete Angler. London: J. M. Dent.’. This is the fifth edition of this classic angling companion which was first printed in 1676. Izaak Walton was a seventeenth-century devotee of the art of angling, nostalgic royalist and friend of bishops.
# Table of Contents

Summary iv  
Acknowledgements vi  
Dedication viii  
Table of Contents ix  

Preface: Threatened fishes of the world: *Galaxias auratus* Johnston, 1883  

(Galaxiidae) xii  

1. General Introduction 1  
   1.1. Conservation of freshwater fishes 1  
   1.2. Galaxiid fishes and the golden galaxias 2  
   1.3. Lakes, littoral habitats and hydrology 6  
   1.4. Research objectives and approach 7  
   1.5. Thesis structure and format 9  

2. Status of galaxiid fishes in Tasmania, Australia: conservation listings, threats and management issues 11  
   2.1. Abstract 11  
   2.2. Introduction 12  
   2.3. Taxonomy 16  
   2.4. Conservation listings of Tasmanian galaxiids 17  
   2.5. Threats to Tasmanian galaxiids 19  
   2.6. Management issues for galaxiids in Tasmania 26  

3. Comparison of day and night fyke netting, electro-fishing and snorkelling for monitoring a population of the threatened golden galaxias 35  
   3.1. Abstract 35
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.2. Introduction</td>
<td>36</td>
</tr>
<tr>
<td>3.3. Materials and methods</td>
<td>40</td>
</tr>
<tr>
<td>3.4. Results</td>
<td>46</td>
</tr>
<tr>
<td>3.5. Discussion</td>
<td>55</td>
</tr>
<tr>
<td>4. Spawning related seasonal variation in fyke net catches of golden galaxias <em>(Galaxias auratus)</em>: implications for monitoring lacustrine galaxiid populations</td>
<td>62</td>
</tr>
<tr>
<td>4.1. Introduction</td>
<td>62</td>
</tr>
<tr>
<td>4.2. Materials and methods</td>
<td>63</td>
</tr>
<tr>
<td>4.3. Results and discussion</td>
<td>64</td>
</tr>
<tr>
<td>5. Age, growth and population structure of the golden galaxias <em>(Galaxias auratus Johnston)</em> in lakes Crescent and Sorell, Tasmania, Australia</td>
<td>68</td>
</tr>
<tr>
<td>5.1. Abstract</td>
<td>68</td>
</tr>
<tr>
<td>5.2. Introduction</td>
<td>69</td>
</tr>
<tr>
<td>5.3. Materials and methods</td>
<td>71</td>
</tr>
<tr>
<td>5.4. Results</td>
<td>78</td>
</tr>
<tr>
<td>5.5. Discussion</td>
<td>88</td>
</tr>
<tr>
<td>6. Reproductive biology of the threatened golden galaxias, <em>Galaxias auratus</em> Johnston 1883 (Galaxiidae) and the influence of lake hydrology</td>
<td>96</td>
</tr>
<tr>
<td>6.1. Abstract</td>
<td>96</td>
</tr>
<tr>
<td>6.2. Introduction</td>
<td>97</td>
</tr>
<tr>
<td>6.3. Materials and methods</td>
<td>100</td>
</tr>
<tr>
<td>6.4. Results</td>
<td>111</td>
</tr>
<tr>
<td>6.5. Discussion</td>
<td>125</td>
</tr>
<tr>
<td>Chapter</td>
<td>Title</td>
</tr>
<tr>
<td>---------</td>
<td>----------------------------------------------------------------------</td>
</tr>
<tr>
<td>7</td>
<td>Spawning-related fungal infection of golden galaxias, <em>Galaxias auratus</em> (Galaxiidae)</td>
</tr>
<tr>
<td></td>
<td>7.1. Abstract</td>
</tr>
<tr>
<td></td>
<td>7.2. Introduction</td>
</tr>
<tr>
<td></td>
<td>7.3. Materials and methods</td>
</tr>
<tr>
<td></td>
<td>7.4. Results</td>
</tr>
<tr>
<td></td>
<td>7.5. Discussion</td>
</tr>
<tr>
<td>8</td>
<td>Recruitment dynamics of a non-diadromous lacustrine galaxiid fish: the roles of water level fluctuations and habitat availability</td>
</tr>
<tr>
<td></td>
<td>8.1. Abstract</td>
</tr>
<tr>
<td></td>
<td>8.2. Introduction</td>
</tr>
<tr>
<td></td>
<td>8.3. Materials and methods</td>
</tr>
<tr>
<td></td>
<td>8.4. Results</td>
</tr>
<tr>
<td></td>
<td>8.5. Discussion</td>
</tr>
<tr>
<td>9</td>
<td>General Discussion</td>
</tr>
<tr>
<td></td>
<td>9.1. Conservation of the golden galaxias and other lacustrine galaxiids</td>
</tr>
<tr>
<td></td>
<td>9.2. Management strategies and further research</td>
</tr>
<tr>
<td>References</td>
<td></td>
</tr>
<tr>
<td>Appendices</td>
<td></td>
</tr>
</tbody>
</table>
Preface: Threatened fishes of the world: *Galaxias auratus*

**Johnston, 1883 (Galaxiidae)**


**Common name:** Golden galaxias.

**Conservation status:** Rare – (Tasmanian Threatened Species Protection Act 1995); Endangered – (2003); Endangered – (Commonwealth Environment Protection and Biodiversity Conservation Act 1999).

**Identification:** D 7-10, A 11-12, P 14-18, vertebral count 53-56 (McDowall & Frankenberg, 1981). Small scaleless salmoniform fish, maximum size: 240 mm TFL, 130 g (Hardie, 2003). Colouration: golden to olive-green on dorsal surface and sides, silvery-grey on ventral surface. Back and sides are covered with round to oval black spots (McDowall & Frankenberg, 1981) (Fig. 1).

**Fig. 1.** Golden galaxias (*Galaxias auratus*). Drawing by Carol Kroger in Fulton (1990).
**Distribution:** Endemic to the interconnecting lakes Crescent and Sorell and their associated creeks and wetlands in the headwaters of the Clyde River catchment central Tasmania, Australia. Two translocated populations were established in farm dams in the Clyde River catchment, between 1996 and 1998. Currently, only four breeding populations exist including two natural and two translocated populations.

**Abundance:** Natural populations in lakes Crescent and Sorell are currently abundant, although relative abundance differs significantly between the two with the Lake Crescent population being an order of magnitude greater than the Lake Sorell population. The two translocated populations of golden galaxias are currently abundant (Hardie, 2003).

**Habitat and ecology:** A non-diadromous species preferring lentic waters. Adults frequently feed in the water column but tend to be benthic and prefer the shelter of rocky lake shores, in-lake macrophyte beds and wetland habitat. The adult diet consists of aquatic and terrestrial insects, small crustaceans, molluscs and cannibalism of eggs and juvenile fish is common (Hardie, 2003). Juveniles are pelagic and feed on zooplankton and small insect larvae (Frijlink, 1999).

**Reproduction:** Spawning takes place in late autumn – winter on rocky shores and possibly in wetland habitat when available (Hardie, 2003). Spawning occurs at approximately 4°C (range 2-7°C) and appears to be triggered by rising lake levels. Fecundity ranges from 1000 to 15 000 eggs. Fertilised eggs are ~1.5 mm in diameter, transparent and adhesive. Spawned eggs are scattered over cobble substrate or aquatic vegetation at a depth of 200-600 mm. Fertilized eggs are thought to incubate for 30-45 days in the wild. Larval hatching peaks
during late winter – early spring. Newly hatched larvae are 5-7 mm in length and are pelagic until 4-5 months of age (40 mm TFL).

**Threats:** Low water levels in lakes Crescent and Sorell are the primary threat to natural populations of golden galaxias (Hardie, 2003). In Lake Crescent, low water levels can de-water rocky shorelines which are a critical habitat for spawning and refuge. Competition and predation from introduced fish is also a significant threat. Four introduced species currently inhabit lakes Crescent and Sorell (*Salmo trutta, Oncorhynchus mykiss, Cyprinus carpio* and *Galaxias maculatus*). Brown trout are known to predate heavily on golden galaxias in both lakes (Stuart-Smith, 2001).

**Conservation action:** The golden galaxias is protected under State legislation and may only be collected under permit. The findings of the recent work of Hardie (2003) have been incorporated into a water management planning process for lakes Crescent and Sorell and have also provided baseline data for future monitoring of populations. The translocated population of golden galaxias in the Jericho area has been formally reserved.

**Conservation recommendations:** The significance of adjacent wetlands and in-flowing creeks and their associated wetlands needs to be determined. Wild and translocated populations of golden galaxias should continue to be monitored on an annual basis.

**Remarks:** Water level management, including the allocation of water to maintain base ‘environmental’ levels in lakes Crescent and Sorell, is critical to the survival and health of natural populations of golden galaxias.
1. General Introduction

1.1. Conservation of freshwater fishes

Freshwater fishes are increasingly being considered threatened at regional (Bruton, 1990; Moyle, 1995; Fu et al., 2003) and international (Cambray & Giorgio Bianco, 1998) levels. In order to maintain their associated fishery resources, aquatic biodiversity, and the health of the systems which they inhabit, freshwater fish conservation has been recognised as an important action globally (Lowe-McConnell, 1990; Cowx & Collares-Pereira, 2002). A broad range of threats, which are mostly linked to anthropogenic impacts and biological invasions, increase the vulnerability of fishes (Bruton, 1995). Additionally, rare species which have restricted distributions, occur infrequently or have low abundances, are often at greater risk of extinction (Economidis, 2002; Fagan et al., 2002). Recent studies (Angermeier, 1995; Parent & Schriml, 1995; Duncan & Lockwood, 2001; Reynolds et al., 2005) have tried to determine if phylogeny and life history traits of freshwater fishes correlate with extinction risk; however, their results have been largely inconclusive. Whilst some biological and ecological attributes, such as small size (Reynolds et al., 2005) and diadromy (Angermeier, 1995), do increase the risk of extinction, identification of extrinsic factors which affect families or individual species is paramount to their conservation (Duncan & Lockwood, 2001).

Strategies to manage threatened species take many forms and include population monitoring, risk assessments, habitat restoration and reservation, captive propagation, and translocation of taxa. Techniques to monitor wildlife populations are needed to estimate abundance and guide decisions regarding their management (Hauser et al., 2006). Additionally, knowledge of the biology and ecology of target species is essential to their conservation as these data underpin methods used to assess status (IUCN, 2003), identify threats and facilitate recovery. Recently, management of threatened taxa has shifted from the traditional single-species focus to multi-
species approaches due to the inclusion of increasing numbers of taxa on threatened species lists, and the economic and resource constraints of management agencies. Species-specific biological understanding is often limited under multi-species recovery plans in comparison to those for single species (Clark & Harvey, 2002). However, data for well studied species can provide insight into the biological attributes and key threats of other closely related taxa, which have yet to be examined.

Knowledge of population dynamics and relationships between species and their habitats is required to perform quantitative risk assessments (Lindenmayer & Burgman, 2005). Such data often exist prior to the decline of commercially exploited species, but for taxa like small-sized freshwater fishes which are of no commercial or recreational value, these data are usually scarce. The life histories of many fishes rely on the spatial and temporal alignment of access to certain habitats. Therefore, the lack of favourable habitats for different life stages can have significant consequences for fish populations (Naiman & Latterell, 2005). In modified environments, this variability may be the primary threat to populations. Thus, identification of biology-habitat linkages can aid conservation efforts (Rosenfeld & Hatfield, 2006).

1.2. Galaxiid fishes and the golden galaxias

Fish of the salmoniform family Galaxiidae are relatively small (adults generally <300 mm long), scaleless and often cryptic (McDowall & Frankenberg, 1981). They occupy freshwater and estuarine environments in mostly cool temperate regions on several land masses in the Southern Hemisphere, but are particularly prominent in the freshwater fish faunas of southern Australia and New Zealand (McDowall & Fulton, 1996; McDowall, 2000). Members of the family, of which there are around 50 species, exhibit both diadromous and non-diadromous
life histories. This enables them to occupy a diverse range of habitats. Whilst some migratory species contribute to regional whitebait fisheries (McDowall & Fulton, 1996; McDowall, 2000), most galaxiid species are not of recreational or commercial value and more than 50% of species are threatened (i.e. protected under legislation in their region(s) of occurrence or listed on conservation awareness lists) (McDowall, 2006).

Despite the broad distribution of the family, particularly some species (e.g. Galaxias maculatus Jenyns (Waters & Burridge, 1999)), many non-diadromous species have highly restricted distributions. Several galaxiid species only occur in a single river system or a few lentic waters. Similar to many small-sized endangered fishes, galaxiids face threats from exotic species, particularly those associated with introduced salmonids which have been well documented (Tilzey, 1976; Crowl et al., 1992; Ault & White, 1994; McIntosh, 2000; McDowall, 2003). However, anthropogenic alterations of their habitats are also likely to have contributed to the decline of some galaxiids, and data regarding these impacts are limited (Hanchet, 1990; Eikaas & McIntosh, 2006). For example, impoundment can dramatically alter hydrological regimes and habitat landscapes in natural lentic waters that are occupied by lacustrine galaxiids. However, at present little is known of the roles of hydrological variables in the life histories of galaxiids or the strategies by which they use different habitats.

The island of Tasmania, southern Australia, has a diverse galaxiid fauna, with 16 species, of which 11 are endemic. Seven endemic non-migratory species occur in discrete populations in highland lakes and lagoons in the central highland district known as the Tasmanian Central Plateau (TCP). Six of these species occur in lakes that have been impounded during the past century for hydro-electric power generation and municipal and agricultural water storage purposes. Despite conservation efforts under multi-species recovery plans (Crook & Sanger, 1997; Threatened Species Section, 2006), some Tasmanian lacustrine species (e.g. Galaxias
pedderensis Frankenberg (Hamr, 1995) and Paragalaxias mesotes McDowall and Fulton (Threatened Species Section, 2006)) in impounded lakes have recently undergone significant declines. Whilst there is conjecture surrounding the reasons for this, a lack of biological and ecological data and effective population monitoring methods for these and other local species make management and recovery of their populations difficult.

The golden galaxias, Galaxias auratus Johnston, is a typical example of a localised lacustrine galaxiid (Fig. 1). This species is endemic to the interconnected Lake Crescent and Lake Sorell (Fig. 2) in the south-east of the TCP in the upper reaches of the Clyde River catchment (McDowall & Fulton, 1996). These shallow lakes (mean depths <3.5 m) are very similar chemically and physically and have been impounded for agricultural and municipal water storage purposes. Since being described over 120 years ago (Johnston, 1883), the biology of G. auratus has remained largely unstudied. In Australia, this species is listed under State and national threatened species legislation, but unlike many threatened galaxiids, and despite predation from introduced salmonids (Stuart-Smith et al., 2004), wild populations of G. auratus are abundant and juvenile and adult fish are reasonably easy to collect (Fig. 3). Two translocated ‘refuge’ populations of G. auratus have also recently been established in nearby, small off-stream agricultural water storages (Hardie, 2003), one of which is also relatively abundant. For these reasons, G. auratus is a good model species to use to investigate population monitoring methods for threatened lacustrine galaxiids and the biology and ecology of these fishes in waters that have altered hydrology.
**Fig. 1.** Female *Galaxias auratus* (183 mm fork length). This individual has well developed gonads; thus, the abdominal wall is reasonably distended.

**Fig. 2.** View from a north-western shore of Lake Sorell looking south towards Table Mountain during 2000.
Fig. 3. Hauling a catch of *Galaxias auratus* in a fine-meshed fyke net in Lake Sorell during 2000 (samplers: Scott Hardie (left), Brett Mawbey (right)). Overnight fyke netting was the main technique used to sample juvenile and adult fish in this study.

1.3. Lakes, littoral habitats and hydrology

Water level fluctuations are an important hydrological variable in lacustrine systems, particularly as they control the availability and condition of habitats in littoral areas (Gasith & Gafny, 1990). Many lacustrine fishes use littoral habitats at some stage of their life cycle (e.g. for spawning or during a juvenile phase (Winfield, 2004a)); therefore, access to these areas can greatly influence fish production (Gafny *et al.*, 1992; Rowe *et al.*, 2002b). Anthropogenic manipulation of water levels in impounded natural lentic waters (i.e. natural lakes that have been dammed for water storage purposes) can alter the timing, magnitude, duration and periodicity of fluctuations. For these reasons, alterations to hydrological regimes are likely to be a major threat to some freshwater fishes. Additionally, fish play important ecological roles in lake ecosystems, particularly as many species pass through a zooplanktivorous stage during their ontogeny (Winfield, 2004b). Their ontogenetic habitat shifts can link different areas of
lakes by providing pathways for energy flow between habitats (Schindler & Scheuerell, 2002; Vander Zanden & Vadeboncoeur, 2002). Therefore, if fish are reliant upon certain hydrological conditions and the habitats they provide to complete their life cycle, lake hydrology may also indirectly control connectivity between littoral, pelagic and benthic habitats.

Lakes high in the local hydrological landscape (e.g. highland lakes) often have relatively small catchments and, thus, receive a greater proportion of their water from precipitation than lakes lower in the hydrological landscape (Warren & French, 2001). Because the hydrology of these systems depends heavily on local climatic conditions, these waters can be greatly influenced by climatic extremes, such as droughts. Whilst some researchers have documented the affects of droughts on riverine fishes (Matthews & Marsh-Matthews, 2003), few have investigated the response of lacustrine fishes to these events. In southern Australia, one of the main drivers of climatic variability is the El Niño Southern Oscillation (ENSO) (Kershaw et al., 2003). The periodic occurrence of El Niño-induced droughts causes high temporal variability in the hydrological regimes of rivers in the region (McMahon & Finlayson, 2003). Coupled with increasing demands for water resources, El Niño-induced droughts may represent a significant threat to the freshwater fish fauna of southern Australia. Therefore, knowledge of the processes by which these events affect fish populations is needed, particularly for species with restricted distributions where refuge habitats may be scarce or unavailable.

1.4. Research objectives and approach

The objective of this thesis was to examine the crucial aspects of the biology and ecology of *G. auratus* that are likely to be vulnerable to the two main anthropogenic disturbances in lakes
Sorell and Crescent: (1) changes in habitat quality and quantity that are associated with altered water levels, and (2) predation and competition from introduced salmonids. By studying this species, I hoped to gain insight into the ecological attributes of other threatened galaxiids, threats to this family and other similar small-sized lentic species.

I focused on the likely stages of this species’ life cycle and their habitat associations using data for other lacustrine galaxiids as a guide (Fig. 4). A field-based (rather than a laboratory-based) approach that involved examining all five suspected life stages of *G. auratus* (see Fig. 4) was taken by studying wild populations in lakes Crescent and Sorell. Over a temporal scale of several years (up to 5 years for some data), *G. auratus* populations were subject to seasonal hydrological and climatic cycles which allowed the roles of these factors to be explored. However, at a smaller spatial and temporal scale, a translocated population of *G. auratus* in an agricultural water storage was used to evaluate methods to monitor populations as this small closed system enabled more robust comparisons to be made.

The approach I used for this research followed a logical series of steps which helped develop the concepts for each chapter of this thesis. Firstly, due to a lack of information regarding the Tasmanian galaxiid fauna, I reviewed its status and identified threats and knowledge gaps using existing literature (Chapter 2). This highlighted the lack of data regarding the life cycles and habitat requirements of the Tasmanian fauna and illustrated the significance of the non-migratory species which inhabit highland lakes on the TCP. Secondly, because several population sampling methods are routinely used to monitor galaxiid populations in lentic waters but none had been formally evaluated, I conducted a study to do this using a translocated population of *G. auratus* (Chapter 3). Thirdly, I focused on the wild *G. auratus* populations in lakes Crescent and Sorell and sampled them intensively (i.e. principal sampling
at monthly intervals) over 2.5 years, to examine: i) seasonal variation in catches (Chapter 4),
ii) age and growth, and population structure (Chapter 5), iii) reproduction (Chapter 6) and its
associated mortality (Chapter 7), and iv) recruitment dynamics (Chapter 8). During this time, I
also identified and surveyed the littoral spawning habitats of *G. auratus* in Lake Crescent
which have a limited extent. This exercise showed that the availability of this critical habitat
is heavily influence by water level fluctuations in Lake Crescent, whereas in Lake Sorell,
access to this habitat is not reliant upon hydrology. Because of these findings, I continued to
monitor the recruitment of these populations for a further 2.5 years (5 breeding seasons in
total) to examine the roles of hydrology and habitat availability (Chapter 8).

1.5. Thesis structure and format

The structure of this thesis reflects the logical approach followed for this research.
Consequently, chapters are presented in a sequence which allows them to build upon the
findings of previous ones and, in some cases, investigate previously posed questions. All
chapters, which vary in length, have been prepared as papers for publication in scientific
journals; some have been published, accepted or submitted for publication and others have not
yet been submitted. Because of this formatting and the multiple use of sampled material (i.e.
fish specimens) and other data (e.g. water levels), there is some repetition within the chapters.
However, each chapter has a unique focus and seeks to address a different set of aims which
relate to the conservation biology of *G. auratus*. 
Fig. 4. Five typical stages in the life cycle of a non-diadromous lacustrine galaxiid and the main habitats used during each stage based on published data for other similar species (Pollard, 1971; Humphries, 1989; Rowe & Chisnall, 1996a; Barriga et al., 2002; Rowe et al., 2002a; Morgan, 2003). The relative proportion of time each life stage occupies the three habitats is represented by the position of the horizontal bars.