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Conservation Biology of the Golden Galaxias
(*Galaxias auratus*) (Pisces: Galaxiidae)

Scott Anthony Hardie

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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June 2007

Statement of Co-authorship

The following people and institutions contributed to the publication (or submission for publication) of some of the work undertaken as part of this thesis:

- Preface Candidate*† (96%), Leon A. Barmuta (2%), Robert W. G. White* (2%)
- Chapter 2. Candidate*† (82%), Jean E. Jackson† (6%), Leon A. Barmuta* (10%), Robert W. G. White* (2%)
- Chapter 3. Candidate* (82%), Leon A. Barmuta* (14%), Robert W. G. White* (4%)
- Chapter 4. Candidate*† (85%), Leon A. Barmuta* (13%), Robert W. G. White* (2%)
- Chapter 6. Candidate*† (85%), Leon A. Barmuta* (13%), Robert W. G. White* (2%)
- Chapter 7. Candidate*† (80%), Stephen B. Pyecroft‡ (10%), Leon A. Barmuta* (8%), Robert W. G. White* (2%)

**School of Zoology and Tasmanian Aquaculture and Fisheries Institute, University of Tasmania, Private Bag 5, Hobart, Tasmania 7001, Australia*

†Inland Fisheries Service, PO Box 288, Moonah, Tasmania 7009, Australia

‡Animal Health Laboratory, Department of Primary Industries and Water, PO Box 46, Kings Meadows, Tasmania 7249, Australia

L.A.B. supervised the administration of these studies, helped develop the key concepts, and assisted with data analyses for each paper. R.W.G.W. helped refine the content of these papers. J.E.J. and S.B.P. contributed to the development of the content of Chapters 2 and 7, respectively, and S.B.P. also provided laboratory assistance for Chapter 7.

We the undersigned agree with the above stated “proportion of work undertaken” for each of the above published (or submitted) peer-reviewed manuscripts contributing to this thesis:

Signed:

Dr Leon A. Barmuta

Dr Susan M. Jones

Supervisor

Head of School

School of Zoology & TAFI

School of Zoology

University of Tasmania

University of Tasmania

Date: June 2007

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.

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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.

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Preface: Threatened fishes of the world: *Galaxias auratus*

Johnston, 1883 (Galaxiidae)*

*Published as Hardie S.A., Barmuta L.A. & White R.W.G. (2004) in *Environmental Biology of Fishes* 71, 126.

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).

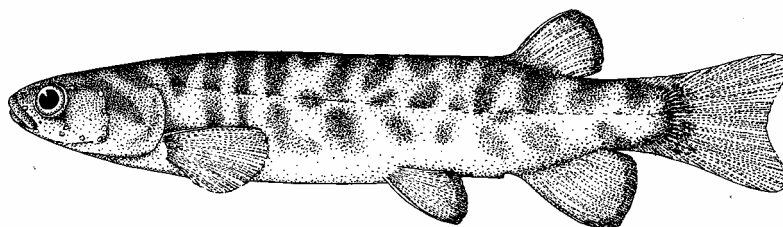


Fig. 1. Golden galaxias (*Galaxias auratus*). Drawing by Carol Kroger in Fulton (1990).

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. Spawning 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*.

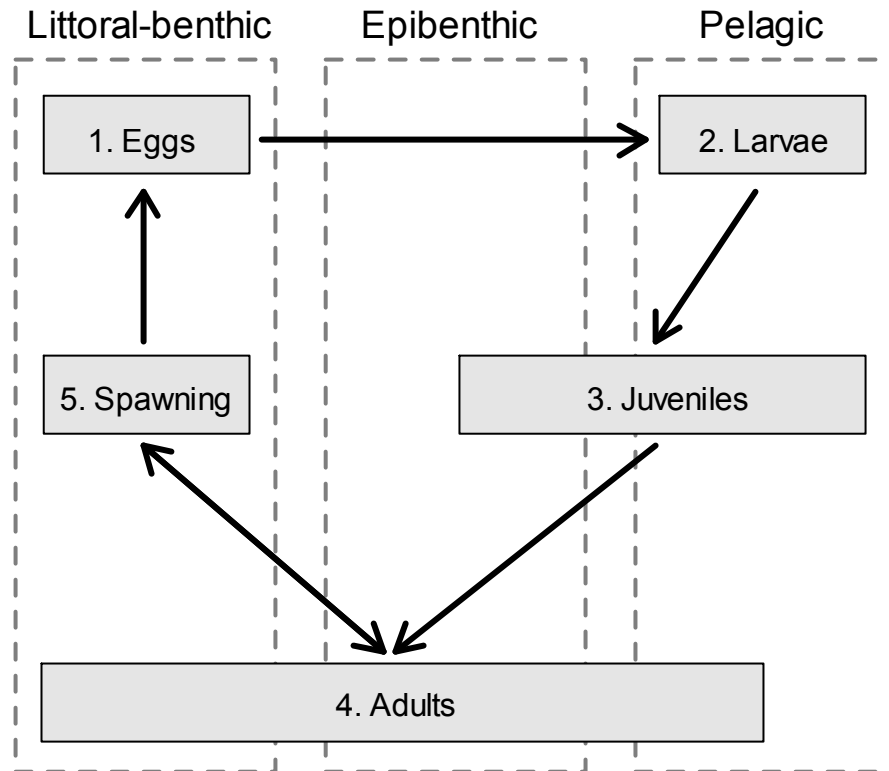


Fig. 4. Five typical stages in the life cycle of a non-diadromous lacustrine galaxiid and the main habitats used during each stage based on published data for other similar species (Pollard, 1971; Humphries, 1989; Rowe & Chisnall, 1996a; Barriga *et al.*, 2002; Rowe *et al.*, 2002a; Morgan, 2003). The relative proportion of time each life stage occupies the three habitats is represented by the position of the horizontal bars.