



# Current Status and Ecology of the Golden Galaxias (*Galaxias auratus*)

*Rehabilitation of Lakes Sorell and Crescent Report Series*

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Natural Heritage Trust

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AQUATIC FAUNA

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# **Current Status and Ecology of the Golden Galaxias (*Galaxias auratus*)**

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**Integrated and multi-disciplinary approach to the  
rehabilitation of Lakes Sorell and Crescent**

Scott A. Hardie

**Inland Fisheries Service**

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This report is part of a series of documents, which provide management recommendations for the environmental requirements of lakes Sorell and Crescent as part of the Lakes Sorell and Crescent Rehabilitation Project.

The aim of the rehabilitation project is to obtain an understanding of the systems, identify the needs of the users of the lakes and subsequently provide recommendations for the future management and protection of these important ecosystems.

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## Executive Summary

A decline in the trout fishery, water quality and ecological values of lakes Sorell and Crescent has occurred over the past few years. In light of these problems, the Inland Fisheries Service (IFS) secured State and Commonwealth (Natural Heritage Trust) funding to implement on-ground works and formulate management options to address the recent environmental decline. The key problem associated with the lakes is low water levels due primarily to drought conditions and competition for water by various users. A multi-disciplinary project was adopted to address the situation – the *Lakes Sorell and Crescent Rehabilitation Project*. This project was comprised of ten sub-projects targeting key areas of physical and biological importance to the functioning and management of lakes Crescent and Sorell. The ten sub-projects were:

- Lake Crescent Outflow Screen Duplication
- Mountain Creek Rehabilitation
- Catchment Management Plan
- Water Management Plan
- Water Quality
- Wetlands
- Aquatic Fauna
- Recreational Fisheries
- Carp Management
- Ecological Modelling

This report outlines some of the findings and management recommendations for the *Aquatic Fauna Sub-project*.

The aquatic fauna of lakes Crescent and Sorell thought to be of particular importance, in terms of the health of the aquatic eco-systems and conservation value, were populations of the ‘rare’ and endemic freshwater fish, golden galaxias (*Galaxias auratus*), and the macroinvertebrate communities of both lakes. It was suspected prior to the project that the recent decline in the environmental condition of lakes Crescent and Sorell had adversely impacted on these faunal components of the lakes.

The *Aquatic Fauna Sub-project* of the *Lakes Sorell and Crescent Rehabilitation Project* involved studying the ecology and current status of populations of *G. auratus* and also the current status of macroinvertebrate communities in lakes Crescent and Sorell. The project also focused on defining the threatening processes which these fauna are facing.

This report, ‘Current Status and Ecology of the Golden Galaxias (*Galaxias auratus*)’, documents the results of the work that was undertaken on *G. auratus* during the *Aquatic Fauna Sub-project* and details recommendations for the future management of this species. The results of the macroinvertebrate study are documented in a separate report (Hardie 2003).

Several **studies based on the ecology of *G. auratus*** were undertaken to:

- assess the current status and distribution of wild and translocated populations of *G. auratus* in the Clyde River catchment focusing on populations in lakes Crescent and Sorell,
- gain an understanding of the life cycle and biology of *G. auratus* in lakes Crescent and Sorell,
- assess the feasibility of breeding *G. auratus* in captivity,
- determine if competition for food resources occurs between *G. auratus* and juvenile brown trout (*Salmo trutta*),
- determine the effect of lake level on *G. auratus* in lakes Crescent and Sorell,
- identify threatening processes to *G. auratus* in lakes Crescent and Sorell,
- investigate techniques to estimate abundance and biomass of *G. auratus* populations in lakes Crescent and Sorell,
- establish future long term monitoring regimes for *G. auratus* populations and
- produce a report detailing the ecology and current status of *G. auratus* populations and recommendations for maintaining and enhancing the distribution, structure and abundance of populations.

*G. auratus* is a relatively small (grows to 240 mm, commonly 150 mm) but quite unique Tasmanian native fish species. It is a typical example of an endemic Tasmanian galaxiid species, being confined to a relatively small geographical region and only a few water bodies. *G. auratus* is endemic to the interconnecting lakes Crescent and Sorell and their associated streams and wetlands on the south-eastern corner of the Tasmanian Central Plateau.

Given the restricted distribution and threats that *G. auratus* populations are facing, this species has significant conservation status. *G. auratus* is currently listed as 'rare' under the Tasmanian *Threatened Species Protection Act 1995* and 'endangered' on the International Union for Conservation of Nature and Natural Resources (IUCN) Red List.

The natural distribution of *G. auratus* is currently confined to the main bodies of lakes Crescent and Sorell. The recent period of below average rainfall and varied rainfall patterns has caused near record low water levels in both lakes, inconsistent flows in in-flowing creeks and the de-watering of adjacent wetlands. These alterations to the Crescent-Sorell system have decreased the amount and diversity of habitats currently available to *G. auratus* populations.

Populations of *G. auratus* in lakes Crescent and Sorell were found to be reasonably abundant, however abundance differed significantly between the two lakes. The *G. auratus* population in Lake Crescent was found to be approximately 10 fold greater in abundance than the population in Lake Sorell. The difference in abundance is thought to be primarily due to the difference in abundance of the salmonid populations in each lake applying different competition and predation pressures.

Although *G. auratus* populations in both Lake Crescent and Lake Sorell appear to be relatively abundant it is difficult to compare the current status of these populations to their historical status, as data in this area is purely anecdotal. It is suspected that the abundance (density) of fish is similar (probably slightly reduced), but the actual size of the populations is much less due to the reduction in the amount of available habitat and a decrease in the diversity of habitat that is available to this species.

As a result of the translocation program that was undertaken by the Inland Fisheries Service (IFS) between 1996-1998, two translocated populations of *G. auratus* also occur in farm dams in the Clyde River catchment. These populations, located on the Rotherwood property and the Interlaken Estate, are currently abundant and appear to be self-sustaining.

On-ground works were undertaken during this project, with the aid of external funding from Greening Australia, to protect the translocated population of *G. auratus* located on the Rotherwood property. A 17 ha area surrounding the dam and its catchment were fenced, alternative stock watering facilities were installed and a weed eradication/control program commenced. The property owner/manager also entered into a Conservation Management Agreement with the State Government of Tasmania to formally reserve this important area.

In general, the life cycle and ecology of *G. auratus* was found to be similar to other non-diadromous (landlocked) galaxiid species. However, the timing of the spawning period of *G. auratus* is quite unique. *G. auratus* were found to spawn in late autumn – winter. This varies considerably from the spring-time spawning of other non-diadromous galaxiid species.

A brief **summary of the ecology of *G. auratus*** follows:

Adult fish begin to develop gonad mass in early summer, with the development period following a decrease in day length and water temperature. Male fish reach sexual maturity in their first year (>50 mm total fork length (TFL)) and females in their second (>70 mm TFL). Spawning takes place in late autumn – winter on rocky shores and possibly wetland habitat when available. Spawning occurs at a water temperature of approximately 4°C (range 2-7°C) and appears to be triggered by rising water levels and a slight increase in water temperature. Females have a high fecundity with the number of eggs varying from 1000 – 15,000 eggs depending on the size of fish. Fertilised eggs are 1.5 mm in diameter and are transparent. Spawning eggs adhere to rocky substrate (aquatic vegetation may also be used when available) in 300-600 mm of water. Eggs incubate for approximately 30-45 days. Newly hatched larvae are 5-6 mm (TFL) and are pelagic, feeding on plankton and small insect larvae in the mid to upper water column.

Juvenile fish remain in the water column until they reach approximately 40 mm (TFL), where they begin to move inshore to benthic habitats. Juvenile fish grow to approximately 60 mm (TFL) by the end of their first year. Adult fish are more benthic and prefer rocky shore habitat, however they are opportunistic feeders and utilise both substrate and water column based food resources. Adult fish feed on aquatic and terrestrial insects, small crustaceans and molluscs.

Cohorts ranging from 0+ to 4+ dominate wild populations of *G. auratus* and hence most fish live for 3 to 4 years, although some reach greater than 6 years of age. Female fish grow larger and possibly live longer than males. Female fish are also more abundant than male fish in wild populations.

Captive breeding trials were largely successful in determining appropriate methods for the reproduction of *G. auratus* in a captive environment. Stripping of ripe *G. auratus* adults was found to be an effective method to fertilise eggs. *G. auratus* eggs collected in the wild were also successfully incubated until hatching. The length of the incubation period of *G. auratus* eggs in captivity was 55-65 days at a water temperature of 4-5° C. Rearing the newly hatched larvae was found to be the most difficult component of the trials due to the need for sufficient quantities of appropriately sized food. Cultures of suitable planktonic food are recommended for future work in this area.

Juvenile brown trout (*Salmo trutta*) were found to compete for both food resources and habitat with adult *G. auratus* in Lake Sorell, although there was strong evidence suggesting that these species have different dietary preferences. Both fish prefer rocky shore habitat for feeding and shelter, although *G. auratus* appear to be more adaptable to other habitats and feeding strategies. It is suggested that adult *G. auratus* may be forced into other habitats and feeding strategies by the more aggressive juvenile *S. trutta*.

Fyke netting was found to be the most effective technique for sampling *G. auratus*, particularly for collecting samples for biological analysis. A sampling regime involving in-lake seine netting in combination with shore based fyke netting was found to be the best option for performing quantitative population estimations of *G. auratus*.

The **main threats** to wild populations of *G. auratus* are:

- low water levels in lakes Crescent and Sorell, causing:
  - decrease in in-lake habitat diversity which affects *G. auratus* habitat and its food resources
  - reduction in availability of rocky shore habitat in Lake Crescent, which is the preferred habitat of this species for feeding, shelter and spawning
  - decrease in water quality which can result in fish kills related to respiration problems
  - reduced habitat diversity and availability which increases competition with other fish species and the risk of predation from salmonids

- alteration to habitats also impacts on invertebrate communities (food resources)

**Other general threats** to *G. auratus* include impacts associated with:

- competition and predation from introduced fish such as salmonids and carp
- draining and grazing of adjacent and associated wetlands which has the potential to damage habitat and decrease habitat availability
- risk of translocations of introduced fauna associated with the recreational use of the lakes

In light of the significant findings of the ecological research that has been undertaken on *G. auratus* and the threatening processes that have been identified, several management issues have been highlighted. A brief summary (see section 5 for more detail) containing **9 key recommendations** for the management of *G. auratus* follows:

1. Historical seasonal cycles in the water level regimes of lakes Crescent and Sorell should be altered as little as possible. Sudden decreases in water level, >600 mm, between May and September should not occur in either Lake Crescent or Lake Sorell, as this will de-water incubating *G. auratus* eggs.
2. Lakes Crescent and Sorell should be managed at mid to high water levels to protect habitat diversity and ensure good water quality. Water levels in Lake Crescent should be managed above 802.20 m AHD, which is a critical level for *G. auratus* spawning during late autumn - winter. The minimum frequency for Lake Crescent to have a water level below 802.20 m AHD during late autumn – winter, is 1 in every 3 years. This is however a high risk strategy which may have long term impacts on the structure and abundance of the *G. auratus* population.
3. The salmonid and eel populations in lakes Crescent and Sorell should be managed at abundances that are comparable to historical levels. Varying salmonids stocking rates to suit water level - dependent habitat availability for *G. auratus* populations should be considered.
4. Carp eradication work should continue to use methods that minimise the risk of *G. auratus* bi-catch. If the Carp Control/Eradication Program does remove all carp from the Crescent-Sorell system then the containment screens should be removed to allow *G. auratus* to move downstream of Lake Crescent and between the two lakes.
5. Forestry operators (via the Forestry Practices Board) should seek advice from the IFS of the potential impacts associated with forestry operations within the catchment of lakes Crescent and Sorell, particularly those that are in close proximity to waterbodies.
6. The formal reservation of all wetlands located on Crown land associated with lakes Crescent and Sorell should be pursued to protect *G. auratus* habitat. Land owners in the catchment of lakes Crescent and Sorell, particularly those that own wetland and/or lake shore areas, should be encouraged to reserve these areas of land.

7. *G. auratus* should be included in a state-wide public information and education campaign to increase the profile of Tasmania's threatened freshwater fish, and in particular to raise awareness amongst users of lakes Crescent and Sorell about the significance of the *G. auratus* populations.
8. Wild and translocated populations of *G. auratus* and populations of the introduced native fish, *G. maculatus*, in lakes Crescent and Sorell should continue to be monitored. *G. maculatus* has the potential to impact on *G. auratus* populations if it becomes fully established.
9. The influence of higher water levels in lakes Crescent and Sorell on the abundance, distribution and life cycle of *G. auratus* populations should be examined as well as the relationship between the abundance of salmonid and *G. auratus* populations.

## Acknowledgments

Many people provided valuable support and advice during the *Aquatic Fauna Sub-project* and made significant contributions towards the work undertaken on the golden galaxias (*Galaxias auratus*) and this report.

Several people from the Inland Fisheries Service (IFS) are thanked. John Diggle managed the project and gave valuable advice that helped direct the project. Warwick Nash also guided the project and assisted in the design of fish sampling methodologies. Jenny Deakin provided water level and metrological data at regular intervals during the study and also helped direct the project. Adam Uytendaal and Danielle Heffer were fantastic Project Officers to work with and gave valuable support and encouragement in the areas of project management, field work, data analysis and reporting of results. Brett Mawbey assisted in a large proportion of the field and laboratory work. Brett also gave technical support and advice in regard to the husbandry of native fish, galaxiid captive breeding techniques and methods used for field work. Brett's guidance based on his extensive knowledge of the Interlaken area was also much appreciated. Helen Mulcahy and Keith Breheny also provided technical support. Members of the IFS Carp Management and Recreational Fisheries teams also gave support in the field.

Dr Jean Jackson (IFS) supervised the initial *G. auratus* population monitoring which was undertaken by the IFS between October 1998 and November 1999. Jean also provided valuable feed-back in regard to the results obtained during this project. Captive breeding trials were conducted in conjunction with other galaxiid captive breeding trials being supervised by Jean. Andrew Harvey and Paul Voss (IFS) also provided technical support during the captive breeding trials.

Several people were involved in the establishment of the *G. auratus* translocation program. Andrew Sanger and Wayne Fulton (IFS) were supportive of the concept and managed the program in its early stages. Richard Morrison, David Andrews and Chris Wisniewski (IFS) assisted during the initial surveying of potential translocation sites.

The translocation program could not have been conducted without the assistance of several property owners/managers in the Clyde River catchment and for this Jim McShane (Rotherwood property), Alan Jarvis and Steve Lovell (Interlaken Estate), Andrew Downey and Pat Branch (Serat property) are thanked. Alan Jarvis and Steve Lovell allowed the IFS to access Interlaken Estate to monitor the translocated population. Special thanks goes to Jim McShane and family for generously allowing the IFS to utilise a portion of their property to establish and manage a translocated population of *G. auratus*. Their decision to properly reserve the area around the dam and enter into a Conservation Management Agreement with the state government will help the long term survival of this fish species. Jim also put in a considerable amount of time and effort towards the establishment of the reserve. The McShane family is also thanked for their kind hospitality to IFS staff during the project.

Ron Mawbey (Aquenal) provided inspiration and useful information from his extensive knowledge of Interlaken area.

Tom Sloane (SSS Wildlife Services) identified the diet items of *G. auratus* and helped define the feeding strategies being employed by the wild populations of *G. auratus*.

The work that was undertaken on *G. auratus* was conducted in accordance with the terms of an Inland Fisheries Service Exemption Permit (IFS Permit Number 2000/31 and PWS Permit Number TFA00022) and conditions of the Department of Primary Industries Water and Environment Animal Ethics Committee (DPIWE AEC certificate number 20/2001-2002). The work was funded by the Inland Fisheries Service and the Natural Heritage Trust.

## Abbreviations

### *Acronyms*

AEC	Animal Ethics Committee
AHD	Australian Height Datum
DPIWE	Department of Primary Industries, Water and Environment
IFS	Inland Fisheries Service
IUCN	International Union for Conservation of Nature and Natural Resources
NTU	Nephelometric Turbidity Units
PWS	Parks and Wildlife Service
SL	Standard Length
TLF	Total Fork Length

### *Terminology*

Integrated and multi-disciplinary approach to the rehabilitation of Lakes Sorell and Crescent

*Lakes Sorell and Crescent Rehabilitation Project*

The 'Aquatic Fauna Sub-project' of the Lakes Crescent and Sorell Rehabilitation Project

*Aquatic Fauna Sub-Project*

The 'Water Quality Sub-project' of the Lakes Crescent and Sorell Rehabilitation Project

*Water Quality Sub-Project*

The 'Wetlands Sub-project' of the Lakes Crescent and Sorell Rehabilitation Project

*Wetlands Sub-project*

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# 1. Introduction

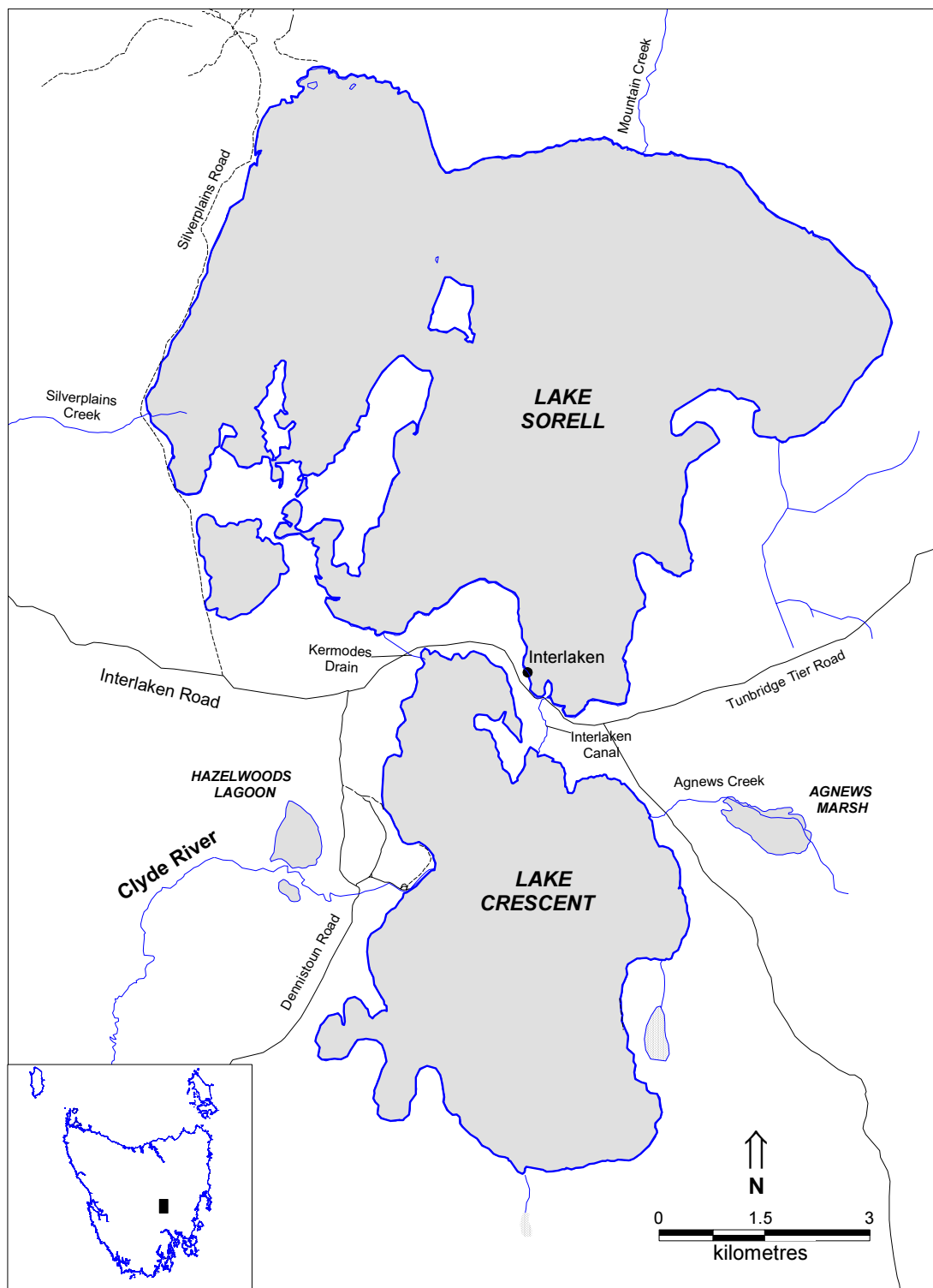
## 1.1 Lakes Crescent and Sorell

The golden galaxias (*Galaxias auratus*) is endemic to the lakes Crescent-Sorell system, with the main bodies of these two lakes providing the stronghold for the species. The biological research that has been undertaken on *G. auratus* during this study and management recommendations that have been made, focus on the wild populations of this species in lakes Crescent and Sorell.

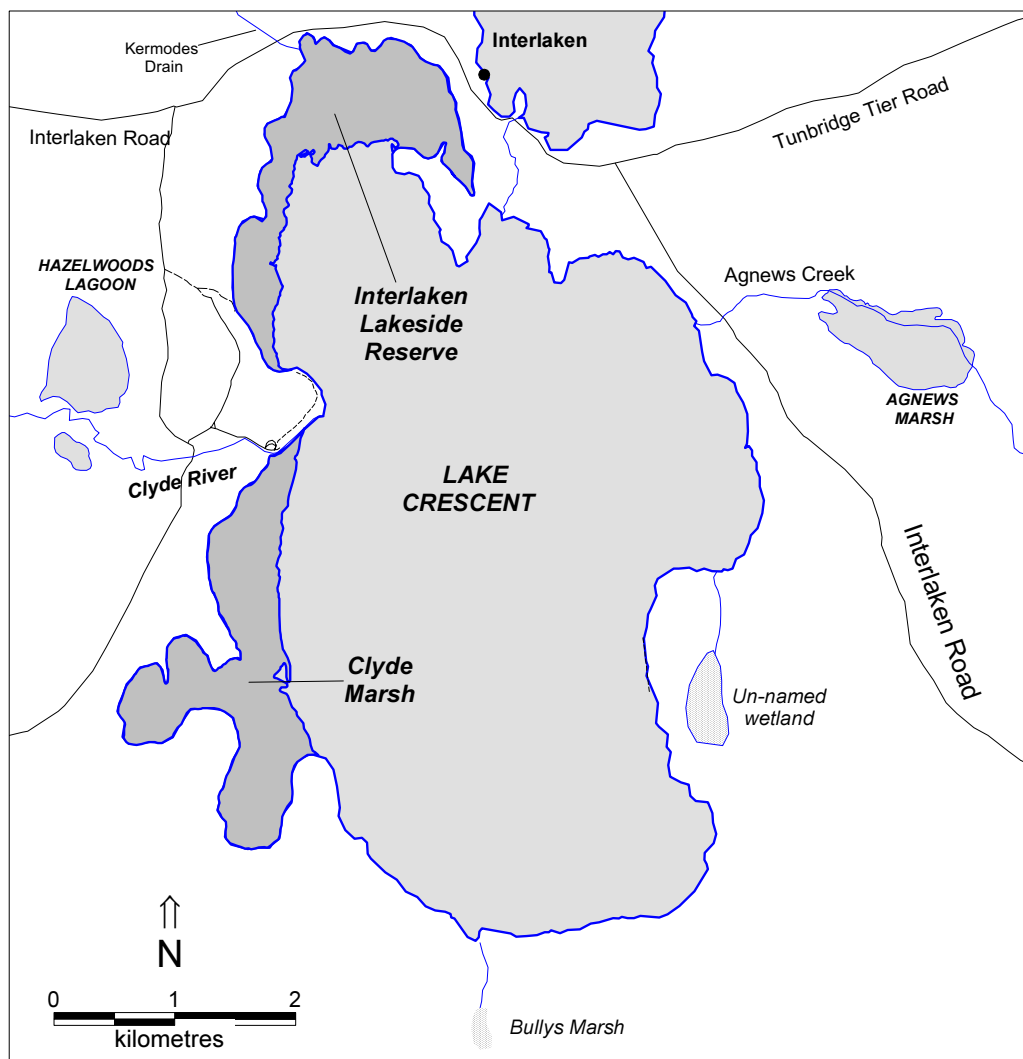
Lakes Crescent and Sorell lie approximately 1 km apart and are situated at approximately 800 m AHD on the south-eastern corner of the Tasmanian Central Plateau (Figure 1). In comparison to most lakes in Tasmania, lakes Crescent and Sorell are quite large (surface areas of 23 and 50 km<sup>2</sup>, respectively), relatively shallow (average depths of 1.5 and 2.5 m at full supply levels, respectively) and are exposed to strong wind action and are turbid. Lakes Crescent and Sorell are very similar, physically and chemically and are located in an area of uniform geology, climate, soils and vegetation (Cheng & Tyler 1976b). The lakes are located on an extensive plateau of Jurassic dolerite but Tertiary basalt and sandstone outcrop around both lakes and there are sandy dunes and beaches on the eastern shores (Cheng & Tyler 1973b). Dry sclerophyll forests dominate the Crescent-Sorell catchment although there is some forestry and grazing of sheep and cattle in semi-cleared farmland areas.

The physico-chemical properties, nutrient and trophic status, plankton populations and primary productivity of lakes Crescent and Sorell have previously been described in detail (Buckney 1976; Cheng & Tyler 1973a, b, 1976a, b). Despite physical and chemical similarities, plankton communities were found to vary markedly between the two lakes (Cheng & Tyler 1973b). The trophic status of these lakes also differs with Lake Sorell being regarded as mesotrophic and Lake Crescent moderately eutrophic (Cheng & Tyler 1976b). Uytendaal (2003) has monitored and investigated processes that influence water quality in lakes Crescent and Sorell during 2000-2002 as a part of the *Water Quality Sub-project* of the *Lakes Sorell and Crescent Rehabilitation Project*.

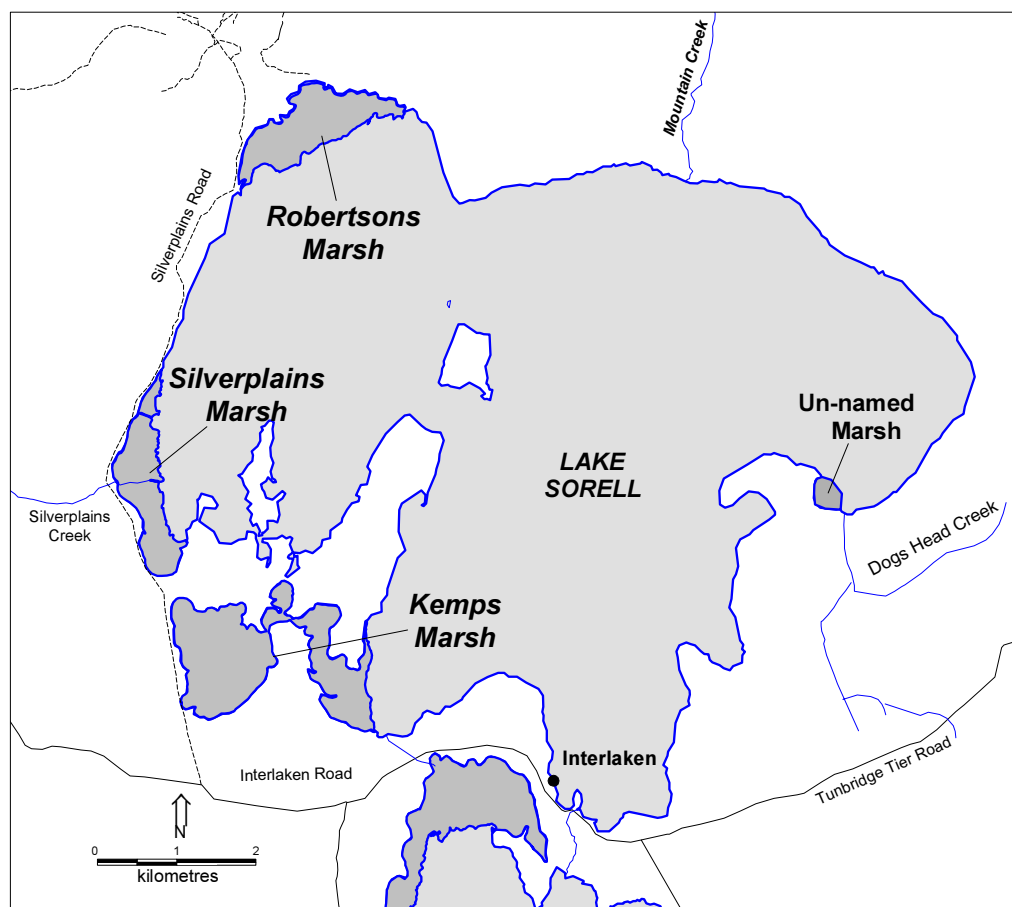
Extensive adjacent wetland areas connect to the main body of lakes Crescent and Sorell during periods of high water levels (Figures 2 and 3). These wetlands are some of the largest areas of shallow freshwater marsh in Tasmania (Kirkpatrick & Tyler 1988). The wetlands account for 7.8 % (385 ha) and 17 % (415 ha) of the surface area of lakes Crescent and Sorell, respectively (Heffer 2003). These wetlands provide important habitat for *G. auratus* as well as a diverse range of animals such as invertebrates (including the endemic snail *Austropyrgus* sp), frogs (with populations of the threatened southern bell frog (*Litoria raniformis*) previously recorded), snakes, waterbirds, platypus and water rats. The aquatic vegetation of these wetlands has previously been briefly surveyed as a part of a large-scale study of macrophyte communities in wetlands across Tasmania (Kirkpatrick & Harwood 1981, 1983). The *Wetlands Sub-project* of the *Lakes Sorell and Crescent Rehabilitation Project* has surveyed the aquatic vegetation of the Crescent-Sorell wetlands in detail during 2000-2002 (Heffer 2003).



**Figure 1.** Map of the location of lakes Crescent and Sorell.



**Figure 2.** Map of Lake Crescent wetlands.



**Figure 3.** Map of Lake Sorell wetlands.

For the purpose of this study the Lake Crescent and Lake Sorell areas were defined as all lands and waters contained within the full supply levels of the lakes and all lands and waters within 100 m of the full supply levels. Wetlands of note within the Lake Crescent area are Clyde Marsh and the Ramsar listed Interlaken Lakeside Reserve (Figure 2). These wetlands connect to the main body of Lake Crescent at lake levels above 802.7 and 802.8 m AHD, respectively (Heffer 2003). Other creeks and wetlands associated with Lake Crescent which may provide habitat for *G. auratus* include Agnews Creek and Agnews Marsh on the eastern shore of Lake Crescent, the creek flowing out of Bullys Marsh (southern shore) and the unnamed wetland and its out-flowing creek (eastern shore).

Wetlands of note within the Lake Sorell area are Kemps/Kermodes Marsh, Silver Plains Marsh and Robertsons Marsh (Figure 3). These wetlands connect to the main body of Lake Sorell at lake levels above 803.6 m AHD (Heffer 2003). Another smaller unnamed wetland exists in Powells Bay near the mouth of Dogs Head Creek (locally known as Powells Marsh). The three main in-flowing creeks of Lake Sorell are Mountain Creek (northern shore), Silver Plains Creek (western shore) and Dogs Head Creek (eastern shore).

During this study, lakes Sorell and Crescent were in a state of severe environmental degradation. Since 1997, the lakes have experienced near record-low water levels causing a significant deterioration in water quality (particularly very high water turbidity) and also a decrease in habitat diversity. Low lake levels have caused all of the wetland areas to be de-watered and permanently disconnected from the main body of the lakes for an extended period. Consequently, the habitat provided by the extensive marsh areas have essentially been removed from the Crescent-Sorell system. Likewise, low water levels have caused a decrease in the amount of rocky littoral habitat in the main body of both lakes. It also appears that in-lake macrophytes have decreased in abundance due to the high turbidity levels and severe wind action that have persisted in both lakes in recent years. In general, habitats that have been lost or significantly reduced include in-lake macrophyte beds, adjacent wetlands and rocky and sandy shorelines.

## 1.2 Fish Fauna

Six species of fish currently inhabit lakes Crescent and Sorell. Two of these six species are native; short-finned eel (*Anguilla australis*) and golden galaxias (*Galaxias auratus*). The remaining four species are introduced (brown trout (*Salmo trutta*), rainbow trout (*Oncorhynchus mykiss*), European carp (*Cyprinus carpio*) and common galaxias (*Galaxias maculatus*) which is a non-indigenous native species (see Appendix 1 for descriptions of fish other than *G. auratus*). The fish communities in lakes Crescent and Sorell are typical of many lakes on Tasmania's Central Plateau, with populations of indigenous galaxiids co-existing with introduced salmonids. An exception to the typical structure of the fish communities is the presence of *C. carpio* which is only found in lakes Crescent and Sorell in Tasmania.

*G. auratus* (see section 1.3) and *A. australis* (Family Anguillidae) are the only indigenous species present in the fish communities of lakes Crescent and Sorell. The ancestors of *G. auratus* are thought to have invaded the precursors of lakes Crescent

and Sorell up to 100,000 years ago (Ovenden *et al.* 1993). It is speculated that *A. australis* have also inhabited lakes Crescent and Sorell for a similar period, during which time both species have evolved to co-exist. *A. australis* populations in these lakes have supported a commercial eel fishery since 1965. The eel fishery is currently managed by the IFS under the *Inland Fisheries Act 1995* and relies on the annual stocking of elvers. Eels are currently harvested from the lakes using a combination of fyke netting and migratory traps.

*S. trutta* and *O. mykiss* (both Family Salmonidae) were introduced into lakes Crescent and Sorell in 1868 and 1922, respectively. *S. trutta* dominate the salmonid populations in both lakes with an abundant population of medium sized fish (average weight 0.8 – 1.5 kg) in Lake Sorell and a smaller population of larger fish (average weight 2.0 – 4.0 kg) in Lake Crescent (IFS unpublished data). In the past, these lakes supported two of Tasmania's most popular and productive trout fisheries. In recent years, the state of the salmonid fisheries in both lakes has declined along with the health of the lake ecosystems. The salmonid fisheries are managed by the IFS, with self-sustaining populations in Lake Sorell while populations in Lake Crescent are supplemented by periodic stocking.

*C. carpio* (Family Cyprinidae) were discovered in lakes Crescent and Sorell in 1995 and are thought to have been introduced into the lakes during the mid 1980's. *C. carpio* are listed as a noxious fish species in Tasmania due to it's ability to breed prolifically and dominate fish communities and their destructive bottom feeding behaviour which is known to degrade water quality and aquatic habitats. Since the discovery of *C. carpio* in lakes Crescent and Sorell, the IFS has been managing the lakes under the *Inland Fisheries Act 1995* in consultation with the other stakeholders. A control and eradication program has also been implemented. Populations of *C. carpio* are currently very small in both lakes (P. Donkers pers. comm.).

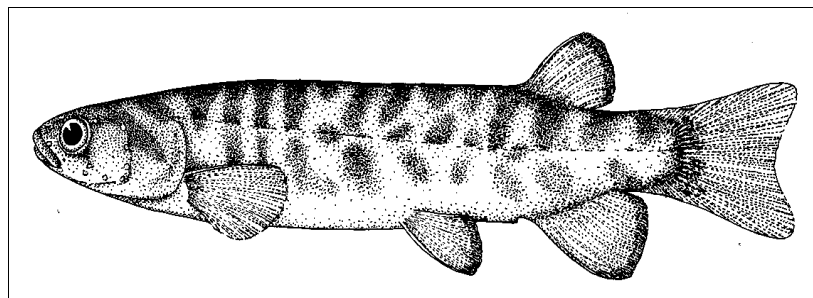
*G. maculatus* (Family Galaxiidae) were first discovered in lakes Crescent and Sorell in January 2000. This species, which is common to coastal waterways of Tasmania, is thought to have been accidentally translocated into the lakes. Populations appear to be very small and at this stage there is no evidence that they are self-sustaining.

### 1.3 Golden galaxias (*Galaxias auratus*)

#### 1.3.1 Description and Distribution

The golden galaxias (*Galaxias auratus*) (Family Galaxiidae) has a restricted natural distribution, being endemic to the interconnecting lakes Crescent and Sorell and their associated streams and wetlands. It is a typical example of an endemic Tasmanian galaxiid species, being confined to a relatively small geographical region and only a few water bodies. It is a relatively small fish that grows to approximately 240 mm in length but is commonly found to 150 mm. In comparison to other fish of the Galaxiidae family, *G. auratus* is one of the largest species. *G. auratus* closely resembles the more widespread, spotted galaxias (*G. truttaceus*) and is thought to be a land-locked derivative of the ancestral version of this species (Johnson & White 1981; Johnson *et al.* 1981; Ovenden & White 1990; Ovenden *et al.* 1993).

Adult fish are streamlined but have a stout body shape with well developed fins that are thick and fleshy at the base and a slightly fork-shaped tail (McDowall 1996) (Figure 4). Juveniles have a very slender shape and are transparent until a few months of age, when they obtain a pale green–yellow colour. Juvenile fish begin to develop adult colouration at about 30-40 mm in length (Frijlink 1999). Adult fish are golden to olive-green on the back, paling to bronze-gold on the sides and silver grey on the belly. Back and sides are covered profusely with round to oval black spots. Fins are amber to pinkish orange in colour with black fringes on dorsal, anal and pelvic fins (McDowall 1996) (Appendix 2 – Picture 1).



**Figure 4.** Adult golden galaxias (*Galaxias auratus*) (Fulton 1990).

### 1.3.2 Biology and Habitat

The life history of the golden galaxias (*Galaxias auratus*) has not been studied in great detail to date, with no publications on the subject. An honours thesis recently completed by Frijlink (1999) has outlined the early life history and development of *G. auratus*. The IFS has anecdotal knowledge of the behaviour of *G. auratus* during various components of their life cycle and also holds some population monitoring data which was collected between October 1998 and November 1999.

*G. auratus* is known to complete its entire life cycle in freshwater, preferring still water environments, although it is thought to move up in-flowing creeks during periods of consistent flows (Fulton 1990). Rocky shores are thought to be the preferred habitat of adult fish and spawning has been reported to occur in this habitat during spring, with eggs being laid on rocks in shallow water (Fulton 1990). Newly hatched larvae are elongate, transparent, approximately 7 mm in length and pelagic, feeding on plankton in the water column (Frijlink 1999). A peak in larval hatching has been reported to occur between September and October (Frijlink 1999).

Anecdotal accounts of habitats occupied by *G. auratus* suggest that vegetated areas, both in-lake and marsh areas, also provide important habitat for this species (J. Diggle and R. Mawbey pers. comm.). These areas are thought to have been used for a combination of shelter, feeding and spawning.

### 1.3.3 Threats

Possible threats to golden galaxias (*Galaxias auratus*) populations in lakes Crescent and Sorell include loss of habitat and poor water quality caused by low lake levels, predation from salmonids and the potential impact of the recent introduction of European carp (*Cyprinus carpio*).

In the past, significant intermittent mortality events of *G. auratus* have been reportedly occurring approximately every three to four years. Pathological investigations identified 'gill erosion' as the cause of death, linking the deaths to high water turbidity (IFC 1994). The current decline in water quality, particularly the extremely high turbidity levels, are thought to be a possible catalyst for fish kills of *G. auratus* in the future.

The distribution and abundance of several species of galaxiids has been shown to decrease due to the introduction of salmonids into their habitat (Ault & White 1994; Jackson 1981; Jackson & Williams 1980; McIntosh *et al.* 1994; Tilzey 1976). *G. auratus*, however, appears to have been able to maintain a high abundance in both lakes in spite of predation and competition from salmonids for more than a century (McDowall 1996). Surveys conducted by the then Inland Fisheries Commission in 1986 and 1992/3 in lakes Crescent and Sorell, respectively, illustrated the dietary significance of *G. auratus* in salmonids (IFC unpublished data). This was particularly evident in Lake Crescent, where *S. trutta* were found to feed almost exclusively on *G. auratus*, resulting in an exceptionally high growth rate.

### 1.3.4 Conservation Status

Golden galaxias (*Galaxias auratus*) populations in both lakes Crescent and Sorell are thought to have remained reasonably abundant during the recent drought period (IFS unpublished data). However, the threatening processes both populations are facing, the lack of ecological data on the species and their restricted distribution has led to their threatened conservation status at State and International levels. *G. auratus* is currently listed as 'rare' under the Tasmanian *Threatened Species Protection Act 1995* and 'endangered' on the IUCN Red List (ASFB 2001).

## 1.4 Management of Threatened Freshwater Fish in Tasmania

The freshwater fish fauna of Tasmania consist of 25 species of native fish and a further 8 introduced species (Fulton 1990). Eleven of the native fish species found in Tasmania's inland waters have significant conservation status and are listed at varying levels (Appendix 3). Fish belonging to the family Galaxiidae dominate the fish fauna of Tasmania with 15 galaxiid species occurring in the island state (60% of native species) and of these, 10 species are endemic to Tasmania. All endemic galaxiid species have significant conservation status and are listed at State level under the Tasmanian *Threatened Species Protection Act 1995*. Four species are also listed at the Commonwealth level under the *Environment Protection and Biodiversity Conservation Act 1999*.

The IFS is responsible for the conservation and management of Tasmania's native fish fauna under the *Inland Fisheries Act 1995* while the DPIWE also has responsibility under the *Threatened Species Protection Act 1995*. An example of the work that the IFS has recently undertaken in regard to native fish management is the Galaxiid Recovery Program (Crook & Sanger 1997). Since 1998, this project has involved monitoring populations, undertaking research where necessary and implementing on-ground works to ensure the survival of 5 of Tasmania's threatened endemic galaxiid species (J. Jackson pers. comm.).

The establishment of translocated populations and captive breeding trials are two management strategies commonly employed when dealing with threatened fish species. These management techniques have been successfully used to ensure the survival of species which have suffered a serious decline in the size of their wild populations. A translocated population is defined as a population that has been established through stocking, in an area outside of its natural distribution range. Captive breeding involves either the use of artificial reproduction techniques and/or holding fish (broodstock) in a captive environment and allowing natural spawning to take place. An example of the use of these two management strategies in Tasmania is the IFS recovery program for the Pedder galaxias (*Galaxias pedderensis*) (Crook & Sanger 1997; Threatened Species Unit 1998).

The golden galaxias (*Galaxias auratus*) is a typical example of a threatened galaxiid species in Tasmania, having a restricted distribution of a small number of populations which are facing threats from introduced fish and alterations to the natural water level regimes of their habitat. *G. auratus* is protected under State threatened species legalisation – the Tasmanian *Threatened Species Protection Act 1995* and the *Inland Fisheries Act 1995*.

The findings of this study have broad implications for the management of threatened freshwater fish in Tasmania. This project has substantially added to the scientific community's understanding of Tasmanian endemic galaxiid species and has increased the efficiency of population monitoring and management techniques.

#### **1.4.1 Previous Management of Golden galaxias (*Galaxias auratus*)**

Since the discovery of European carp (*Cyprinus carpio*) in lakes Crescent and Sorell in 1995, the Inland Fisheries Service (IFS) has undertaken action directed towards the formal management of golden galaxias (*Galaxias auratus*).

To prevent the potential loss of wild populations and safeguard the survival of the species, the Inland Fisheries Service (IFS) initiated a translocation program during 1996. This program aimed to establish translocated populations of *G. auratus* in farm dams in the Clyde River catchment so that a viable supply of broodstock would be available should the populations in lakes Crescent and Sorell suffer serious declines. The initial work undertaken in the translocation program has been followed-up during this study and all works are documented in this report.

Another part of the IFS Native Fish Recovery Program included bi-monthly *G. auratus* population abundance, in-lake distribution and recruitment sampling, between October 1998 and November 1999. The data obtained from this work has been incorporated and analysed in this study.

## 1.5 Objectives

The *Aquatic Fauna Sub-project* has examined the current status and ecology of the 'rare' freshwater fish, golden galaxias (*Galaxias auratus*). The project has also focused on defining the threatening processes this species is currently facing in Lake Crescent and Lake Sorell. This report documents all of the work that has been undertaken on *G. auratus* during the *Aquatic Fauna Sub-project* (and previous work on the species by the IFS) and details recommendations for the future management of the species.

Several studies based on the ecology of *G. auratus* were undertaken to:

- assess the current status and distribution of wild and translocated populations of *G. auratus* in the Clyde River catchment focusing on populations in lakes Crescent and Sorell,
- gain an understanding of the life cycle and biology of *G. auratus* in lakes Crescent and Sorell,
- assess the feasibility of breeding *G. auratus* in captivity,
- determine if competition for food resources occurs between *G. auratus* and juvenile brown trout (*Salmo trutta*),
- determine the effect of lake level on *G. auratus* in lakes Crescent and Sorell,
- identify threatening processes to *G. auratus* in lakes Crescent and Sorell,
- investigate techniques to estimate abundance and biomass of *G. auratus* populations in lakes Crescent and Sorell,
- establish future long term monitoring regimes for *G. auratus* populations and
- produce a report detailing the ecology and current status of *G. auratus* populations and recommendations for maintaining and enhancing the distribution, structure and abundance of populations.

## 2. Methodology

### 2.1 Climatic Conditions

J. Deakin (Inland Fisheries Service (IFS)) provided rainfall data for the Interlaken area. Data was collated from several sources including the IFS, Hydro Tasmania, Bureau of Meteorology, Department of Primary Industry, Water and Environment (DPIWE) and private landowners, R. Bowden (Cluny property, Bothwell) and A. Jarvis (Interlaken Estate, Interlaken).

### 2.2 Physico-chemical Water Parameters

In-lake water temperatures in both Lake Crescent and Lake Sorell were measured using Optic StowAway Temperature loggers (Model WTA). Temperature loggers were deployed at the mid-water water sampling site in each lake (Uytendaal 2003) and data was down-loaded at bi-monthly intervals.

Turbidity data was provided by (Uytendaal 2003). See Uytendaal (2003) for methodology.

### 2.3 Habitat Mapping

A survey of the rocky shore habitat in Lake Crescent was conducted during March 2002. The survey aimed to identify and map the extent of rocky habitat and determine the effect of lake level on rocky habitat availability. Survey work involved locating the edge of the rocky habitat and measuring the water depth (cm) at intervals of approximately 100 m along the shorelines using a global positioning system (GPS), 1 m rule and a tape measure. The lake level was recorded on each day of the survey and was used as the reference level. The survey data was used to produce a map of the rocky shore habitat in Lake Crescent.

### 2.4 Golden Galaxias Distribution Surveys

The natural distribution of the golden galaxias (*Galaxias auratus*) was investigated during the study by surveying the tributaries and associated wetlands of lakes Crescent and Sorell. Surveys were carried out during periods of stable flow and wetland inundation between September 2000 and June 2002. All connecting waterbodies were surveyed on at least one occasion. The presence or absence of *G. auratus* in waterbodies was determined using a backpack electro-fisher (Smith and Root 12-B POW), Freshwater Biological Association (FBA) nets (250 µm mesh) and visual observation where appropriate.

The tributaries surveyed included the in-flowing Mountain Creek, Silver Plains Creek and Dogs Head Creek of Lake Sorell (Figure 3), and the in-flowing Agnews Creek, Bullies Marsh Creek and the out-flowing Clyde River of Lake Crescent (Figure 2). Wetlands that were surveyed included all wetlands that are adjacent to lakes Crescent and Sorell (Clyde Marsh, Interlaken Lakeside Reserve, Kemps Marsh, Silver Plains

Marsh and Robertsons Marsh) as well as associated wetlands such as Lagoon Plain, Hazelwoods Lagoon, Bullies Marsh, Agnews Marsh and an un-named wetland near Boat House Shore.

The historical distribution of *G. auratus* in the upper Clyde River catchment was examined by identifying and surveying suitable habitats and collating anecdotal accounts of their past distribution.

## 2.5 Fish Sampling Regimes

### 2.5.1 Life History and Population Structure

Golden galaxias (*Galaxias auratus*) life history and population structure sampling was conducted monthly over a 25 month period, between July 2000 and July 2002. Fish were collected at 3 littoral sites in each lake (Figures 5 and 6), on each sampling occasion. The sampling sites were spatially distributed across each lake and consisted of 500 m transects along shorelines that represented one of the 3 dominant littoral habitats in each lake at the time of the study.

The Lake Crescent sampling sites and the habitats they represented were:

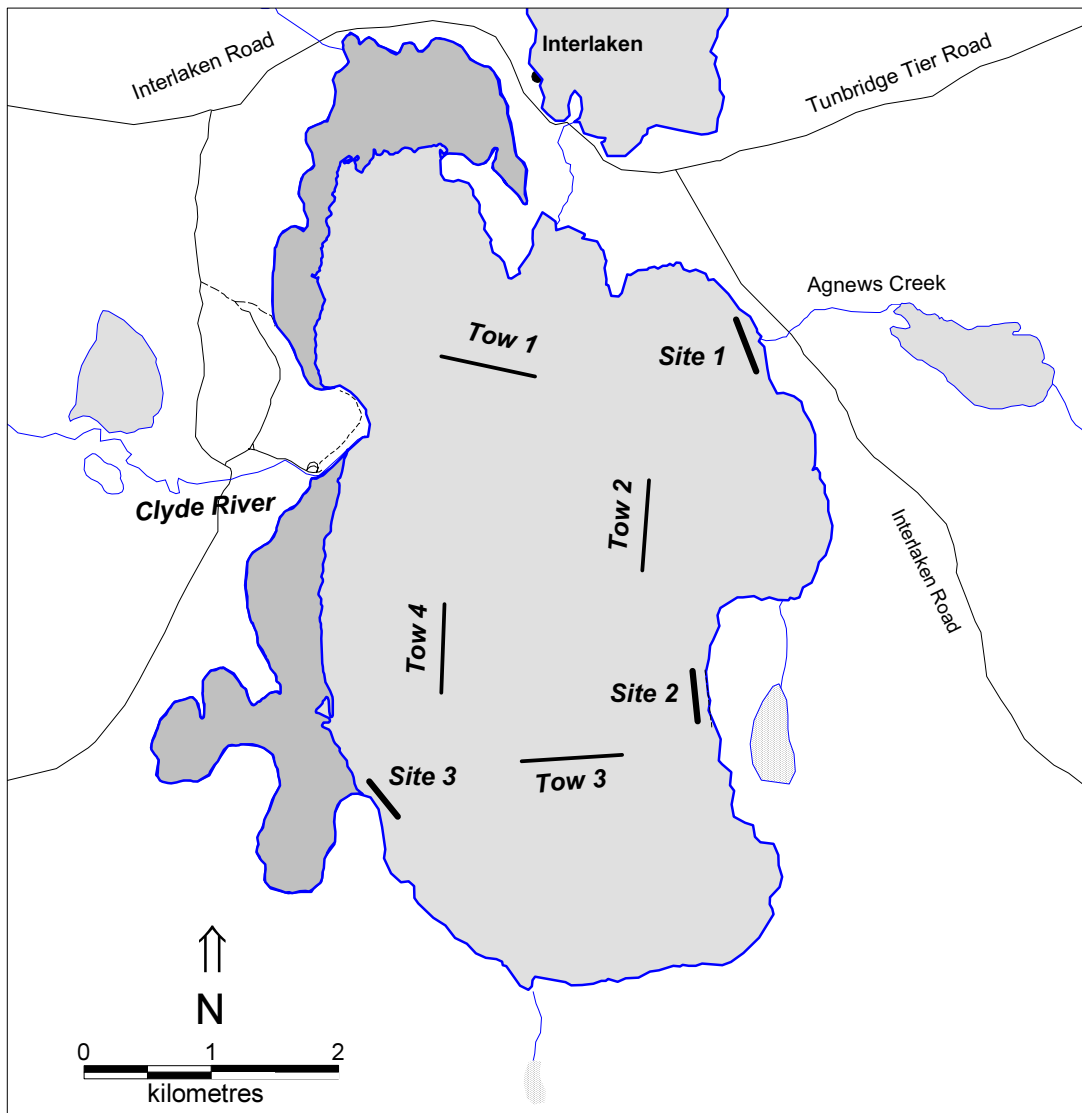
1. sandy shore near Agnews Creek mouth = fine sand
2. Boathouse Shore = cobble rock
3. Jacks Point = degraded marsh area that was dominated by muddy sediment

The Lake Sorell sampling sites and the habitats they represented were:

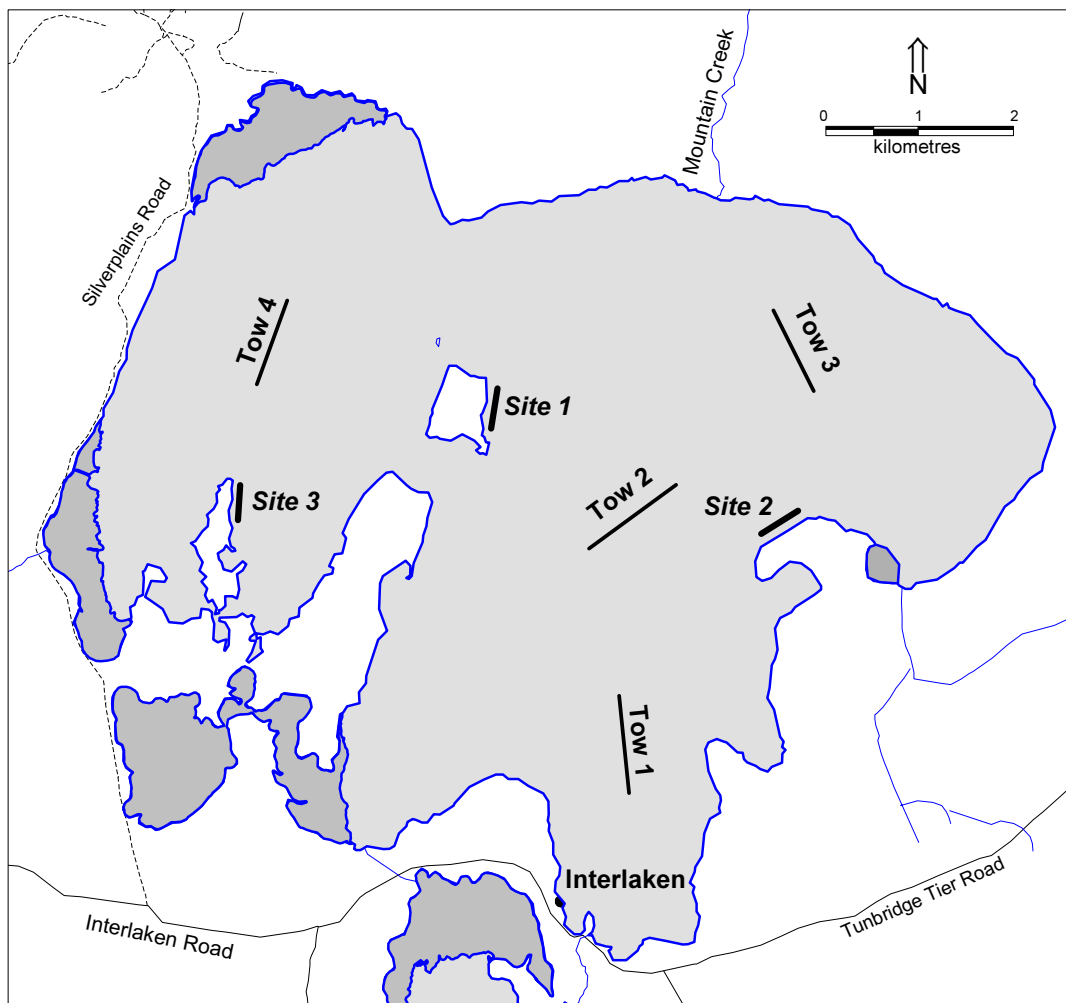
1. St Georges Island = fine sand
2. Dogs Head = cobble rock
3. Grassy Point = mixture of sediment and some cobble rock

On the first 3 sampling occasions (July-September 2000) fish were sampled by electrofishing 100 m of shoreline at each site with a backpack electro-fisher. On the remaining sampling occasions fish were sampled using 4 single wing (3 m wing (x2) and 5 m wing (x2)) fine mesh fyke nets (2 mm stretched mesh) at each site. All nets had an 84 x 70 mm aluminium platypus screen in the entrance to the cod bag.

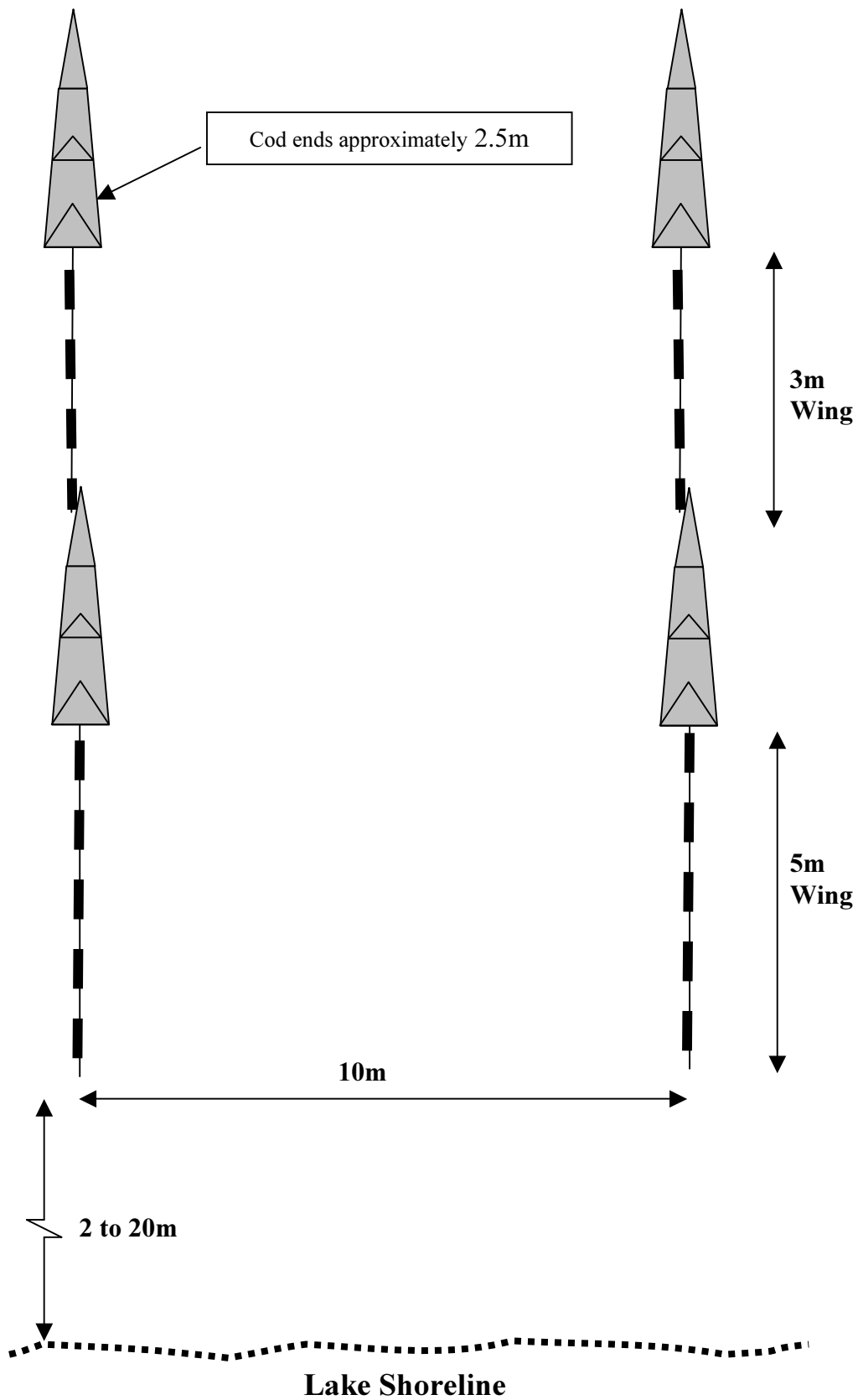
Fyke nets were set in the same manner at each site on each sampling occasion (Figure 7). An area of approximately 20 x 20 m was randomly selected along the site transect. Nets were positioned in two tandem sets of a 5 and a 3 m wing net, at 90° to the shoreline. The 5 m wing nets were set closest to the shore with the cod ends set away from shore, 3 m wing nets were set behind with a 1.0 m overlap. Nets were generally set at depths <1.0 m and secured using either wood stakes or 2 kg lead weights and floats. Fyke nets were set late in the afternoon and retrieved the following morning (average of 18 hrs).



**Figure 5.** Map of Lake Crescent *Galaxias auratus* sampling sites.



**Figure 6.** Map of Lake Sorell *Galaxias auratus* sampling sites.



**Figure 7.** Orientation of fyke net sets used to sample *Galaxias auratus*.

### 2.5.2 Recruitment

Recruitment was studied by sampling golden galaxias (*Galaxias auratus*) larvae and juveniles in the water column of each lake. Sampling was conducted monthly over a 25 month period, between July 2000 and July 2002. Fish were collected at 4 tow sites spatially distributed across each lake (Figures 5 and 6), on each sampling occasion (except August 2000 in Lake Crescent due to equipment failure). Fish were sampled using a specially designed conical plankton net (400 mm diameter, 1.25 m tail with 500 µm mesh). The plankton net was towed at each site for 10 min approximately 15 m behind a boat at a speed that ensured the net was sampling the top 1 m of the water column. During the summer and autumn of 2001, lake levels were very low so to ensure the plankton net kept clear of the lake bottom, two 200 mm diameter polystyrofoam floats were attached to the outer rim of the tow net. The presence or absence and relative abundance of larvae in the tows was used to identify spawning and hatching periods and study the growth of juvenile fish.

### 2.5.3 Population Estimation

Techniques to estimate the size and biomass of golden galaxias (*Galaxias auratus*) populations in Lakes Crescent and Sorell were investigated. Fyke and seine netting and electro-fishing techniques and regimes were trialed to determine methods that could be used to quantitatively sample *G. auratus* across various habitats.

## 2.6 Definition and Monitoring of Spawning Sites

The location of golden galaxias (*Galaxias auratus*) spawning sites was investigated in lakes Crescent and Sorell during the 2000-02 spawning periods (autumn–spring months). Littoral areas were searched by observing different substrates such as rock, woody debris and macrophytes. Freshwater Biological Association (FBA) nets (250 µm mesh) were used to perform sweeps over substrates such as rock, sediment and sand, that had been disturbed by foot. Spawning habitat was defined and the environmental conditions that trigger spawning, including physico-chemical water parameters, lake levels and weather conditions, were investigated. The length of the egg incubation period in the wild and the fate of spent fish was also investigated.

Once the preferred spawning habitat had been defined, a monitoring site was established in each lake (sampling site 2 in each lake, Figures 5 and 6). These sites were surveyed approximately fortnightly for *G. auratus* eggs during the 2001 and 2002 spawning periods. Sampling involved 30 sweeps of a 250 µm mesh FBA net for 30 seconds at each site. The contents of the net after each sweep were observed with the naked eye and the number of *G. auratus* eggs present was counted. The total number of eggs observed at each site on each sampling occasion was recorded. The number of eggs observed was used as a relative estimate of the number of eggs currently incubating at the site. On each sampling occasion a sub-sample of up to 50 eggs were preserved in 70 % ethanol for laboratory analysis of the stage of development.

## 2.7 Field Recording and Processing

Golden galaxias (*Galaxias auratus*) and other fish species sampled during the study were anaesthetised in a clove oil-based anaesthetic solution (Aqui-s). During the monthly population structure sampling, the total number of fish captured at each site was recorded. Where large numbers of fish were captured ( $> \sim 500$ ), the total catch was weighed (to the nearest 0.01 kg) and the total number of fish in a sub-sample of 500 g was counted to enable the calculation of total number captured. The length (nearest mm) of 50 *G. auratus* at each site was measured and the bulk of captured fish were revived in freshwater and released. A sub-sample of between 40-60 fish (where possible) from each lake (10-15 per site) representing the size range of fish captured, were euthanased in an anaesthetic solution and preserved in 70 % ethanol for life history analysis.

*G. auratus* samples collected in plankton tows were also euthanased in an anaesthetic solution and preserved in 70 % ethanol for later analysis.

## 2.8 Biological Analysis

All golden galaxias (*Galaxias auratus*) life history specimens were processed in the same manner. Total fork length (TFL) (nearest mm), total weight (nearest 0.1g) and gonad weight (0.01g) were measured and sex and reproductive stage of development was determined. Reproductive stage of development was assessed using a method modified from Fulton (1982) (Appendix 4). Diet was analysed by the 'occurrence' and 'points' methods (Ball 1961; Hynes 1950). Dietary analysis involved estimating gut fullness, identifying and counting diet items and estimating the relative volumetric contribution made by each dietary component. Appendix 5 shows the stomach fullness rank, percentage volume and the volumetric points scale used to perform the 'points' method of dietary analysis. Otoliths of 10 fish from the monthly samples from each lake were removed and stored for later analysis (note: not all otoliths have been examined in this study). The fecundity of 'ripe' female fish in the June and July 2001 samples was also examined. Fecundity analysis involved counting the number of eggs in a 200 mg sub-sample of gonad from each fish and extrapolating to determine the total number present in the gonad. On 8 occasions fecundity analysis was replicated 5 times to determine the accuracy of the analysis technique. All replicates gave percentage errors of  $< 10$  %.

10 fish ranging in size from 57 – 162 mm (TFL) collected during July 2000 from Lake Crescent were aged. Otoliths were analysed by sectioning and staining with toluidine blue using methods modified from (Liew, 1974; Richter & McDermott 1990).

Plankton tow samples were analysed by measuring the total fork length (TFL) (mm) of the first 100 larvae and all juvenile fish in each sample. Where more than 100 larvae were present in a sample, the number of unmeasured fish was counted to give a total number for the sample.

## 2.9 Captive Breeding

Golden galaxias (*Galaxias auratus*) captive breeding trials were conducted between July-October 2000 in conjunction with trials on Swan and Clarence galaxiids (*G. fontanus* and *G. johnstoni*) performed by Jackson (2001) as a part of the Galaxiid Recovery Program (Crook & Sanger 1997).

Captive breeding experiments were conducted using methods that attempted to simulate the natural habitat of *G. auratus* where possible. The use of chemicals such as water conditioner and hormone injections was avoided to determine if simple methods could be successful.

### 2.9.1 Aquarium and Pond Set up

Five aquariums were set-up in a controlled temperature aquarium room at the IFS Liawenee laboratory in July 2000. One aquarium (200 L) was used to hold adults and 4 smaller aquariums (60 L) were used for incubating eggs and rearing larvae. All aquariums contained natural habitat, with a layer of fine gravel and larger rocks (approximately 10–20 cm diameter) in all tanks and the adult tank also contained woody debris. All aquariums were fitted with under-gravel filters and untreated water used was sourced directly from Liawenee Canal. The room was maintained under natural lighting.

A circular fibreglass pond (approximately 800 L) was set up outside the laboratory to trial natural spawning. Gravel collected from the Liawenee Canal and rocks from the shore of Great Lake were placed over the bottom to mimic the natural rocky habitat of the shores of lakes Crescent and Sorell. The pond was stocked with macroinvertebrates collected from Lake Sorell and Camerons Lagoon. The pond had no water circulation or aeration but was flushed with freshwater regularly. A shade-cloth lid was used to completely cover the top of the pond to provide shade and protection.

Temperatures in the aquarium room and the outside pond were monitored weekly. Uncontrolled temperature in the room ranged between 4–9°C up until the 16<sup>th</sup> October 2000 after which the temperature ranged between 9–15°C. Pond temperatures fluctuated with ambient temperatures and ranged between 1–21°C.

### 2.9.2 Fish Collection and Transportation

Adult golden galaxias (*Galaxias auratus*) (n=22) were captured in lakes Crescent and Sorell with fine mesh fyke nets and transferred to the Liawenee laboratory during July 2000. Fish were transferred in 20 L plastic buckets. At this time, approximately 60 % of the wild populations in lakes Crescent and Sorell appeared to have spawned and many captured fish were found to be ripe.

### 2.9.3 Adult Fish Maintenance

At least 50 % of the water in the aquarium and outside pond containing broodstock, was changed weekly. Adult fish were fed at least once per week with live food (zooplankton and macroinvertebrates) collected from Camerons Lagoon and/or Lake Sorell.

### 2.9.4 Stripping and Fertilisation

Adult fish were judged ripe when eggs and milt were easily stripped by applying light pressure to the gut cavity. Artificial fertilisation was performed by determining the sex of broodstock individuals, then male and female fish were held in separate buckets containing freshwater. Fish were not anaesthetised, as an anaesthetic solution was thought to be a possible source of contamination for eggs and milt. Stripping of non-anaesthetised fish was found to be feasible given fish were handled appropriately.

A thin layer of eggs was stripped into a petri dish containing a small amount of water. Within 60 seconds of the eggs being stripped, milt was then stripped from male fish into the petri dish. Each batch of eggs was fertilised by either one or two males. The dish was swirled to ensure fertilisation of all eggs and left to stand for approximately 5 minutes. Eggs were then transferred to egg incubation trays and the trays were floated in aquariums. Incubation trays consisted of plastic trays (200 x 100 x 30 mm) with 1.0 mm mesh on the bottom and lid.

Egg development was observed weekly by examining a sub-sample of approximately 10 viable eggs under a dissecting microscope against a black background.

The outdoor pond was searched every fortnight for spawned eggs.

### 2.9.5 Feeding Larvae

Larval golden galaxias (*Galaxias auratus*) were fed live plankton derived from a green culture set-up and maintained by Jackson (2001), as well as plankton collected from Lake Sorell and/or Camerons Lagoon. Water from both sources was sieved through 154 µm nylon mesh plankton net and retained organisms were added to larval aquariums. The content of this material varied but included at times protozoa, rotifers, cladocerans, copepods and algae (Jackson 2001).

## 2.10 Translocated Populations

### 2.10.1 Site Selection Survey

The site selection survey was undertaken in June 1996 by the IFS during the initial stages of the golden galaxias (*Galaxias auratus*) translocation program. The survey involved inspecting farm dams on both private property and Crown land within the Clyde River catchment. The Clyde catchment covers an area of 1150 km<sup>2</sup> encompassing the townships of Bothwell and Hamilton (Figure 8). Each dam was assessed against four primary criteria:

1. dams and wetlands had to be within the Clyde River catchment,
2. it was desirable for dams not to contain other species and/or have potential for introductions,
3. water needed to be permanent and of reasonable quality, and
4. co-operation from landowners was required.

Liaising with the property owners/managers took place to gain co-operation and to identify waterbodies that were not marked on maps. The properties surveyed included Serat, Interlaken Estate, Woodspring, Alma and Rotherwood.

### 2.10.2 Fish Collection and Translocation

All golden galaxias (*Galaxias auratus*) used in translocations were collected from Lake Crescent, which has a more abundant population than Lake Sorell. The majority of fish (~80 %) were collected using a fish trap on the Lake Crescent outflow screens, while the rest (~20 %) were captured by electro-fishing along the rocky shore of Tea Tree Point. The majority of the fish captured measured between 60 – 90 mm (TFL) and were thought to be fish of 1+, 2+ and 3+ year classes. Fish were transported in 20 L plastic buckets to translocation sites and released near cover.

### 2.10.3 Follow-up Surveys

The presence/absence and abundance of juvenile and adult fish was surveyed using a combination of electro-fishing and netting techniques during January 2001. The aim of surveys was to determine if the populations had been able to establish and hence if the translocating program was successful. Where established populations were found, the length (TFL mm) of 50 –100 fish was measured to analyse population structure.



**Figure 8.** Map of Clyde River catchment

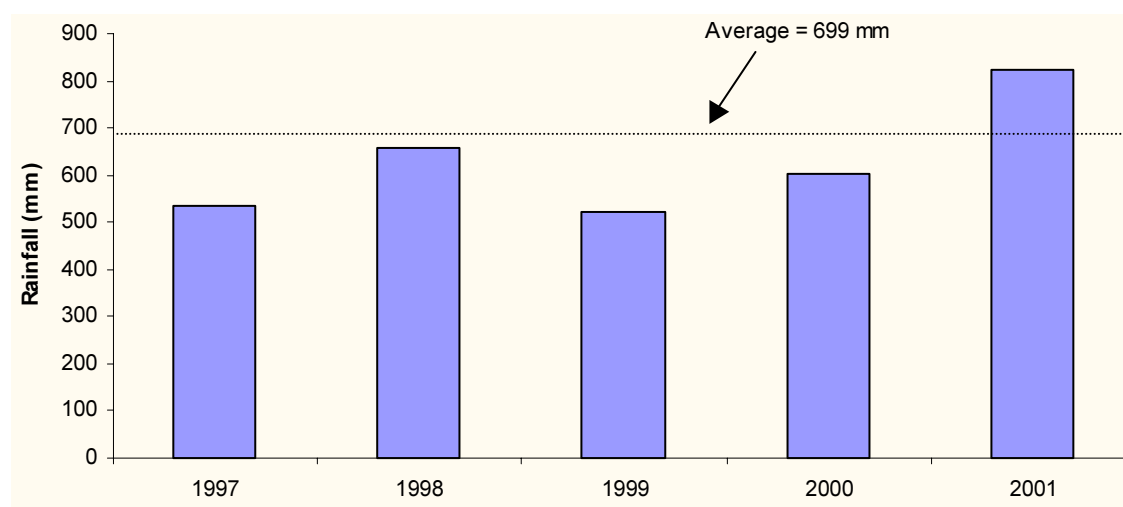
### 3. Results

#### 3.1 Status of Lakes Crescent and Sorell

During the 2 year period of the study (June 2000 – July 2002), lakes Crescent and Sorell were in a very degraded state in terms of water quality, and habitat diversity and availability. The lakes were experiencing record low water levels resulting in loss and degradation of habitat and high to extremely high water turbidity.

##### 3.1.1 Climatic Conditions

This study was undertaken at the end of a significant drought period in the Interlaken area. Annual rainfall totals for the area were below average in 4 of the 5 years between 1997-2001 (Figure 9), while the current rainfall total for 2002 is also below average. In addition to below average annual totals, the annual rainfall patterns have also varied from the long term averages for the area (J. Deakin pers. comm.). As a result of the low and varied rainfall pattern, the net climatic losses from the lakes have been relatively high resulting in near record low water levels in both lakes during the study.



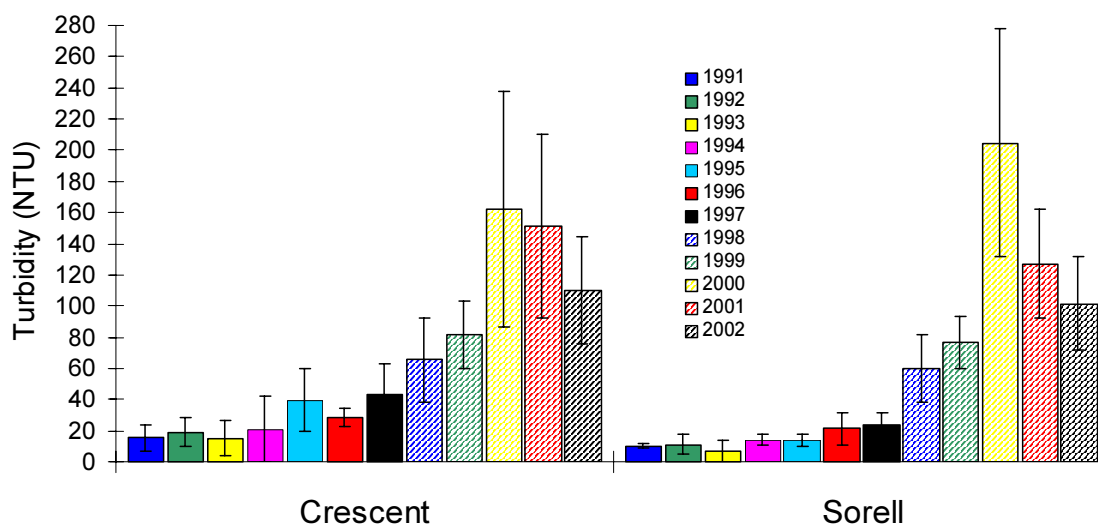
**Figure 9.** Total annual rainfall in the Interlaken area 1997-2001 (Deakin unpublished data). The historical average for the area is also shown.

### 3.1.2 Physico-chemical Water Parameters

Physico-chemical water parameter monitoring by the *Water Quality Sub-project* indicated that both Lake Crescent and Lake Sorell had very poor water quality during the study period (Uytendaal 2003).

Turbidity, which is a measure of water clarity, is thought to be the most important parameter in regard to the condition of the lakes and to the health of the golden galaxias (*Galaxias auratus*) populations. High water turbidity decreases the penetration of light into the water column, which decreases the growth of aquatic plants (important habitat). High turbidity can also cause the sedimentation of other substrates as turbidity is a direct measure of sediment loading in the water column and therefore reflects increases in erosion that can potentially lead to increases in sedimentation (A. Uytendaal pers. comm.).

Lakes Crescent and Sorell have experienced a steady increase in turbidity over the past 10 years (Figure 10). This increase in water turbidity coincides with a general decrease in water levels. A strong relationship between turbidity and water levels has been quantified which indicates that low water levels and strong wind action are the driving forces behind the turbidity of the water in lakes Crescent and Sorell (Uytendaal 2003). During the study period (2000-2002) turbidity levels in both Lake Crescent and Lake Sorell averaged >100 NTU and reached extremely high levels (up to 400 NTU) (Uytendaal 2003).

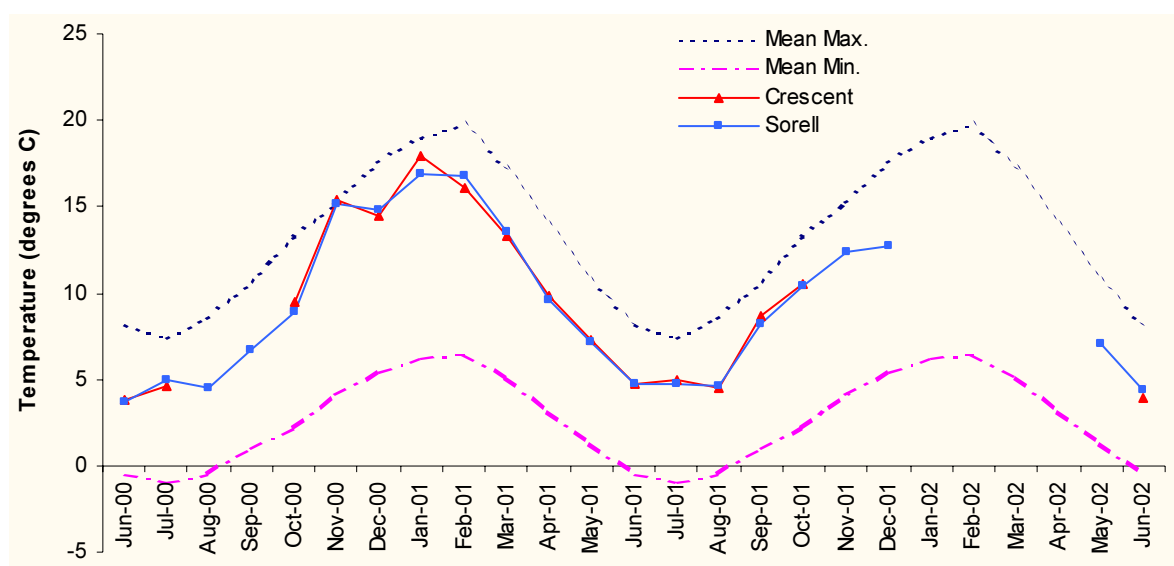


**Figure 10.** Mean annual turbidity levels in lakes Crescent and Sorell, 1991-2002. Means are plotted with one standard deviation confidence limits. Data taken from (Uytendaal 2003).

As a result of the significant increase in the concentration of suspended solids (major component of turbidity) in the water column of lakes Crescent and Sorell nutrient concentrations have also increased in recent years (Uytendaal 2003).

Water temperature varied closely with air temperature in both lakes with annual cycles being typical of lakes on Tasmania's Central Plateau (Figure 11). Mean summer and winter water temperatures were  $\sim 15^{\circ}\text{C}$  and  $\sim 5^{\circ}\text{C}$  respectively. Autumn and spring months show significant decreases and increases in water temperature respectively.

Historically, lakes Crescent and Sorell have been prone to freezing over however this was not observed during the study. Formation of sheets of ice in shallow margins was, however, common in late autumn - winter.



**Figure 11.** Water temperature in lakes Crescent and Sorell 2000-2002. Mean monthly water temperature is plotted with mean historical maximum and minimum air temperatures for the Interlaken area. Gaps in water temperature data are due to equipment failure.

Refer to Uytendaal (2003) for further information on the water quality of lakes Crescent and Sorell during the study period.

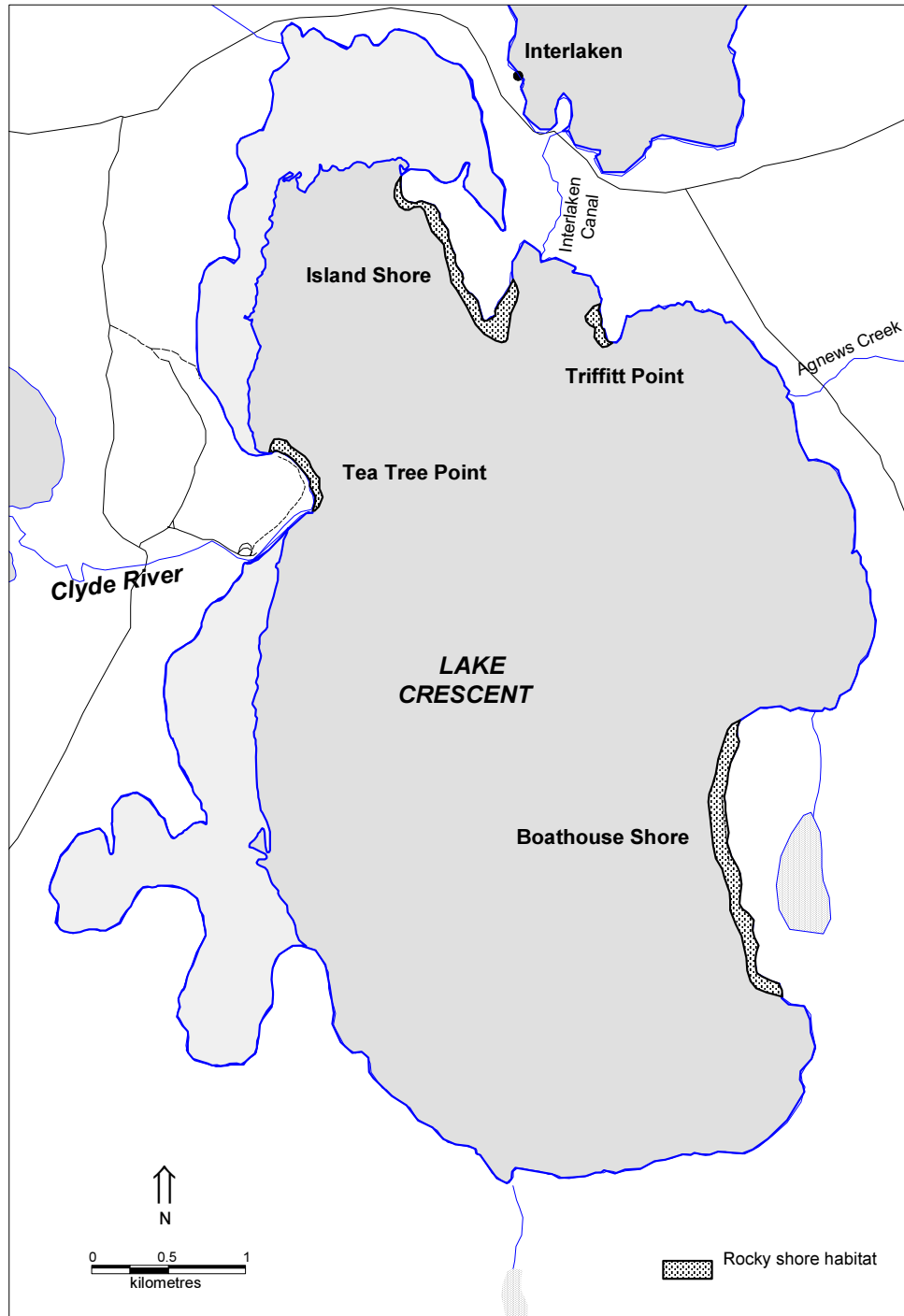
### 3.1.3 Habitat Diversity

The habitat diversity of the lakes Crescent-Sorell system has been significantly reduced in recent years through a number of processes. Prolonged low water levels in both lakes have caused decreases in habitat diversity and availability. This was particularly evident during 2000/01. Low lake levels have altered the types of substrate present in the littoral zones and have also indirectly reduced the abundance of aquatic macrophytes where elevated water turbidity has decreased light penetration. Agricultural practices have also impacted on the area through the draining of associated wetlands (such as Agnews Marsh) and the channelling of swamp areas. These works have caused flows to be less consistent in the in-flowing creeks and hence further restricted the habitat available to the golden galaxias (*Galaxias auratus*).

The main habitats that have been affected by the low lake levels and agricultural practices include:

- ***in-lake macrophyte (aquatic plant) beds***: Due to the recent high water turbidity and hence a decrease in the euphotic depth, plants have not been able to receive enough light for survival or growth in Lake Sorell. Severe disturbance of substrate by wind action is also thought to have contributed to the loss and lack of regeneration of in-lake macrophytes. In some areas, in-lake macrophyte beds that were previously in the littoral zone of both lakes have been fully de-watered.
- ***rocky shorelines***: In Lake Crescent particularly, rocky substrate is only found on a few shores (Figure 12) where it is inundated at water levels >802.20 m AHD. Water levels <802.20 m AHD leave the majority of the rocky shores de-watered (Appendix 2 – Picture 2). The large amounts of sediment that become mobile during periods of strong wind also smother the fringe of the rocky shorelines. In the case of Lake Sorell, the substrate of the lake is composed of large areas of rock and the rocky shorelines extend to quite low water levels. Therefore this threat is not as significant in Lake Sorell.
- ***sandy shorelines***: Sandy shorelines are also found in both lakes. The water levels at which these become inundated has not been surveyed but have been observed to approximate those found for rocky shores. Significant areas of sandy habitat have been de-watered during the recent low lake levels (Appendix 2 – Picture 3). The fringes of the shores that have been inundated also suffer from being smothered with sediment.
- ***adjacent wetlands***: The de-watering of adjacent wetlands and their disconnection from the main body of the lakes has eliminated vast areas of macrophyte dominated habitat from the lake systems (Appendix 2 – Picture 4). Grazing by cattle and sheep on the wetlands is also thought to have an impact on this habitat.

The reduction in the availability of certain habitats is thought to be a significant threat to *G. auratus* populations in both lakes, particularly the population in Lake Crescent. The lack of habitat diversity in Lake Crescent decreases the food, shelter and spawning resources available to the *G. auratus* population.



**Figure 12.** Map of Lake Crescent rocky shore habitat.

## 3.2 Status of Wild Populations

### 3.2.1 Distribution

#### *Historical*

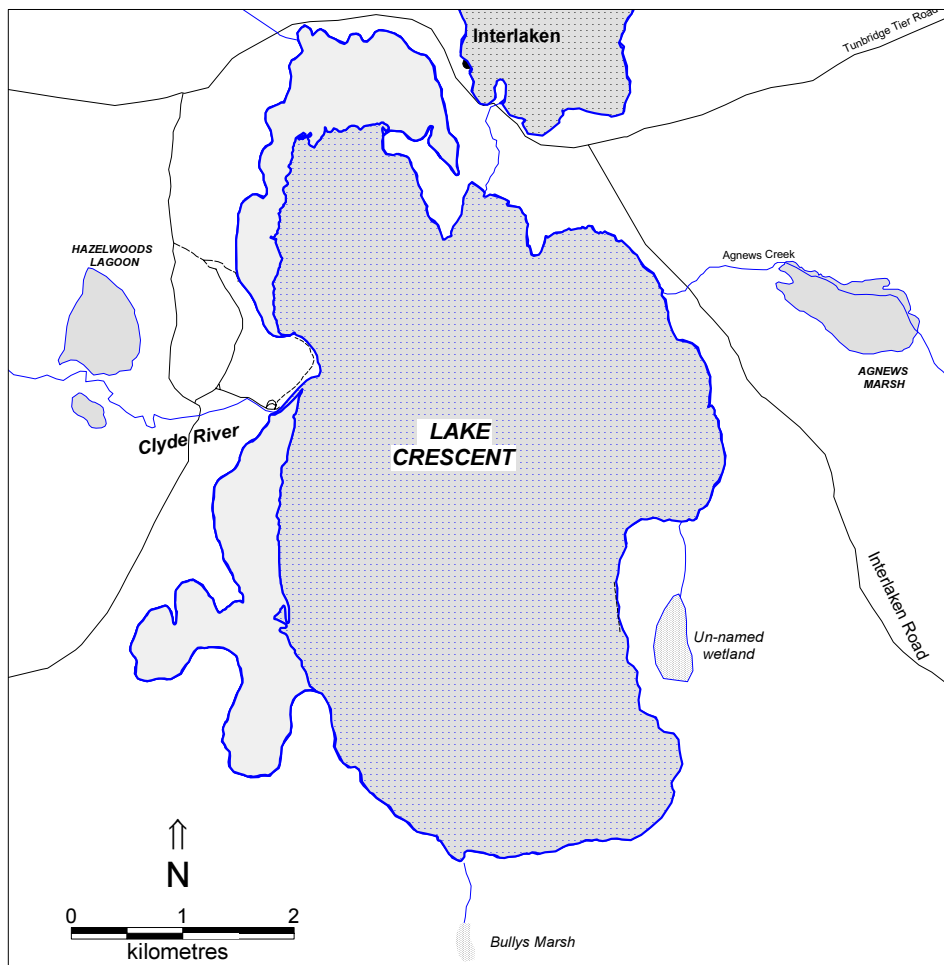
The golden galaxias (*Galaxias auratus*) is thought to have evolved from the land-locking and subsequent speciation of an ancestral version of the diadromous spotted galaxias (*G. truttaceus*) (Ovenden & White 1990; Ovenden *et al.* 1993). The ancestors of *G. auratus* are thought to have invaded the precursors of lakes Crescent and Sorell up to 100, 000 years ago (Ovenden *et al.* 1993). The historical distribution of *G. auratus* is thought to have included the lower reaches of all associated in-flowing creeks and wetlands of the lakes Crescent-Sorell system which connected with the main body of the lakes for extended periods (Figures 13 and 14).

In recent years, the distribution of *G. auratus* extended approximately 10 km downstream of Lake Crescent in the Clyde River and its associated wetlands (IFS unpublished data). *G. auratus* became very scarce further downstream until approximately 30 km downstream of Lake Crescent to where there is a defined natural barrier in the Clyde River. Redfin (*Perca fluviatilis*) are abundant in the fish fauna of the river below this barrier and are thought to heavily predate on *G. auratus* that are swept downstream of the barrier.

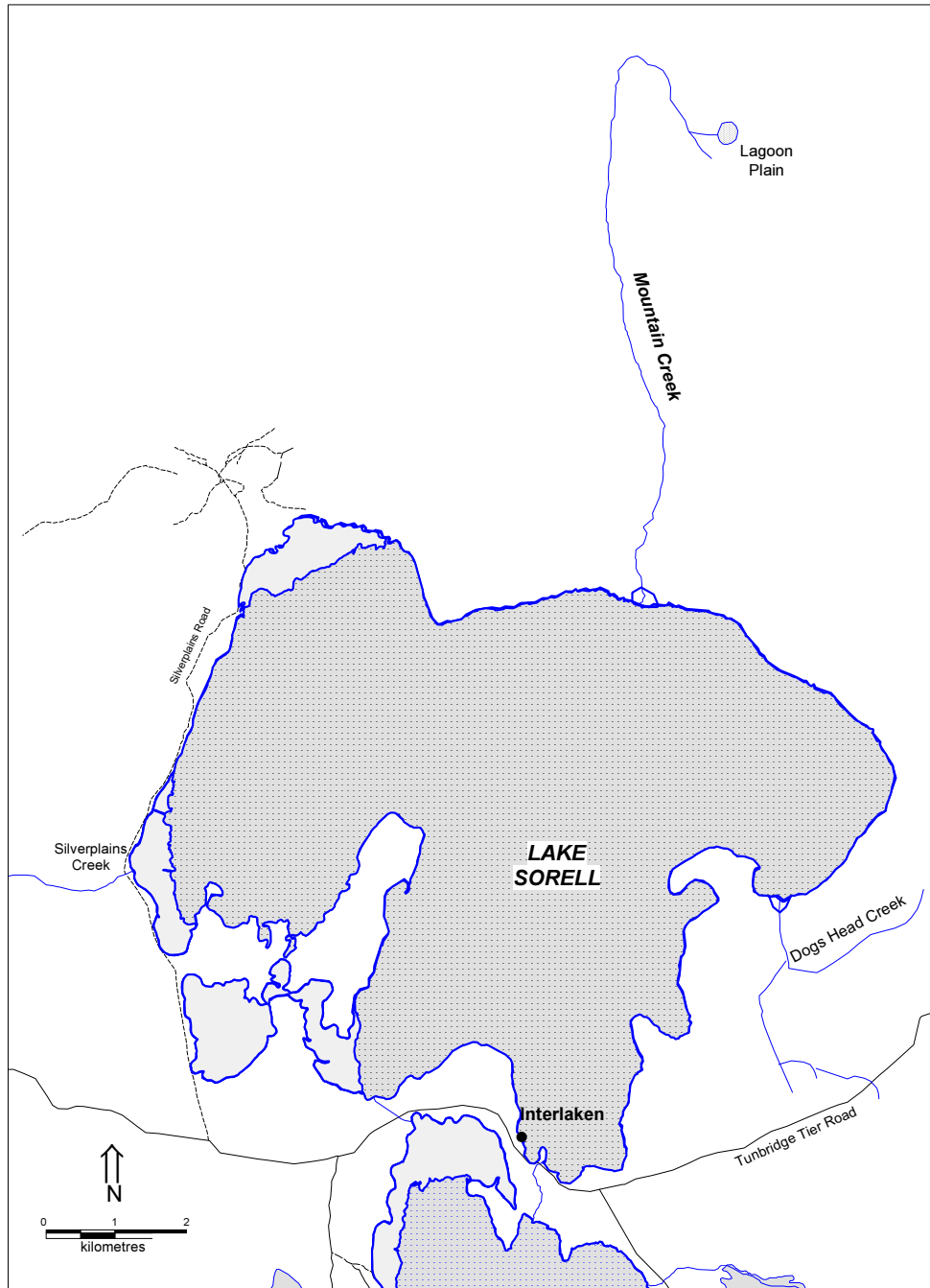
*G. auratus* appeared to be continually swept out of Lake Crescent in the past and did not establish a large self-sustaining population in the Clyde River. *G. auratus* also moved into wetlands that connect to the Clyde River, such as Hazelwoods Lagoon, which is located approximately 2 km downstream from Lake Crescent (T. Byard pers. comm.). Since the IFS installed carp containment screens (1.1 mm mesh) on the Lake Crescent outflow during 1996, the abundance of *G. auratus* in the upper Clyde River has been significantly reduced, to the extent that the population in the river is now basically non-existent.

Lagoon Plain is a shallow temporary wetland at the headwaters of Mountain Creek, approximately 10 km upstream from Lake Sorell. The lagoon was surveyed for *G. auratus* on two occasions. Once during August 2000 and then again in March 2001. The entire length of Mountain Creek was surveyed during the second survey. During August 2000, the water level of Lagoon Plain was high with a steady out-flow of water from the lagoon via Mountain Creek. During March 2001, Mountain Creek was basically dry with only a trickle of water being visible in some reaches connecting small intermittent pools. Lagoon Plain was also found to be completely dry.

*G. auratus* were not found in Mountain Creek or Lagoon Plain on either survey. The only fish species recorded above Lake Sorell was brown trout (*Salmo trutta*) which were found in small pools in Mountain Creek approximately 3 km upstream of Lake Sorell. Mountain Creek did not appear to have any natural barriers that would prevent *G. auratus* from moving up into the Creek and/or Lagoon Plain. However the inconsistent and seasonal nature of flows in Mountain Creek and water levels in Lagoon Plain make these habitats upstream of Lake Sorell only marginal for fish.



**Figure 13.** Map of *Galaxias auratus* habitat associated with Lake Crescent. The dotted area represents the habitat currently being occupied by *G. auratus*.



**Figure 14.** Map of *Galaxias auratus* habitat associated with Lake Sorell. The dotted area represents the habitat currently being occupied by *G. auratus*.

There is a possibility that in the past, during wet years, Mountain Creek and Lagoon Plain may have been included in the distribution range of *G. auratus*. However, the recent construction of the trout anti-jump barrier on Mountain Creek, approximately 1 km upstream from Lake Sorell, is thought to be an impassable barrier for *G. auratus*.

Agnews Creek and possibly Agnews Marsh on the eastern shore of Lake Crescent were inhabited by *G. auratus* in the past (R. Mawbey pers. comm.). The recent draining of Agnews Marsh and channelisation of the creek has altered the water regime of the Agnews system so that the marsh does not hold a significant volume of water and the creek has more variable flows. The Agnews system now offers a very marginal habitat for *G. auratus*.

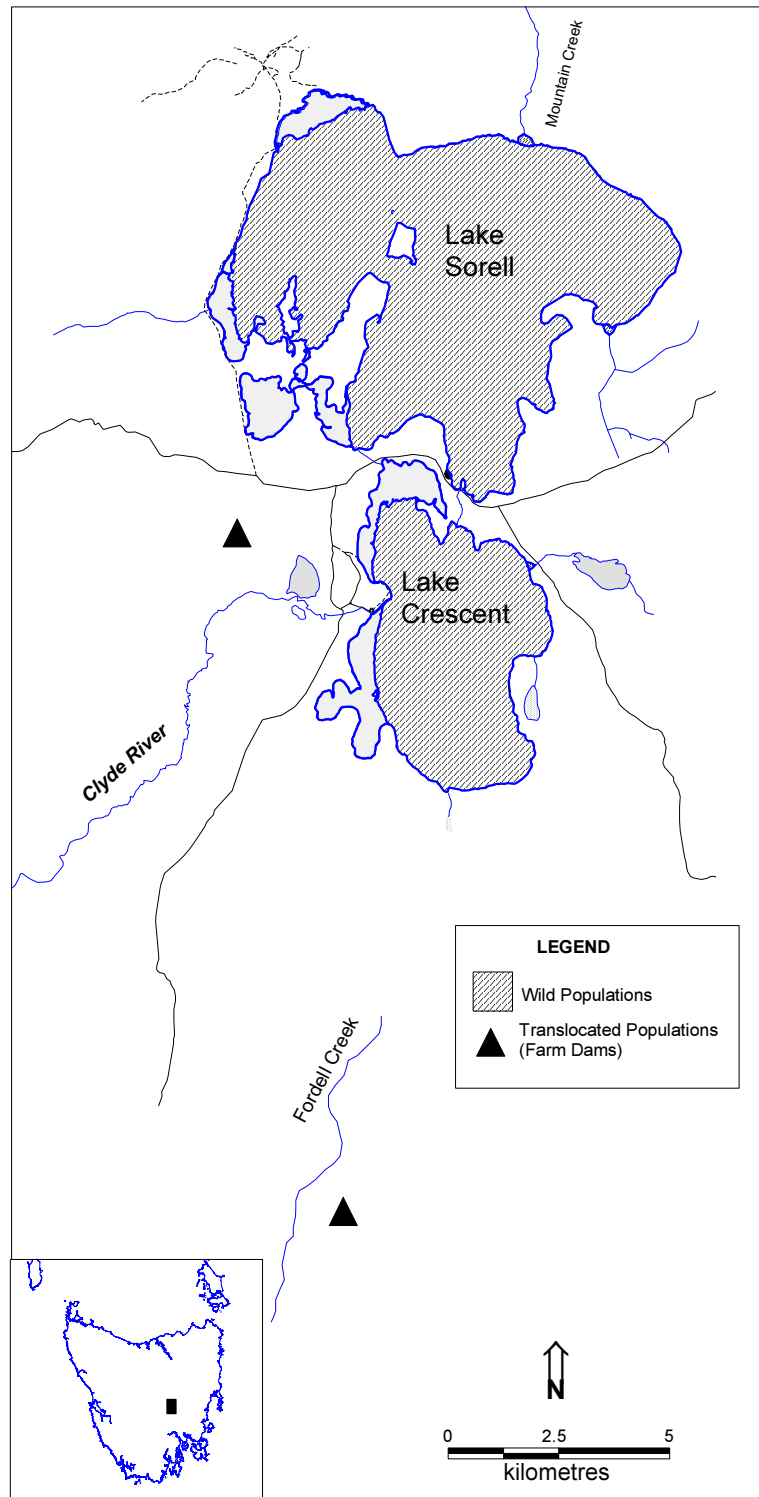
### **Current**

The natural distribution of *G. auratus* is currently confined to the main bodies of Lakes Crescent and Lake Sorell (Figure 15). The area currently occupied by *G. auratus* is approximately 76 km<sup>2</sup> where they occur in only a few waterbodies (Lake Crescent and Lake Sorell and their associated creeks and wetlands) and two translocated farm dam populations (see section 3.5). The current extent of occurrence of *G. auratus* is approximately 313 km<sup>2</sup>.

Recent years of low rainfall and low lake levels have prevented *G. auratus* from utilising adjacent wetlands or in-flowing creeks and their associated wetlands for significant lengths of time. The Inland Fisheries Service (IFS) carp containment screens on the outflow of the Clyde River from Lake Crescent has also stopped the downstream movement of *G. auratus*.

The Lake Crescent area is defined as all lands and waters contained within the full supply level of the lake and all lands and waters within 100 m of the full supply level. The main wetlands surrounding Lake Crescent, that *G. auratus* are thought to periodically inhabit when they are available, are Clyde Marsh and the Ramsar listed Interlaken Lakeside Reserve (Figure 13). These wetlands connect to the main body of Lake Crescent at lake levels above 802.7 and 802.8 m AHD, respectively. Other smaller associated creeks and wetlands which may provide habitat for *G. auratus* in the Lake Crescent area include the creek flowing out of Bullys Marsh (southern shore) and the unnamed wetland behind Boathouse Shore and its out-flowing creek. The Agnews system, particularly the creek, is still thought to provide habitat for *G. auratus* during wet years.

The Lake Sorell area is defined as all lands and waters contained within the full supply level of the lake and all lands and waters within 100 m of the full supply level. The main wetlands surrounding Lake Sorell, that *G. auratus* are thought to periodically inhabit when they are available include Kemps, Silver Plains and Robertsons Marshes and an unnamed marsh in Powells Bay (Figure 14). These wetlands connect to the main body of Lake Sorell at lake levels above 803.6 m AHD. The three main in-flowing creeks of Lake Sorell are Mountain Creek (northern shore) Silver Plains Creek (western shore) and Dogs Head Creek (eastern shore). *G. auratus* move relatively short distances up into these creeks during periods of stable flow.

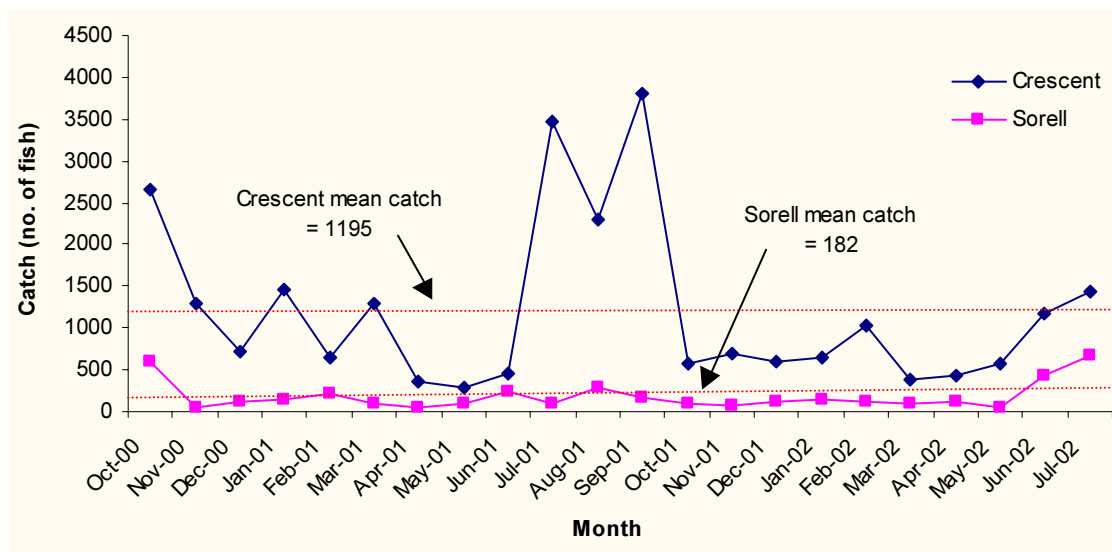


**Figure 15.** Map of the current distribution of *Galaxias auratus*.

### 3.2.2 Abundance

Wild populations of golden galaxias (*Galaxias auratus*) are currently abundant in lakes Crescent and Sorell, although abundance differs significantly between the two lakes. The population in Lake Crescent is currently very abundant and the population in Lake Sorell is reasonably abundant. Figure 16 shows the catch data obtained from monthly sampling of the adult *G. auratus* populations in lakes Crescent and Sorell between October 2000 – July 2002 and illustrates the difference in relative abundance between the two lakes.

The same sampling effort and techniques were applied to each lake on each sampling occasion. Catches in both lakes varied during the study with a general increase in catches during the winter-spring months while *G. auratus* were spawning. The increase in catches during the spawning period is thought to be due to an increase in the abundance of fish in the littoral zone where nets were set and the attraction this species appears to have to the fine mesh of the nets as a spawning substrate. Although catches varied seasonally within each lake, the mean catches of each lake are quite different. The mean catch ( $\pm$  one stand error) of *G. auratus* in Lake Crescent during the study period was  $1195 \pm 214$ , while in Lake Sorell the mean catch was  $182 \pm 36$ . The difference in monthly catches is thought to represent the difference in relative abundance between the two lakes which is approximately 10 fold higher in Lake Crescent.



**Figure 16.** Total monthly catches of adult *Galaxias auratus* in lakes Crescent and Sorell, 2000-2002.

Anecdotal evidence suggests that the relative abundance of both populations has not changed significantly, but the overall size of the populations may have declined as a result of a decrease in available habitat due to low lake levels. The difference in abundance of *G. auratus* populations between the lakes is thought to be caused by the variation in abundance of the brown and rainbow trout (*Salmo trutta* and *Oncorhynchus mykiss*) populations in lakes Crescent and Sorell (see section 3.4.6).

### 3.2.3 Conservation Status

The golden galaxias (*Galaxias auratus*) has a significant conservation status at State and International levels due to its restricted distribution, current lack of knowledge about its ecology and the many threats that the wild populations are facing.

*G. auratus* is currently listed as 'rare' under the Tasmanian *Threatened Species Protection Act 1995* and 'endangered' on the IUCN Red List (ASFB 2001). A nomination is currently being prepared by the IFS for *G. auratus* to be listed as 'vulnerable' at a Commonwealth level under the *Environment Protection and Biodiversity Conservation Act 1999*.

Any significant decline in the abundance of either or both natural populations in the future would most likely lead to the up-grading of the species' conservation status at all levels.

### 3.3 Sampling Techniques

During the *Aquatic Fauna Sub-project*, the monthly sampling of adult golden galaxias (*Galaxias auratus*) in lakes Crescent and Sorell was undertaken using fine meshed fyke nets. Fyke nets have not been widely used by the scientific community to sample small freshwater fish species. This is particularly so for galaxiid species, which dominate the freshwater fish fauna of Tasmania and south-eastern mainland Australia (Andrews 1976; McDowall & Frankenberg 1981) and are widespread within the Southern Hemisphere (Campos 1984; McDowall 1970). Electro-fishing is one of the most commonly used techniques to sample freshwater fish, particularly smaller species such as galaxiids. An example of the reliance upon electro-fishing, since it became an accepted fishing method in the 1970's, is the almost exclusive use of this method by the Inland Fisheries Service, in Tasmania, to sample freshwater fish (particularly smaller species) in rivers and lakes (B. Mawbey pers. comm.).

During the study, fyke netting was trialed against other methods (especially electro-fishing) and was found to be the most effective across all littoral habitats in the wind swept and turbid waters of lakes Crescent and Sorell. Table 1 evaluates electro-fishing and fyke netting as sampling techniques for studying the ecology of *G. auratus* in lakes Crescent and Sorell. Fyke netting provided more accurate and comprehensive data sets in regard to the ecology of *G. auratus*, particularly in terms of size of catch (relative abundance) over time, across habitats, in various weather conditions and for assessing population structure and spawning period. Several aspects of the evaluation are applicable to sampling galaxiids and other small fish species in other waterbodies in Tasmania and south-eastern Australia.

Trials of techniques to quantitatively estimate population size and biomass of *G. auratus* in lakes Crescent and Sorell were conducted during 2001. Table 2 evaluates fyke and seine netting and electro-fishing as sampling techniques for estimating the size of *G. auratus* populations in lakes Crescent and Sorell. Fyke and seine netting appear to be the best techniques which can be used to design a sampling regime to estimate population size. If these techniques were to be used in combination, fyke netting could be shoreline based and seine netting could be performed in-lake.

**Table 1.** Evaluation of fyke netting versus electrofishing as techniques for collecting life history and population structure samples of *Galaxias auratus* in lakes Crescent and Sorell. Where: 1 = poor, 2 = average and 3 = good.

Criteria	Fyke Netting	Electro-fishing	Comments
Size of catch	3	1	Much larger catches in fyke nets, possibly due to increase in effort (time), greater efficiency and sampling overnight when fish are more active. The efficiency of fyke nets is thought to be related to fish being attracted to nets for cover. Electro-fishing has poor efficiency in turbid water.
Size range of catch	3	1	Greater size range in fyke net catches giving a better estimate of the true structure of populations. This is possibly due to the sampling being undertaken overnight when fish are generally more active and when larger fish move inshore. Electro-fishing during the day only catches smaller fish, although it does have a bias towards larger fish as they are more susceptible to the electric field.
Sampling in different habitats	3	2	Sampling on sand, rock and sediment substrate can be undertaken using both techniques, however electro-fishing on uneven and muddy substrate is arduous/dangerous and is less effective in open water (ie no cover).
Weather dependency	3	1	Fyke netting can be carried out in almost all weather conditions given that the nets are set properly (reasonable depth and secure). Catches however are generally not as good in exposed areas in rough conditions probably due to fish behaviour. Electro-fishing is very inefficient in rough conditions due to poor visibility of stunned fish.
Condition of catch	3	2	Fine-meshed fyke nets are very gentle on fish although some mortality may occur in rough conditions. Electro-fishing requires the users to be aware of the appropriate voltage and ampere output for each given habitat in varying weather conditions. Electro-fishing can cause high catch mortality if not used properly.
Bi-catch	2	3	Fyke nets can be screened to exclude larger fish but small trout and eels are caught which can predate on galaxiids in nets. Electro-fishing is indiscriminate and can harm other species.
Effort needed to sample	3	2	Setting fyke nets is quite simple and quick to perform. Electro-fishing is generally not too strenuous to conduct but can be difficult over uneven or muddy substrates and operators can fatigue during extensive sampling.
Time needed to sample	1	3	Fyke netting is best over-night, meaning longer field trips. Electro-fishing can be conducted during the day and does not take long to perform.
Cost of equipment	3	2	Fyke nets cost approximately ~\$120 (AUS) each and 12 nets (Total cost = \$1440 (AUS)) have been found to provide sufficient effort to collect enough fish for monthly life history samples. A backpack electro-fisher currently costs ~\$10,000 (AUS). Operational costs of both are marginal.
<b>Totals and Conclusion</b>	<b>24</b>	<b>17</b>	<b>Fyke netting takes more time (overnight v's day trip) but is a more effective and reliable sampling technique than electro-fishing for studying the ecology and population structure of <i>G. auratus</i> in lakes Crescent and Sorell.</b>

**Table 2.** Evaluation of different sampling techniques for use in sampling regimes to quantitatively estimate the size of *Galaxias auratus* populations in lakes Crescent and Sorell. Where: 1 = poor, 2 = average and 3 = good.

Criteria	Fyke Netting	Electro-fishing	Seine Netting	Comments
Catching efficiency	3	1	3	Fyke and seine netting are very efficient techniques although seine netting is only applicable to certain habitats. The efficiency of fyke nets is thought to be related to fish being attracted to nets for cover. Electro-fishing has poor efficiency in turbid water.
Sampling in different habitats	3	2	1	Fyke nets can be set on all habitats. Electro-fishing is not as effective where wading is difficult (muddy and uneven substrates). Seine netting can only be performed effectively in-lake over barren substrate or on sandy shores.
Sampling large areas	2	1	3	Fyke nets can be set in a group to sample large areas. Backpack electro-fishing only samples small areas, so multiple runs are needed to sample a larger area. Large seine nets are able to sample large areas quickly.
Weather dependence	3	1	2	Fyke netting can be carried out in varying weather conditions. Electro-fishing and seine netting are very inefficient/difficult to perform in rough conditions.
Quantitativeness	2	1	3	Fyke nets can be set quantitatively but efficiency is dependent upon fish behaviour and catches are difficult to quantify (ie area sampled). The quantitativeness of electro-fishing is operator and habitat dependent and is difficult to specify. Seine netting is seen to be reasonably quantitative in that a net can be swept through a known area.
Replication	2	2	2	All three techniques have replication issues, but can be replicated given attention is paid to the exact procedure used to perform sampling.
Effort needed to sample	3	2	1	Setting fyke nets is quite simple and quick to perform. Electro-fishing is generally not too strenuous to conduct but can be difficult over uneven or muddy substrates. Seine netting is strenuous and requires a small team of people to be effective.
Time needed to sample	1	3	2	Fyke netting is best over-night meaning longer field trips. Electro-fishing and seine netting can be conducted during the day and don't take long to perform.
Cost of equipment	2	1	3	Costs are; Fyke nets ~\$120 (AUS) each, a large seine net ~\$400 (AUS) and a backpack electro-fisher ~\$10,000 (AUS). Operational costs of all techniques are marginal.
<b>Totals and Conclusion</b>	<b>21</b>	<b>14</b>	<b>19</b>	<b>Fyke netting and seine netting have the best potential for use in regimes to estimate the size of populations of <i>G. auratus</i> in lakes Crescent and Sorell.</b>

### 3.4 Ecology of Golden Galaxias

During the *Aquatic Fauna Sub-project* the length of a total of 5,800 golden galaxias (*Galaxias auratus*) (3,725 from Lake Crescent and 2,075 from Lake Sorell), captured by shore based electro-fishing and fyke netting, were measured in the field to analysis the structure of wild populations. Fish captured by the shore based techniques were generally adult fish >50 mm TFL. The length of a total of 7,611 *G. auratus* (3,726 from Lake Crescent and 3,885 from Lake Sorell) captured in the water column by tow net were also measured in the laboratory to examine recruitment and the growth of juvenile fish. Fish captured in the water column were generally larvae and juvenile fish <70 mm TFL.

The length, total weight, gonad weight, reproductive stage of development, sex and diet of a total of 2,376 *G. auratus* was analysed in the laboratory (1,307 from Lake Crescent and 1,069 from Lake Sorell) to study several aspects of the ecology of the species. Dissected fish varied in size, 38-196 mm (TFL) and 0.3-90.3 g, in Lake Crescent, and 31-179 mm (TFL) and 0.1–63.3 g, in Lake Sorell. The age of 10 adult fish was also determined.

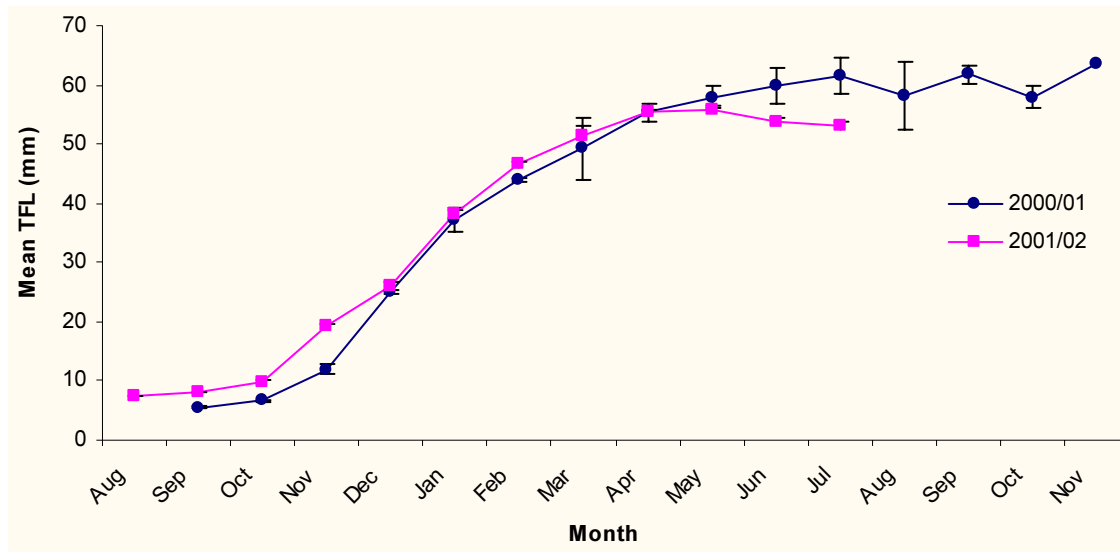
#### 3.4.1 Age, Growth and Population Structure

##### *Growth of Larvae and Juveniles*

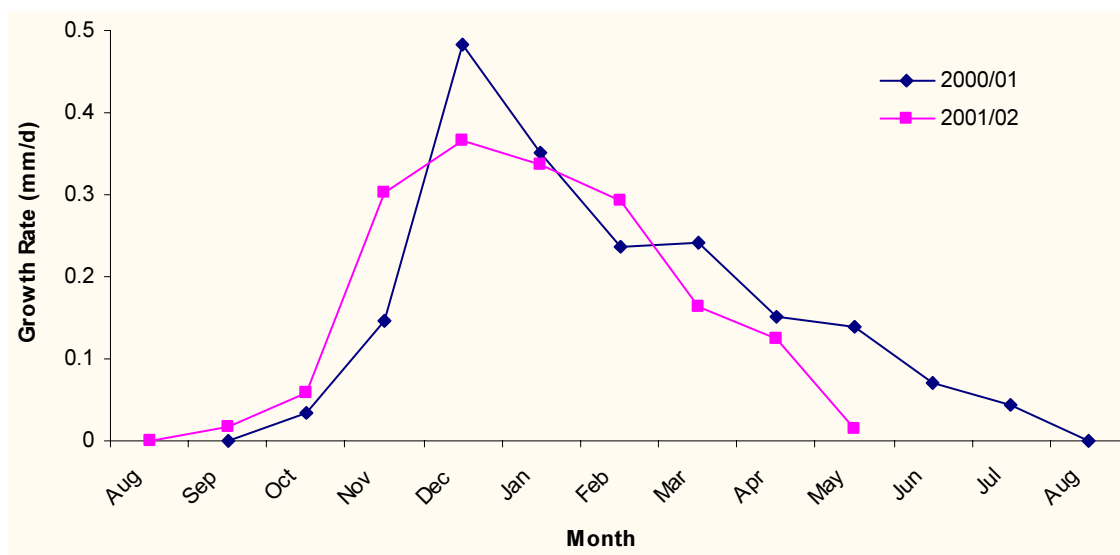
Golden galaxias (*Galaxias auratus*) larvae and juveniles (0+ cohort) collected in tow-net samples have been used to examine the growth of young fish. Figures 17-20 illustrate the growth of *G. auratus* in their first year during 2000 and 2001 recruitments. Figures 17 and 19 show the mean total fork length (TFL) (mm) of the 0+ cohorts at monthly intervals during their first year. Figures 18 and 20 show the corresponding growth rates of the 0+ cohorts, by assigning the date of birth of all larvae in that cohort to the first day of each month that the cohorts were initially sampled. These birth dates are thought to closely approximate the onset of larval hatching in each lake during both spawning seasons.

The data set for the 2000/01 0+ *G. auratus* in Lake Crescent (Figures 17 and 18) is the most comprehensive and provides the best example of the growth of juvenile *G. auratus*. The 0+ cohort data set for 2001/02 in Lake Sorell is in-complete as juvenile fish were difficult to capture in Lake Sorell after the end of their first summer possibly due to their lower abundance and the greater depth of the water column in Lake Sorell (larger pelagic habitat). However, Figures 17-20 all illustrate similar trends in the growth of juvenile *G. auratus*.

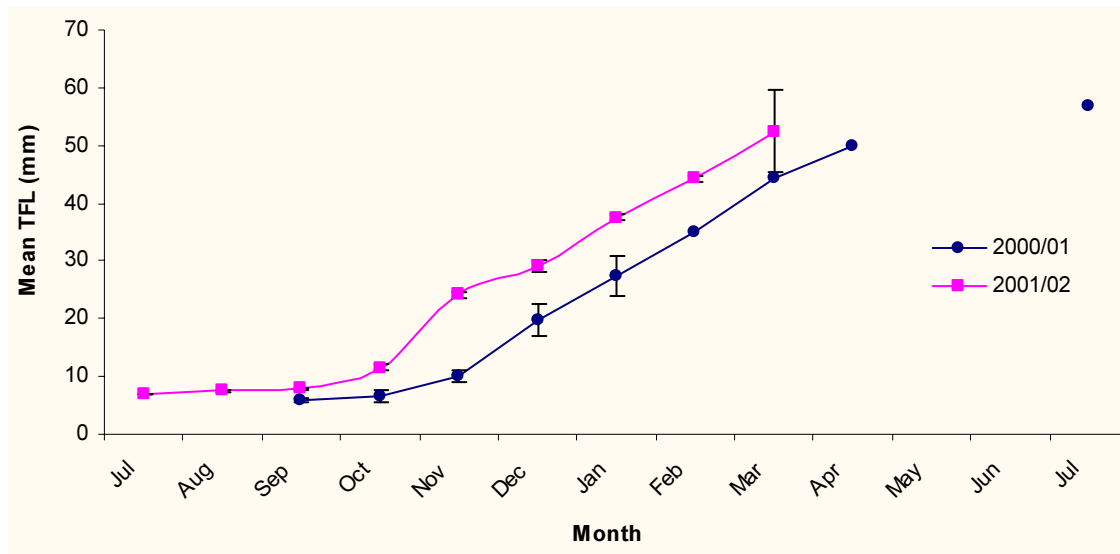
Once *G. auratus* larvae have hatched they almost immediately enter the water column at a size of 5-7 mm (TFL) (verified in section 3.4.7) where their growth is slow for the first 2-3 months. The initial period of slow growth is thought to be due to *G. auratus* larvae having to adjust to their new environment and develop survival and feeding strategies.



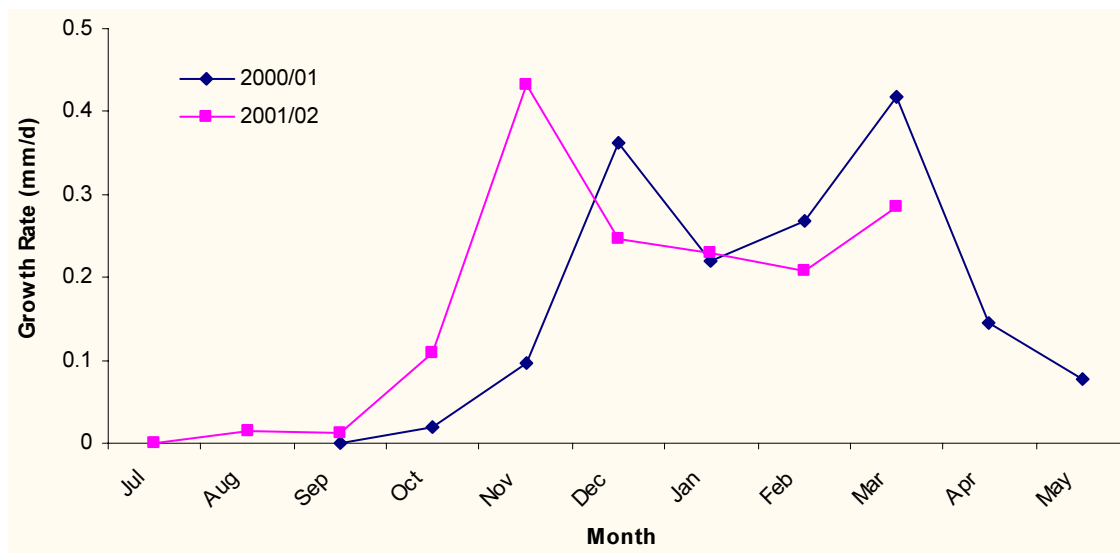
**Figure 17.** Growth of 2000/01 and 2001/02 juvenile *Galaxias auratus* cohorts in Lake Crescent. Average total fork lengths (TFL) (mm) for each monthly sample are plotted with 95 % confidence limits.



**Figure 18.** Growth rate of 2000/01 and 2001/02 juvenile *Galaxias auratus* cohorts in Lake Crescent.



**Figure 19.** Growth of 2000/01 and 2001/02 juvenile *Galaxias auratus* cohorts in Lake Sorell. Average total fork lengths (TFL) (mm) for each monthly sample are plotted with 95 % confidence limits.



**Figure 20.** Growth rate of 2000/01 and 2001/02 juvenile *Galaxias auratus* cohorts in Lake Sorell.

The length of this initial slow growth period is thought to be dependent on the time of year larvae hatch. Larvae began hatching in September in both Lake Crescent and Lake Sorell during 2000 (Figures 17 and 19, respectively) and the 0+ cohorts in both lakes reached a mean size of  $\geq 20$  mm (TFL) by late December. In comparison, larvae began hatching in July during 2001 in Lake Sorell (Figure 19) and the mean TFL of the 0+ cohort was only 12 mm (TFL).

Larvae that hatch early in the season experience much colder water temperatures which have the direct effect of slowing the metabolism of fish and the indirect effect of limiting food availability, with plankton being more abundant once water temperatures begin to rise in spring.

By spring, larvae have survived the first 2-4 months of life and have reached approximately 10 mm (TFL). Water temperatures in lakes Crescent and Sorell begin to rise (Figure 11) causing their metabolism to increase and plankton to become more abundant. Juvenile *G. auratus* begin to grow rapidly during late spring-summer and as they grow they are able to feed on progressively larger prey items. During this period the growth rate of *G. auratus* increases and reaches approximately 0.40 mm/day (Figures 18 and 20), a maximum for any stage of their life.

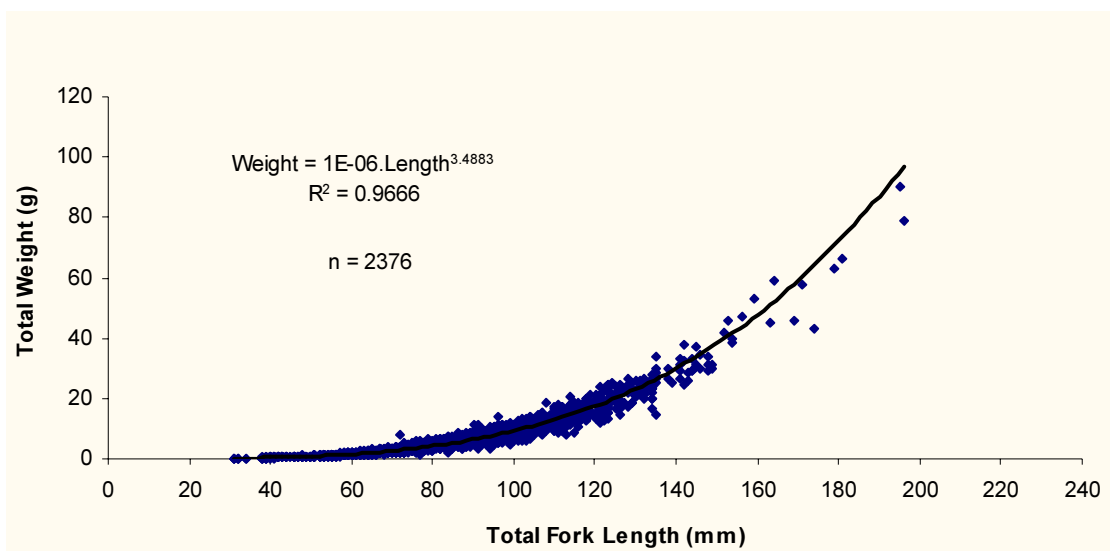
The on-set of colder water temperatures during late summer-autumn slows the metabolism of juvenile *G. auratus* and growth rates decrease to  $< 0.20$  mm/d by the end of autumn (Figures 18 and 20). At the start of their first full winter as a juvenile fish, *G. auratus* are between 50-60 mm (TFL) (Figures 17 and 19). Growth is very limited during winter and by the end of their first year juvenile *G. auratus* are approximately 60 mm (TFL).

There is a significant difference between the growth patterns of the populations of *G. auratus* in Lake Crescent and Lake Sorell. Figure 18 shows a similar trend in the growth of 0+ *G. auratus* in Lake Crescent during 2000 and 2001, with a single climax in growth rate during December. In comparison, Figure 20 suggests a period of fluctuating growth rates during the summers of 2000/01 and 2001/02 in Lake Sorell. It is suspected that the fluctuating growth rates of *G. auratus* in Lake Sorell correlate with fluctuations in the abundance of zooplankton.

### **Growth of Adult Fish**

Once *G. auratus* have reached their second year (1+ years of age) growth is more weight related rather than length related. Figure 21 shows the length-weight relationship for *G. auratus* from lakes Crescent and Sorell. The relationship between length (L) and weight (W) of *G. auratus* can be described by the equation  $W = 1 \times 10^{-6} \cdot L^{3.4883}$  ( $n = 2376$ ,  $R^2 = 0.966$ ).

The shape of the length-weight relationship curve shows that as *G. auratus* reach lengths  $> 60$  mm TFL (at the end of their first year), growth becomes almost equally proportional between increases in length and weight and, as fish become larger, growth via increased weight becomes more dominant.



**Figure 21.** Length-weight relationship of *Galaxias auratus* from lakes Crescent and Sorell. Where n = number of fish analysed.

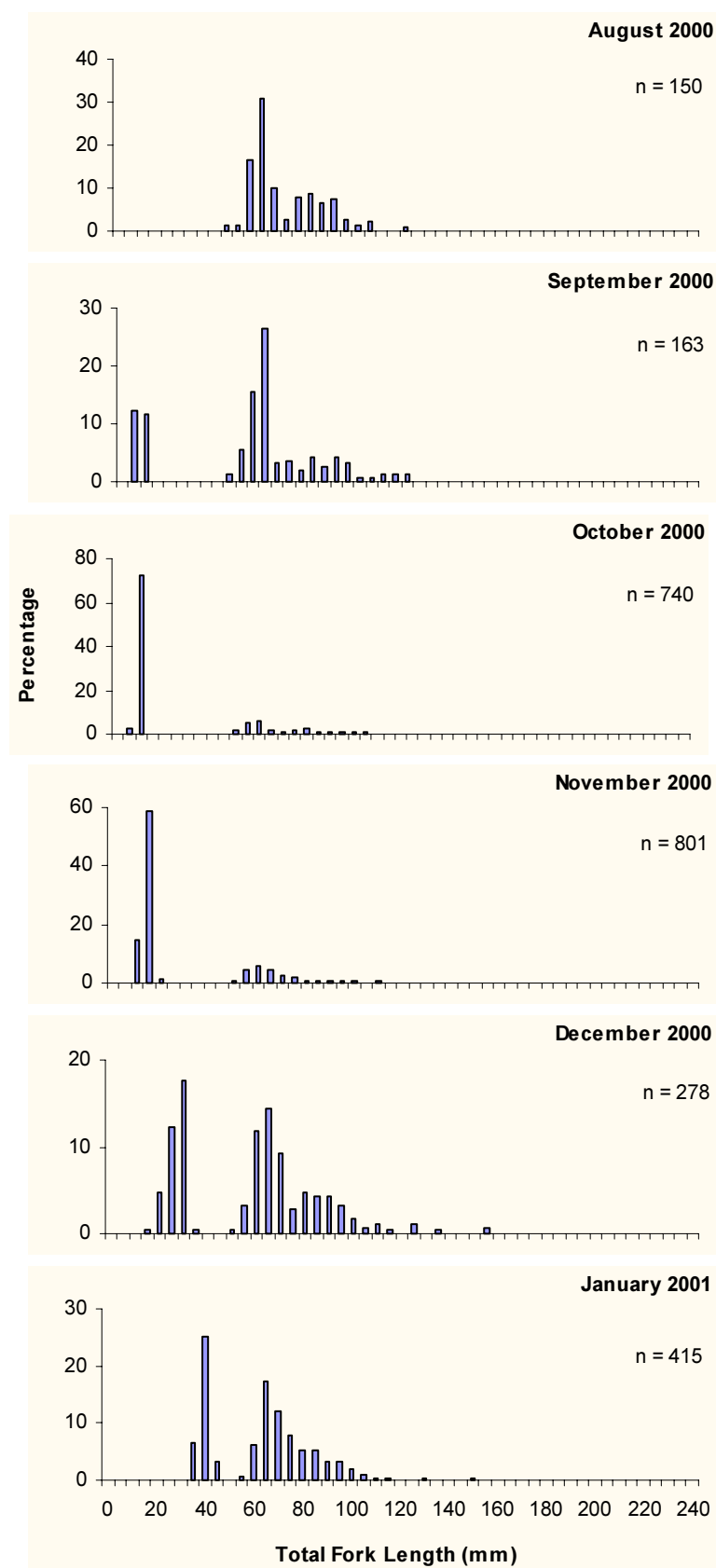
### ***Recruitment and Population Structure***

The recruitment of juvenile *G. auratus* into the adult populations in lakes Crescent and Sorell was examined by combining length data from shore based sampling (using electro-fishing and fyke netting) and water column sampling (using a tow net). Length-frequency plots were then constructed to identify changes that occur in population structure over time. Combining the data from both sampling regimes provides an overview of the full structure of each population.

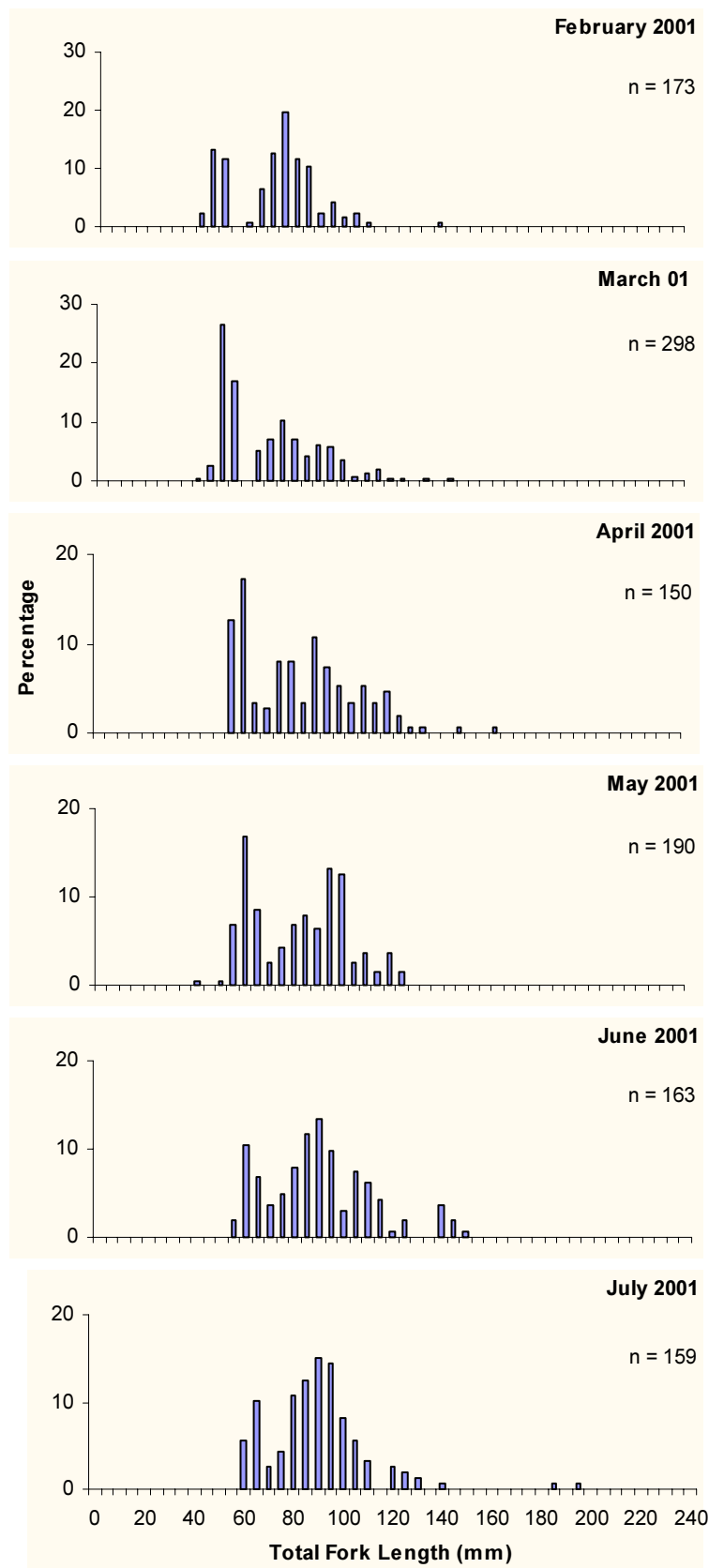
Figures 22 and 23 show monthly length frequency plots of *G. auratus* populations in Lake Crescent and Lake Sorell, respectively, for the 12 month period between August 2000 and July 2001 inclusive. Although both populations have been monitored for 24 months, and all data collected has been analysed, this 12 month period was selected as it provides a clear representation of annual recruitment patterns for both populations.

Populations of *G. auratus* in both lakes Crescent and Sorell show similar recruitment patterns and population structures. The 2000/01 recruitment began in September 2000 with the onset of larval hatching (Figures 22 and 23). From September onwards the growth of juvenile (0+) cohorts is clearly visible until they merge with the adult populations in April and May 2001 in Lake Crescent and Lake Sorell respectively.

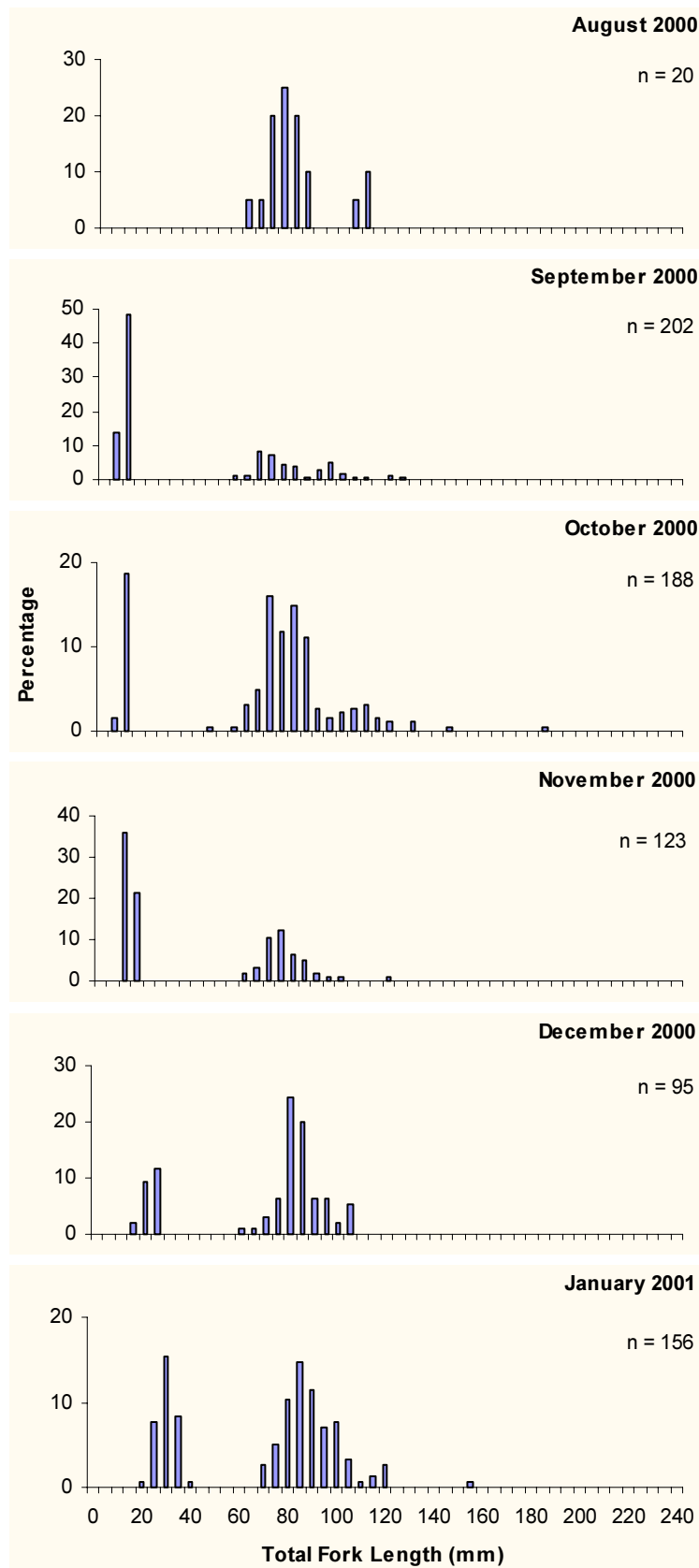
While the juvenile cohort is growing through, the structure of the adult component of each population appears to remain quite stable. However, Figure 22 suggests that the 1+ cohort (mean length ~70 mm) during August 2000 has grown through to the 2+ cohort (mean length ~90 mm) by July 2001. This trend is also evident, to a lesser extent, in Lake Sorell (Figure 23).



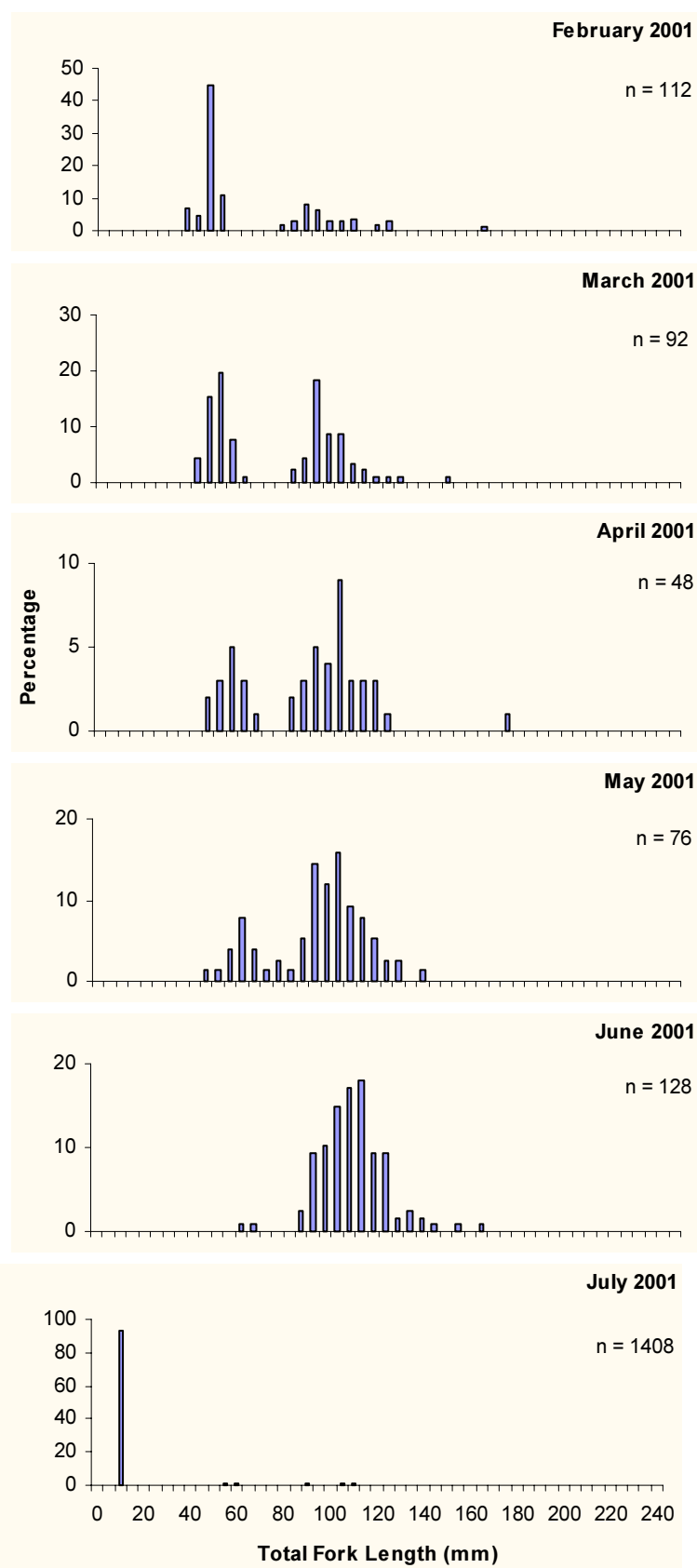
**Figure 22.** Length frequency plots for the *Galaxias auratus* population in Lake Crescent August 2000 – July 2001 (Figure continued on page 42). Where n = number of fish analysed.



**Figure 22.** Length frequency plots for the *Galaxias auratus* population in Lake Crescent August 2000 – July 2001 (Figure continued from page 41). Where n = number of fish analysed.



**Figure 23.** Length frequency plots for the *Galaxias auratus* population in Lake Sorell August 2000 – July 2001 (Figure continued on page 44). Where n = number of fish analysed.

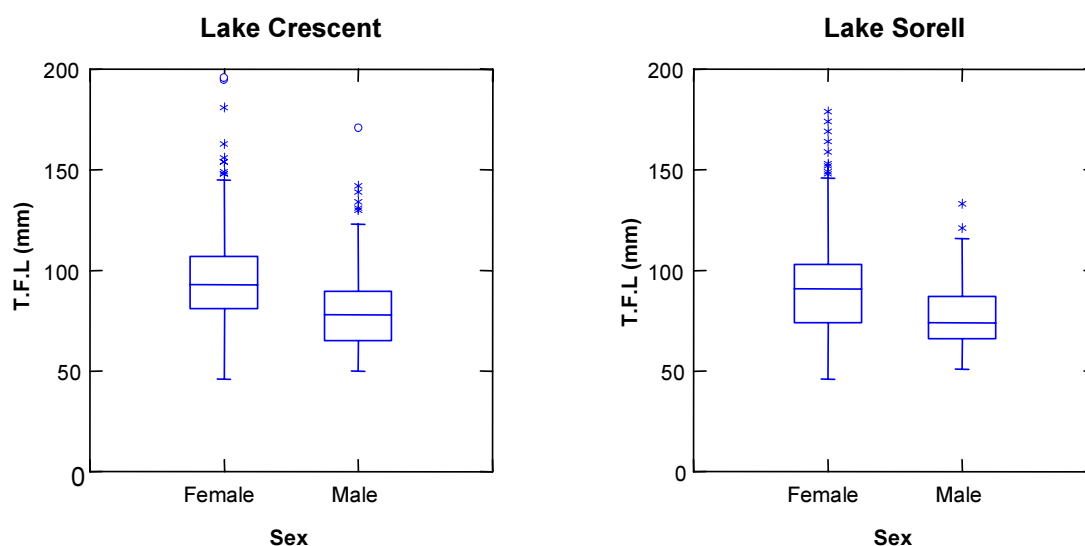


**Figure 23.** Length frequency plots for the *Galaxias auratus* population in Lake Sorell August 2000 – July 2001 (Figure continued from page 43). Where n = number of fish analysed.

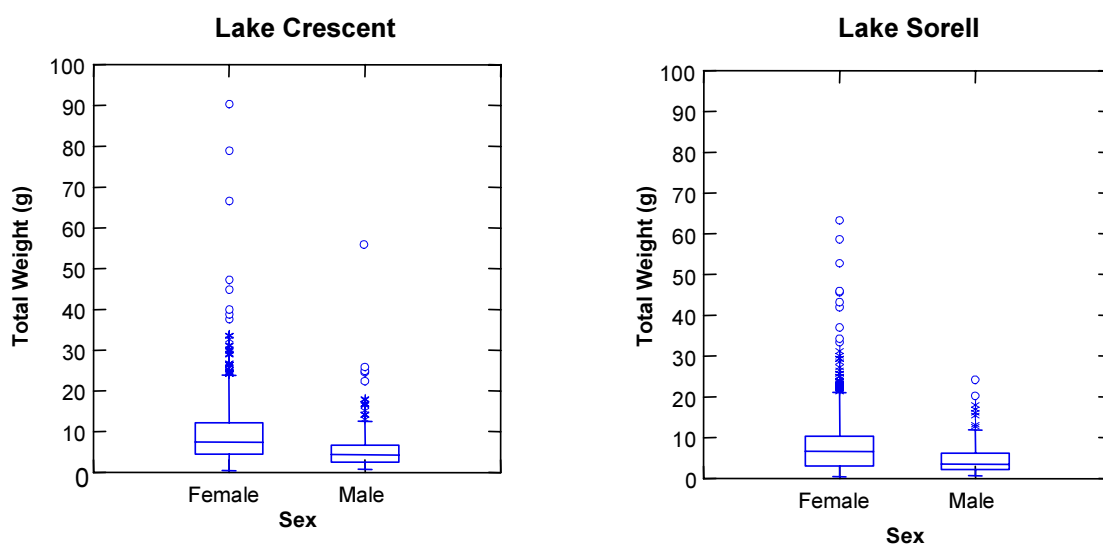
### Sexual Composition of Populations

*G. auratus* populations in lakes Crescent and Sorell have a defined sexual composition with female fish dominating populations. Female fish were found to grow larger (possibly live longer) and also be more abundant than male fish.

Examination of the relationship between sex and length (Figure 24) and sex and weight (Figure 25) for all dissected fish from each lake shows that female fish grow larger than males in terms of both length and weight.



**Figure 24.** Boxplots of the relationship between sex and length of *Galaxias auratus* in lakes Crescent and Sorell. The number (n) of male and female fish analysed in Lake Crescent was 416 and 779 respectively and in Lake Sorell 353 and 607 respectively. Length is measured as total fork length (TFL).



**Figure 25.** Boxplots of the relationship between sex and weight of *Galaxias auratus* in lakes Crescent and Sorell. The number (n) of male and female fish analysed in Lake Crescent was 416 and 779 respectively and in Lake Sorell 353 and 607 respectively.

The observations in regard to the different size of male and female *G. auratus* in the Lake Crescent and Lake Sorell populations were found to be statistically significant at the 0.01 level of probability.

The difference in mean length (TFL) of male (79 mm) and female (94 mm) *G. auratus* in the Lake Crescent population, where n (male) = 416 and n (female) = 779, is statistically significant ( $F_{1, 1195} = 153$ ,  $P < 0.01$ ). The difference in mean length (TFL) of male (77 mm) and female (91 mm) *G. auratus* in the Lake Sorell population, where n (male) = 353 and n (female) = 607, is also statistically significant ( $F_{1, 959} = 126$ ,  $P < 0.01$ ).

The difference in mean weight of male (5.3 g) and female (9.3 g) *G. auratus* in the Lake Crescent population, where n (male) = 416 and n (female) = 779, is statistically significant ( $F_{1, 1191} = 89$ ,  $P < 0.01$ ). The difference in mean weight of male (4.5 g) and female (8.3 g) *G. auratus* in the Lake Sorell population, where n (male) = 353 and n (female) = 607, is also statistically significant ( $F_{1, 959} = 78$ ,  $P < 0.01$ ).

Analysis of the male/female sex ratio of all dissected *G. auratus* indicates that female fish outnumber males by a ratio of 1:1.88 and 1:1.72 in lakes Crescent and Sorell respectively (Table 3). As the sex ratios for both populations are similar it would appear that this is a common trend in *G. auratus* populations.

**Table 3.** Sex ratio of *Galaxias auratus* populations in lakes Crescent and Sorell.

	Male : Female Ratio	Un-sexed	Total Number Analysed (n)
Crescent	1 : 1.88	110	1307
Sorell	1 : 1.72	108	1069

Populations of *G. auratus* in lakes Crescent and Sorell show very similar trends in their sexual composition with mean length and weight values, and sex ratios closely approximating each other.

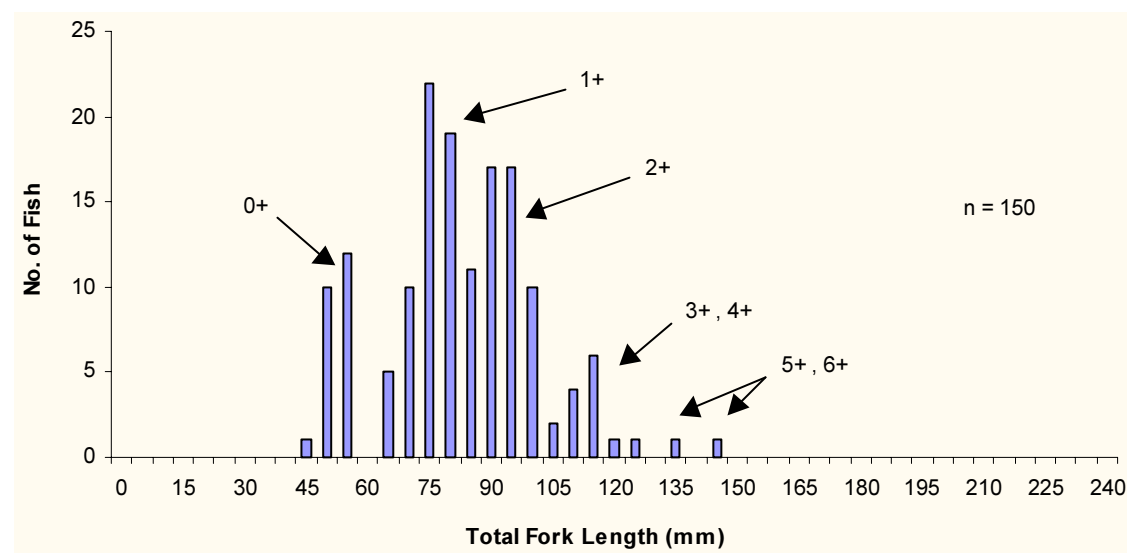
## Age

Analysis of *G. auratus* otoliths (ear bones) indicated that distinct annuli (growth rings) are laid down annually by this species. Age analysis was not formally validated however comparisons between age and length frequency data indicate that age determinations were consistent with the knowledge of recruitment and population structure that has been gained during this study.

Figure 26 shows a length frequency plot of the *G. auratus* population in Lake Crescent in March 2001, with age classes indicated. This length frequency plot shows the typical structure of *G. auratus* populations in lakes Crescent and Sorell observed during this study.

The age structure of wild populations of *G. auratus* is dominated by fish that are 0+, 1+, 2+ and to a lesser extent 3+ and 4+ years of age (Figure 26). Age determination of fish >100 mm (TFL), was found to be more difficult with a decrease in the clarity of defined annuli. A greater number of fish would need to be analysed to improve the precision of aging larger *G. auratus*. However, even though the age analysis has been limited, it is obvious that the majority of *G. auratus* in the wild populations have a maximum live span of 3-4 years.

Specimens greater than 150 mm (TFL) were spasmodically collected during the study, with the largest fish collected being 237 mm (TFL). These larger fish are an interesting characteristic of the *G. auratus* populations, given that most fish don't achieve a very large size. Age determinations have not been undertaken on any of the extremely large individuals, but these fish are suspected to be up to 10+ years of age (possibly more). It is suspected that these very large individuals may not spawn annually or are infertile and are therefore able to direct more energy towards growth without the burden of gonadal development and the stresses related to spawning.



**Figure 26.** Age and length structure of the *Galaxias auratus* population in Lake Crescent March 2001. Where arrows indicate age cohorts and n = number of fish analysed.

### 3.4.2 Reproduction

#### *Sexual Maturation*

Observations on the size at which golden galaxias (*Galaxias auratus*) reach sexual maturation are shown in Table 4. *G. auratus* were found to begin gonad development in their first year, with minimum lengths recorded for fish of both sexes with Stage 1 gonads (resting/virgin) being <52 mm (TFL). The minimum length at which fish were found to have Stage 4 (ripe) gonads indicates that male *G. auratus* reach sexual maturity in their first year but females don't mature until their second year. Male fish from both populations at a length of 51 mm (TFL) were observed with ripe gonads, whereas females were  $\geq 60$  mm (TFL) (generally >70 mm (TFL) using full data set). The maximum sizes at which fish were observed with Stage 4 (ripe) gonads indicates that at least some fish of both sexes remain sexually active at an older age.

**Table 4.** Observations on the size of *Galaxias auratus* at sexual maturation.

	Total Fork Length (TFL) (mm)	
	Male	Female
<b>Crescent</b>		
Minimum Length @ Stage 1	50	46
Minimum Length @ Stage 4	51	69
Maximum Length @ Stage 4	171	181
Number of fish examined (n)	416	779
<b>Sorell</b>		
Minimum Length @ Stage 1	51	46
Minimum Length @ Stage 4	51	60
Maximum Length @ Stage 4	133	179
Number of fish examined (n)	353	607

### ***Gonad Development***

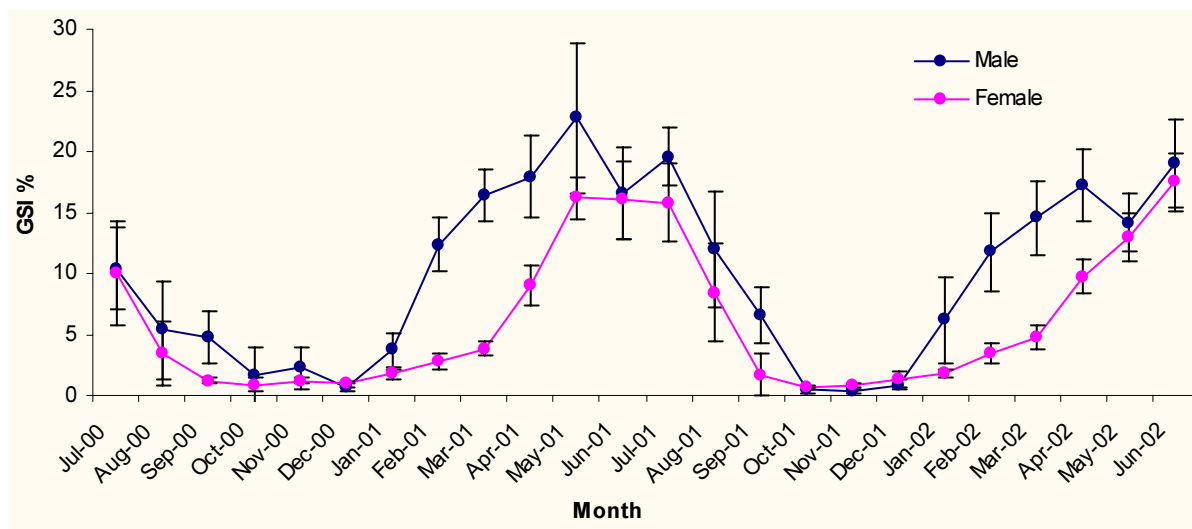
The gonadal cycle of *G. auratus* was examined by calculating the gonado-somatic index (GSI) and reproductive stage of development of the gonads of a proportion of the monthly catches over the study period. Figures 27 and 28 show the gonadal cycle of *G. auratus* in lakes Crescent and Sorell respectively between July 2000 and June 2002. Tables 5 and 6 show the seasonal trends in the reproductive stage of development of *G. auratus* populations in lakes Crescent and Sorell.

The gonad cycle of *G. auratus* was very similar in both lakes during both spawning seasons that occurred during the study. Gonad development begins in early-mid summer in both populations. Just prior to the start of the gonadal development period (December) *G. auratus* populations have mean GSI values of approximately 0.5 – 3 % (Figures 27 and 28) and over 90 % of selected fish are at the resting stage (stage 1) of gonad development (Tables 5 and 6). Gonad development increases significantly during late summer and autumn until the cycle peaks in late autumn - early winter with mean GSI values of 16 – 25 % and >85 % of selected fish at the ripe stage (stage 4) of gonad development. Male fish appear to develop gonads faster than females which suggests that female fish control when spawning will occur. With the onset of spawning in late autumn - early winter, mean GSI values decrease until populations have returned to the resting stage of gonad development by early spring.

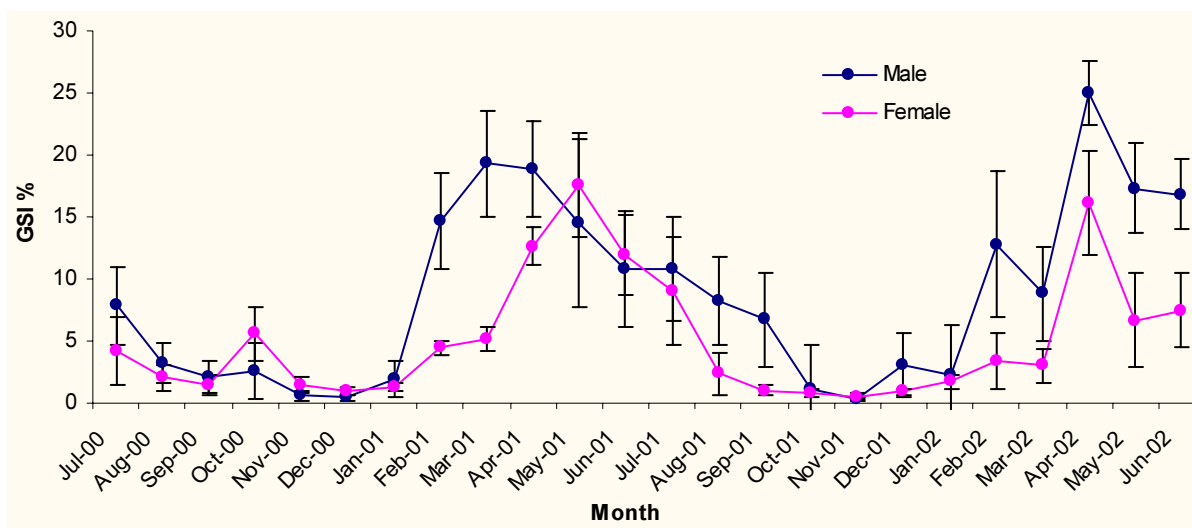
Environmental conditions that trigger gonad development and the actual time of spawning (described later in this section) in *G. auratus* populations were investigated by comparing the gonadal cycle of both populations with changes in lake level, water temperature and photo period (day length) (Figures 29-34).

*G. auratus* gonadal development was found to correspond with decreases in lake level, water temperature and photo period. Although water temperature data sets are incomplete due to equipment failure, sufficient data was collected during the 2001 gonad development period to indicate the significance of this environmental parameter. Water temperature and photo period cycles appear to be inversely proportional to the gonadal cycle of *G. auratus* (Figures 30 and 31, 33 and 34). Gonad development begins around the time of the longest day and highest water temperatures and peaks at the shortest day and coldest water temperatures. Lake level cycles varied during the study and although a significant decrease occurred during the 2001 gonad development period, during the 2002 season the decrease in lake level in both lakes Crescent and Sorell was much less pronounced (Figures 29 and 33).

It is suspected that, of the three environmental parameters investigated, water temperature and photo period are the most important triggers for *G. auratus* gonadal development as they are thought to be less variable from year to year.



**Figure 27.** Gonadal cycle of *Galaxias auratus* in Lake Crescent, July 2000-June 2002. Gonad development is calculated using the gonado-somatic index (GSI). Average monthly GSI values are plotted with 95 % confidence limits.



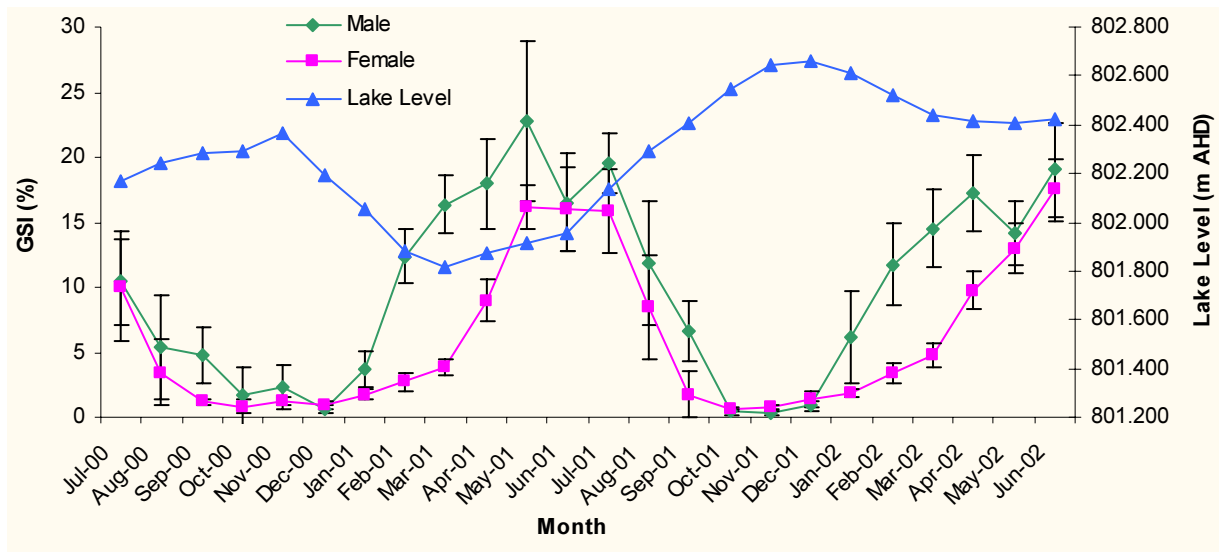
**Figure 28.** Gonadal cycle of *Galaxias auratus* in Lake Sorell, July 2000-June 2002. Gonad development is calculated using the gonado-somatic index (GSI). Average monthly GSI values are plotted with 95 % confidence limits.

**Table 5.** Reproductive stage of development of *Galaxias auratus* in Lake Crescent, July 2000 – June 2002. The data from both sexes is combined and expressed as a percentage of total number of fish examined for each month. The dominant stage(s) of development for each month are represented by bold text.

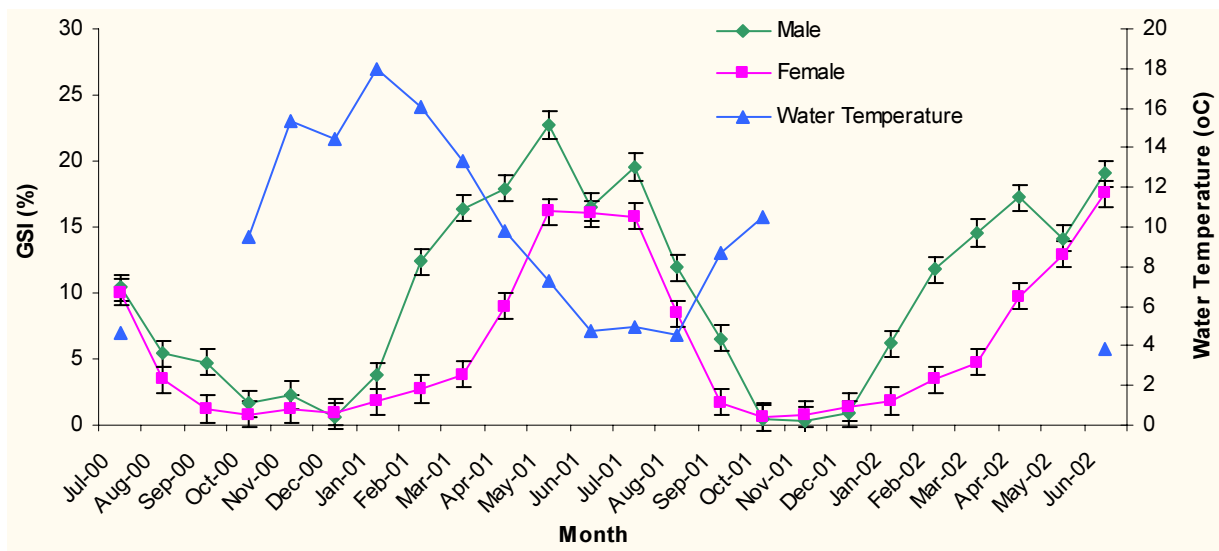
Month	Reproductive Stage of Development					No. of Fish
	1	2	3	4	5	
Jul-00	36	8	2	<b>46</b>	8	50
Aug-00	<b>79</b>	2	2	14	2	42
Sep-00	<b>86</b>	2	2	8	2	49
Oct-00	<b>90</b>	3		5	3	39
Nov-00	<b>95</b>	2		2		42
Dec-00	<b>97</b>	3				36
Jan-01	<b>56</b>	12	10	22		41
Feb-01	23	15	18	<b>45</b>		40
Mar-01	2	20	37	<b>41</b>		41
Apr-01	5		2	<b>86</b>	7	43
May-01	6		2	<b>91</b>		47
Jun-01	10		2	<b>76</b>	12	49
Jul-01	5			<b>73</b>	22	63
Aug-01	16			41	<b>43</b>	51
Sep-01	36	2	2	18	<b>43</b>	61
Oct-01	<b>94</b>				6	54
Nov-01	<b>100</b>					45
Dec-01	<b>98</b>			2		64
Jan-02	<b>70</b>	17	6	8		53
Feb-02	24	22	<b>27</b>	<b>27</b>		51
Mar-02	5	11	32	<b>52</b>		44
Apr-02				<b>100</b>		50
May-02	7		1	<b>87</b>	4	71
Jun-02	1			<b>82</b>	17	77

**Table 6.** Reproductive stage of development of *Galaxias auratus* in Lake Sorell, July 2000 – June 2002. The data from both sexes is combined and expressed as a percentage of total number of fish examined for each month. The dominant stage(s) of development for each month are represented by bold text.

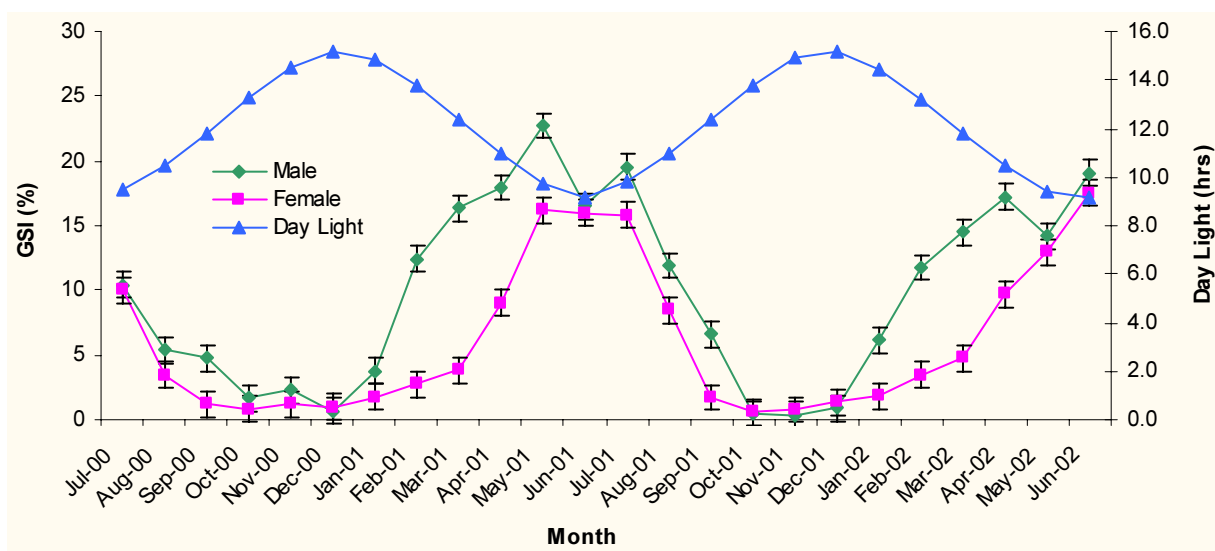
Month	Reproductive Stage of Development					No. of Fish
	1	2	3	4	5	
Jul-00	<b>40</b>	12	4	34	10	50
Aug-00	<b>76</b>	2		17	5	42
Sep-00	<b>93</b>			7		55
Oct-00	<b>61</b>	3	3	32	3	38
Nov-00	<b>88</b>				12	42
Dec-00	<b>95</b>	2			2	42
Jan-01	<b>75</b>	18	5	3		40
Feb-01		15	41	<b>44</b>		27
Mar-01	3	10	<b>47</b>	40		30
Apr-01			6	<b>94</b>		36
May-01	10		4	<b>76</b>	10	49
Jun-01	4			<b>54</b>	42	57
Jul-01	12			<b>44</b>	<b>44</b>	41
Aug-01	19	1		22	<b>58</b>	69
Sep-01	<b>65</b>			10	24	49
Oct-01	<b>97</b>	3				38
Nov-01	<b>100</b>					10
Dec-01	<b>92</b>	4	4			24
Jan-02	<b>55</b>	40	5			20
Feb-02	29	7	21	<b>43</b>		14
Mar-02	<b>31</b>	19	27	23		26
Apr-02	6	2		<b>86</b>	6	49
May-02	41			<b>51</b>	8	49
Jun-02	18			<b>49</b>	33	67



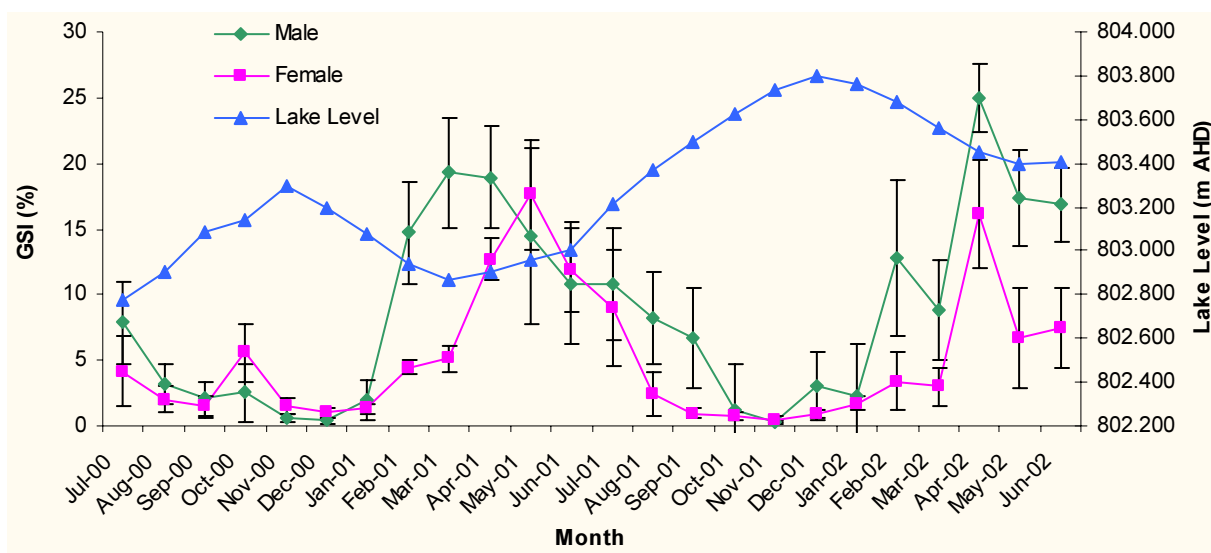
**Figure 29.** Gonadal cycle of *Galaxias auratus* and average monthly lake level in Lake Crescent, July 2000-June 2002. Gonad development is calculated using the gonado-somatic index (GSI). Average monthly GSI values are plotted with 95 % confidence limits.



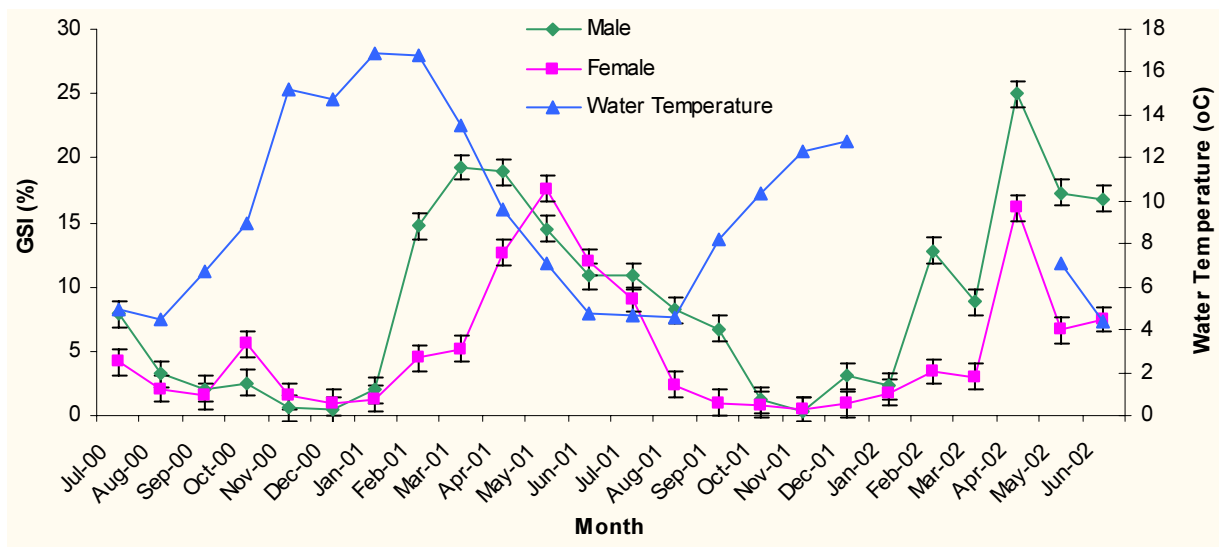
**Figure 30.** Gonadal cycle of *Galaxias auratus* and average monthly water temperature in Lake Crescent, July 2000-June 2002. Gonad development is calculated using the gonado-somatic index (GSI). Average monthly GSI values are plotted with 95 % confidence limits.



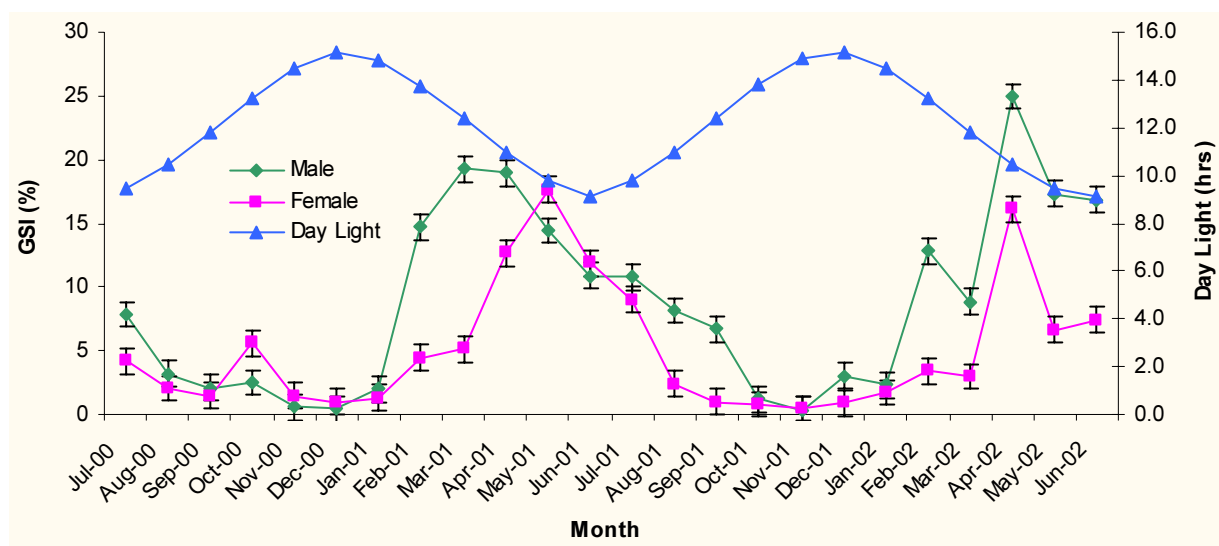
**Figure 31.** Gonadal cycle of *Galaxias auratus* in Lake Crescent and photo period, July 2000-June 2002. Gonad development is calculated using the gonado-somatic index (GSI). Average monthly GSI values are plotted with 95 % confidence limits.



**Figure 32.** Gonadal cycle of *Galaxias auratus* and average monthly lake level in Lake Sorell, July 2000-June 2002. Gonad development is calculated using the gonado-somatic index (GSI). Average monthly GSI values are plotted with 95 % confidence limits.



**Figure 33.** Gonadal cycle of *Galaxias auratus* and average monthly water temperature in Lake Sorell, July 2000-June 2002. Gonad development is calculated using the gonado-somatic index (GSI). Average monthly GSI values are plotted with 95 % confidence limits.

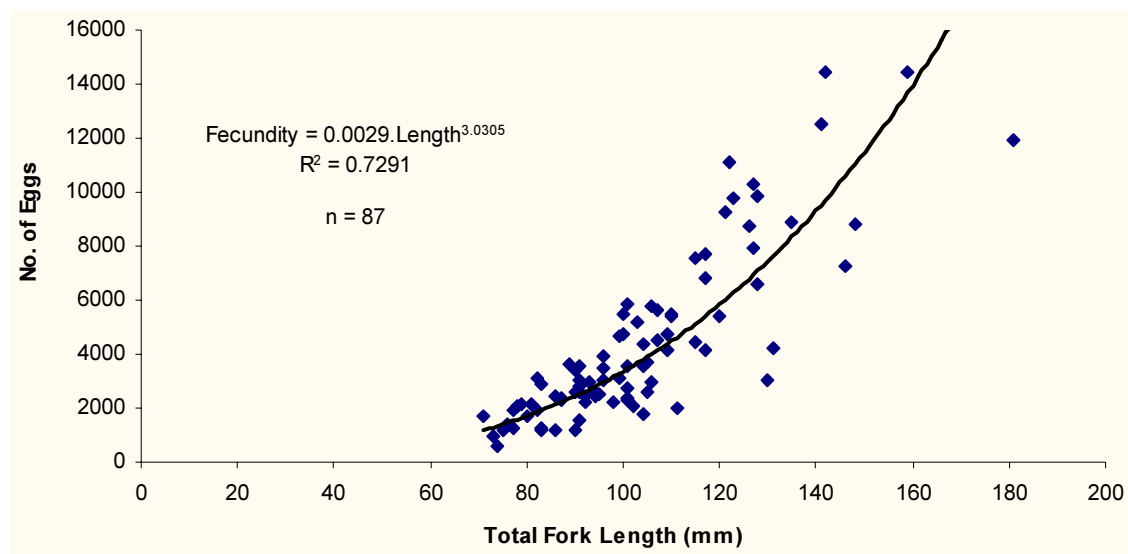


**Figure 34.** Gonadal cycle of *Galaxias auratus* in Lake Sorell and photo period, July 2000-June 2002. Gonad development is calculated using the gonado-somatic index (GSI). Average monthly GSI values are plotted with 95 % confidence limits.

### Fecundity

The fecundity (number of eggs in a female prior to spawning) of a total of 87 fish collected during June and July 2001 from both Lake Crescent and Lake Sorell was analysed. Figure 35 shows the length-fecundity relationship for *G. auratus* that was derived from this data.

The relationship between fecundity (F) and fish length (L) is described by the equation  $F = 0.0029L^{3.0305}$  ( $n = 87$ ,  $R^2 = 0.729$ ) (Figure 35). Given that the length structure of the *G. auratus* populations in lakes Crescent and Sorell is dominated by fish between 70–120 mm (TFL), it is estimated that most female fish hold between 1,100–5,800 eggs. The majority of larger fish (120–180 mm (TFL)) that are present in the wild populations have the capacity to hold up to approximately 19,800 eggs, while the largest recorded *G. auratus* (237 mm (TFL)) could theoretically hold 45,600 eggs. However, the poor condition and lack of development of the gonads of most of the larger specimens that were dissected during the study indicates that most very large fish are quite old (geriatric) and are not sexually active. A more realistic theoretical limit for the fecundity of *G. auratus* would be 15,000 eggs as is suggested by data obtained from the 87 fish that were analysed (Figure 35).



**Figure 35.** Fish length-fecundity relationship for *Galaxias auratus* from Lakes Crescent and Sorell. Fecundity data was collected during June and July 2001. Where  $n$  = number of fish analysed.

## Spawning

The exact timing and length of the spawning period of *G. auratus* was investigated using several techniques during the study. Examination of the gonadal cycle, both analysis of the gonado-somatic index (GSI) (Figures 27 and 28) and determination of the reproductive stage of development of selected fish (Table 5 and 6), provided accurate assessments of the period over which spawning took place. Field observations also provided an indication of the time at which spawning begins and is most intense. Field observations involved recording the presence or absence of *G. auratus* eggs on the fine mesh of fyke nets (used for monthly sampling) and routine eggs searches at known spawning sites (Tables 7 and 8).

The fine mesh (2 mm stretched mesh) of the fyke nets was found to be a suitable spawning substrate for *G. auratus*, with eggs found adhered to net material from late autumn to early spring during 2000/01 monthly sampling (Appendix 2 – Picture 5). To confirm that the eggs adhered to the fyke nets were actually fertilised, approximately 50 eggs were incubated until hatching at the IFS Liawenee laboratory during the *G. auratus* captive breeding trials, spring 2000 (see section 3.4.7). The presence of *G. auratus* eggs on fyke net mesh indicates when the fish are ready to spawn and therefore when spawning is likely to occur in each lake, given that suitable natural substrate is available.

The number of eggs observed at spawning monitoring sites during routine sampling is thought to represent a relative estimate of the number of eggs currently incubating at the site. The technique used to sample eggs (dip net sweeps over disturbed substrate) was found to be an effective method to collect *G. auratus* eggs. However, the accuracy of the method is decreased with the collection of large amounts of detritus in sweep samples, as eggs are much more difficult to observe with the naked eye in the field. To increase the accuracy of the egg collection method it is recommended that sweep samples are preserved and eggs are sorted from the samples in the laboratory in future studies if time permits.

*G. auratus* begin to spawn during late autumn to early winter and spawning extends through to the end of winter. *G. auratus* populations in both lakes Crescent and Sorell followed a similar pattern during the study, however the Lake Sorell population spawned slightly earlier than the Lake Crescent population during both the 2001 and 2002 seasons. The length of the spawning period is shown clearly by gonadal cycle plots for both populations (Figures 27 and 28). Mean GSI values peak in both populations during late autumn - early winter and then gradually decrease during winter until spring, when spawning is finished. This assessment is supported by the reproductive stage of development analysis (Tables 5 and 6), with ripe (stage 4) fish generally dominating the populations during late summer to mid winter and spent (stage 5) fish becoming progressively more frequent and eventually dominate during late autumn to late winter.

**Table 7.** Lake Crescent *Galaxias auratus* spawning site monitoring 2001-2002.

Date	Lake Level (m AHD)	Presence of <i>G. auratus</i> Eggs on Fyke Nets <sup>1</sup>	No. of Eggs Observed at Control Site
24/4/01	~801.892	No	-
23/5/01	801.925	No	-
7/6/01	801.940	-	Nil
19/6/01	801.955	Yes	Nil
2/7/01	~801.955	-	Nil
24/7/01	~802.201	Yes	2
7/8/01	~802.203	-	50
27/8/01	~802.355	Yes	2000
11/9/01	~802.399	-	200
25/9/01	~802.423	Yes	10
23/4/02	802.410	No	-
28/5/02	802.430	No	Nil
13/6/02	802.420	-	Nil
28/6/02	~802.446	No	2
10/7/02	802.470	-	1
25/7/02	~802.485	Yes	5
6/8/02	~802.492	-	150
22/8/02	802.505	-	12

1. Presence of *G. auratus* eggs adhered to mesh of the cod end of at least 1 of the 12 fyke nets set at 3 littoral sites in Lake Crescent during monthly sampling.

**Table 8.** Lake Sorell *Galaxias auratus* spawning site monitoring 2001-2002.

Date	Lake Level (m AHD)	Presence of <i>G. auratus</i> Eggs on Fyke nets <sup>1</sup>	No. of Eggs Observed at Control Site
25/4/01	~802.923	No	-
24/5/01	~802.969	Yes	-
7/6/01	802.980	-	40
20/6/01	803.010	Yes	60
2/7/01	803.030	-	1500
25/7/01	~803.282	Yes	600
7/8/01	803.300	-	400
28/8/01	803.410	Yes	40
11/9/01	803.500	-	1
27/9/01	~803.524	Yes	3
24/4/02	803.425	Yes	3
29/5/02	803.390	Yes	Nil
13/6/02	803.400	-	150
27/6/02	~803.430	Yes	120
11/7/02	~803.443	-	600
26/7/02	~803.503	Yes	20
6/8/02	~803.519	-	2
22/8/02	~803.521	-	0

1. Presence of *G. auratus* eggs adhered to mesh of the cod end of at least 1 of the 12 fyke nets set at 3 littoral sites in Lake Sorell during monthly sampling.

Field observations also support the proposed timing of the spawning period. *G. auratus* eggs were present on fyke nets from June to September and May to September in lakes Crescent and Sorell respectively during 2001 and similar trends are emerging for the 2002 spawning season (Tables 7 and 8). In addition, *G. auratus* eggs were collected at monitoring sites from late July to late September and early July to late September during 2001 in lakes Crescent and Sorell, respectively. Egg searches also indicate that spawning was most intense during August in Lake Crescent and late June in Lake Sorell during 2001, with peaks of 2000 and 1500 eggs being collected.

Environmental conditions that trigger gonad development have previously been discussed. Conditions that trigger spawning were not able to be clearly defined during this study. Water temperature and lake level are thought to be important, however analysis of data related to these parameters in relation to the peaks in spawning intensity (defined by eggs searches) did not provide any clear results. Conditions that prevail while spawning is taking place generally include rising lake level and water temperatures that average 4°C (range 2-7°C). It is suggested that spawning may be triggered by sudden decreases in water temperature and slight increases in lake level that are associated with cold weather patterns typical during late autumn early winter on Tasmanian's Central Plateau. However the most likely scenario is that spawning is triggered by the resultant increases in lake level and slight increases in water temperature that occur in the littoral zone during stable weather after cold fronts have passed.

Spawning was found to take place on rocky shores during the study. Extensive searches for *G. auratus* spawning sites were carried out during winter 2000. It became evident during the searches that *G. auratus* were utilising rocky shores with their small (1.5 mm diameter) transparent and adhesive eggs being abundant in this habitat. Other habitats that were searched included sand and sediment dominated shores and submerged woody debris, however no eggs were found in habitats other than rocky shores.

A small number of eggs were found on one occasion on a single stem of common water milfoil (*Myriophyllum simulans*) which was emerging on a rocky shore. However, the extensive adjacent wetlands were not connected to the main bodies of lakes Crescent and Sorell during the study, and in-lake macrophyte beds which were once abundant in Lake Sorell were found to be non-existent. Therefore it is difficult to assess the importance of aquatic macrophytes as a spawning habitat for *G. auratus* based on the results of this study.

The spawning habitat of *G. auratus* was found to be on cobble dominated rocky substrate (generally 10-200 mm diameter), approximately 200-600 mm deep, in the littoral zone (Appendix 2 – Picture 6). Spawning sites seemed to progress further in-shore with rising lake levels during the spawning season, so that the depth at which eggs were deposited remained reasonably constant and eggs were continually deposited on substrate that had not previously been used. Rocks with eggs attached were observed on several occasions. Eggs were generally found scattered on the top and sides of rocks, positioned individually and occasionally in small clusters of 2-5 eggs.

The spawning behaviour of *G. auratus* remains largely unknown, however some basic observations can be made based on the findings of this study. Catch data indicated that fish become more abundant on shorelines, particularly rocky shores, during the spawning period. It is suspected that male fish may move to the spawning habitat prior to females as they develop their gonads faster. Female fish are thought to dictate the timing of spawning events. Fertilisation and deposition of eggs may involve a mid water release of eggs and milt above suitable rocky substrate after which eggs settle and adhere to rocks and cobble. It is also suggested that there is a reasonably large post-spawning mortality, particularly due to infections that may result from stress, aggressive behaviour and/or abrasions from rocky substrates.

### ***Egg Incubation***

It is difficult to accurately determine the length of the incubation period of *G. auratus* eggs in the wild, however some basic observations can be made from the data collected during this study.

Spawning was first detected through the presence of eggs at spawning control sites, in late July and late June during the 2001 and 2002 spawning season respectively in Lake Crescent (Table 7). Spawning was also found to have been most intense during August of the 2001 season in Lake Crescent with the largest abundance of *G. auratus* eggs being found in late August. In comparison, the beginning of the larval hatching period, as determined by the presence of larvae (fish  $\leq 7$  mm (TFL)) in water column tow samples (Table 9), was found to be late August during 2001 and late June during 2002 in Lake Crescent, while the peak in larval hatching occurred during October 2001. These observations suggest that, during the 2001 spawning season, *G. auratus* eggs that were spawned early in the season took around 34 days to incubate and the eggs that were spawned in the peak of spawning activity took up to 63 days to incubate. Although given that the average size of the larval catch in late October had already begun to increase, the peak in larval hatching is likely to have occurred early in the month resulting in an incubation period of around 40 days for these eggs. The incubation period during the 2002 spawning season in Lake Crescent is not known, as a small number of larvae were already present in the water column when the first eggs were observed at the spawning control site.

In Lake Sorell, spawning was first detected in early June 2001 and late April 2002 (Table 8). Spawning was found to have been most intense during late June – early July in 2001. The beginning of the larval hatching period was found to be late July during 2001 and late May during 2002 (Table 9). The peak in larval hatching occurred during July in 2001. These observations suggest that in Lake Sorell during the 2001 spawning season, *G. auratus* eggs that were spawned early in the season took around 18 days to hatch, while eggs that were spawned during the peak in spawning activity took around 23 days to hatch. During the 2002 season in Lake Sorell *G. auratus* eggs that were spawned early in the season took around 33 days to hatch.

**Table 9.** Length structure of larval (0+) *Galaxias auratus* catch present in water column tow samples from Lake Crescent and Lake Sorell, during the 2000-2002 spawning seasons. Length data is expressed as mean and range and n = number of fish measured. Catches that did not contain newly hatched larvae ( $\leq 7$  mm TFL) are shaded.

Dates	Month	Length of Larval (0+) <i>G. auratus</i> Catch (mm T.F.L)	
		Crescent	Sorell
12-13/9/00	September - 00	5.5 (4-8) n = 39	5.9 (4-7) n = 126
17-18/10/00	October - 00	6.7 (5-8) n = 555	6.6 (4-8) n = 37
22-23/11/00	November - 00	11.9 (5-17) n = 599	10.0 (7-14) n = 70
19-20/12/00	December - 00	25.0 (14-31) n = 98	19.8 (14-23) n = 22
25/7/01	July - 01	-	6.9 (5-9) n = 1320
27-28/8/01	August - 01	7.5 (5-9) n = 142	7.5 (6-9) n = 400
25-26/9/01	September - 01	8.0 (6-10) n = 225	7.9 (6-10) n = 310
29-30/10/01	October - 01	9.9 (7-15) n = 400	11.6 (7-20) n = 370
29/11/01	November - 01	19.3 (13-27) n = 376	24.1 (11-34) n = 245
18/12/01	December - 01	26.2 (8-24) n = 280	29.0 (9-38) n = 93
29/5/02	May - 02	-	6.0 (5-12) n = 88
26/27/6/02	June - 02	7.1 (5-13) n = 30	6.7 (4-9) n = 380
24-25/7/02	July - 02	7.1 (6-8) n = 9	6.8 (5-8) n = 332

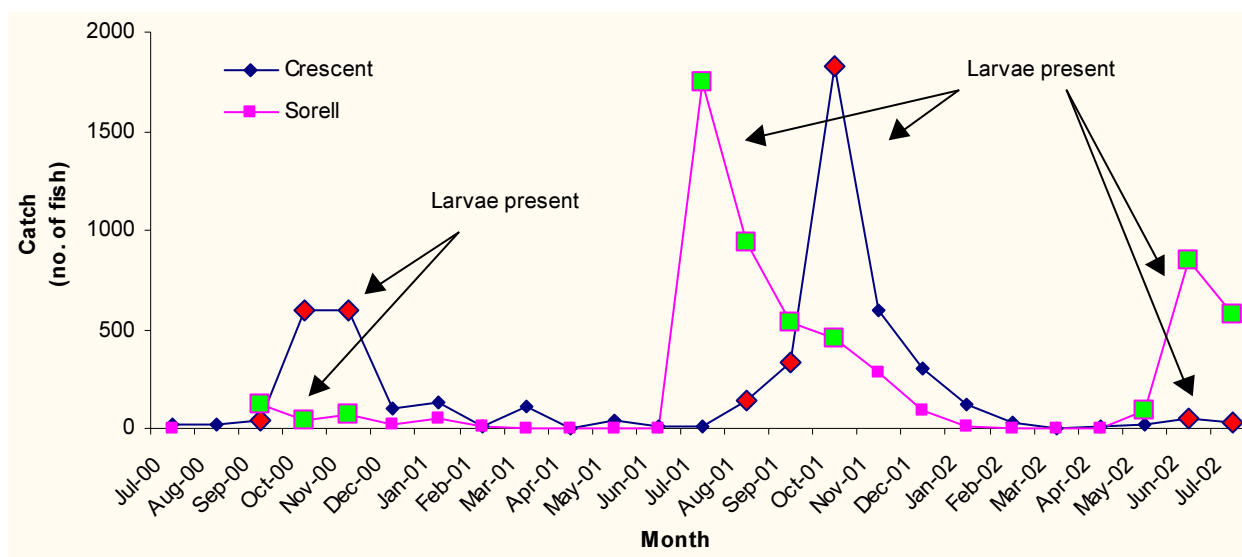
Water temperature is the main environmental parameter controlling the length of the incubation of fish eggs. Average in-lake water temperatures during the spawning period in lakes Crescent and Sorell, were similar to those of the aquariums in the Liawenee laboratory during the captive breeding trials. However, the littoral margins where *G. auratus* eggs incubate in the wild, are thought to be prone to larger fluctuations in water temperature, particularly warming during fine stable weather. As a result, it is suggested that the length of the incubation period of *G. auratus* eggs in the wild is less than that determined in captivity, which was 55-65 days at water temperatures of 4-5°C. It is suspected that *G. auratus* eggs take approximately 30-45 days to incubate in the wild depending on the time of year spawning takes place.

### Larval Hatching

Upon hatching *G. auratus* larvae are transparent, 5-7 mm (TFL) in length and are active swimmers (see captive breeding results section 3.4.7). Once larvae have hatched they become pelagic and enter the mid to upper water column and disperse across lakes Crescent and Sorell, presumably utilising the strong wind driven currents that occur in these lakes. The abundance of larval *G. auratus* across the water column of lakes Crescent and Sorell was generally found to be quite uniform during sampling, although it is suspected that densities may change according to the prevailing currents during strong wind events.

The timing of the *G. auratus* larval hatching period was found to vary during the 2000–2002 spawning seasons, becoming progressively earlier during each season. Larvae began hatching in Lake Crescent during September in 2000, August in 2001 and June during 2002, while larvae began hatching in Lake Sorell also in September in 2000, but in July in 2001 and May in 2002 (Table 9). Peaks in larval hatching are shown in Figure 36, with the obvious peaks in the catches of *G. auratus* in water column sampling being caused by large influxes of larval fish. The rapid decreases in juvenile catches in the water column after the initial peaks in larval hatching, are thought to be due to high mortality of the extremely abundant *G. auratus* larvae (0+ cohort) during the first 4 months of life.

Reasons for earlier spawning and larval hatching in Lake Sorell and the progression towards earlier spawning and hence larval hatching in both lakes, is unclear. Some basic observations and theories in regard to this interesting difference between the two populations are discussed later (see section 4.2.1).



**Figure 36.** Catch of *Galaxias auratus* larvae and juveniles in water column of lakes Crescent and Sorell July 2000–July 2002. The presence of larvae (fish  $\leq 7$  mm TFL) in catches is indicated by arrows and enlarged data points.

### 3.4.3 Diet

#### *Larvae and Juveniles*

During this study the diet of larvae/juvenile (<40 mm) golden galaxias (*Galaxias auratus*) was not investigated as this aspect of the ecology of *G. auratus* populations in lakes Crescent and Sorell has been previously studied (Frijlink 1999).

Frijlink (1999) examined 595 fish ranging in size from 5 to 42 and 5 to 32 mm standard length (SL) in Lake Crescent and Lake Sorell respectively. Larvae were found to feed on zooplankton, primarily rotifers and copepods, until they reach approximately 15 mm (SL). As juvenile *G. auratus* grow from 15 to about 40 mm (SL), they feed progressively on larger zooplankton species such as cladocerans and insect larvae (chironomids) and eventually small crustaceans including decapods (*Paratya australiensis*) and ostracods. Frijlink (1999) concluded that cladocerans, *Bosmina meridionalis* and *Moina micrura* were the major prey items of juvenile *G. auratus* in Lake Crescent, whereas, the calanoid copepod - *Boeckella rubra*, *Daphnia* sp. and chironomid pupae were of greater relative importance in Lake Sorell.

#### *Adults*

In this study, the diet of juvenile fish (generally >40 mm (TFL)) was examined along with adult fish ranging in size up to 201 mm (TFL). The diet of *G. auratus* populations in lakes Crescent and Sorell was generally dominated by *Daphnia* sp. gastropods, amphipods, isopods, dipteran larvae, ostracods and *Paratya australiensis*. Their own eggs were also a significant diet item during spawning. A list of the diet items encountered during the study is shown in Table 10. Notable differences in the diet of the two populations were the additional importance of nematodes in the diet of *G. auratus* in Lake Crescent and the almost exclusive predation upon *Daphnia* sp. by *G. auratus* in Lake Sorell for extended periods.

The diet of the adult *G. auratus* populations in lakes Crescent and Sorell was examined by calculating the frequency of occurrence (FOO) and volumetric contribution (Volume) of 21 diet item groups (generally an Order or Class of invertebrate). Two of the diet item groups are not specific to an animal group, but represent organic and inorganic matter (Detritus) and animal material that could not be identified (Other). This allowed the total volume of material in the guts of fish to be accounted for in a percentage index.

**Table 10.** Dietary items of *Galaxias auratus* in lakes Crescent and Sorell. Diet item groups that dominated the composition of the diet of *G. auratus* are shaded. Where ‘?’ means unconfirmed identification.

Diet Group and Family	Species
<b>Aquatic Items</b>	
<b>Cladocera</b>	
Daphniidae	<i>Daphnia carinata</i> <i>Ceriodaphnia quadrangular</i>
Bosminidae	<i>Bosminia meridionalis</i>
Chydoridae	<i>Chydorus</i> sp.
<b>Copepoda</b>	
Harpacticoid	Unidentified sp.
Calanoid	Unidentified sp.
Cyclopoid	Unidentified sp.
<b>Nematoda</b>	Unidentified sp.
<b>Oligochaeta</b>	Unidentified sp.
<b>Gastropoda</b>	
Planorbidae	<i>Glyptophysa</i> sp. <i>Gyraulus</i> sp.
Hydrobiidae	<i>Austropygrus</i> sp.
<b>Bivalvia</b>	
Sphaeriidae	<i>Pisidium</i> sp.
<b>Amphipoda</b>	
Paramelitidae	<i>Antipodeus</i> sp. ( <i>mortoni</i> ?)
Ceinidae	<i>Austrochiltonia australis/subtemuis</i>
<b>Isopoda</b>	
Phreatoicidae	<i>Colubotelson</i> sp. ( <i>joyneri</i> ?)
Janiridae	<i>Heterias</i> sp.
<b>Collembola</b>	
Isotomidae	<i>Isotomid</i> sp.
<b>Ephemeroptera</b>	
Leptophlebiidae	<i>Tillyardophlebia</i> sp. AV2
<b>Plecoptera</b>	
Eustheniidae	<i>Eusthenia spectabilis/lacaustris</i>
Gripoptergidae	<i>Leptoperla varia</i> <i>Dinotoperla</i> sp. ( <i>serricaudata</i> ?)
<b>Trichoptera</b>	
Ecnomidae	<i>Ecnomus tillyardi</i>
Atriplectididae	<i>Atriplectides dubius</i>
Philoreithridae ?	Unidentified sp.
<b>Diptera</b>	
Tanypodinae	<i>Coleopynia pruinosa</i>
Chironomidae	Sub F. Chironominae sp. Sub F. Orthoclaadiinae sp.
Tipulidae	Unidentified sp.
<b>Ostracoda</b>	Unidentified sp.
<b>Decapoda</b>	
Atyidae	<i>Paratya australiensis</i>

Table 10. Continued...

<b>Hemiptera</b>	
Corixiidae	<i>Diaprepocoris barycephala</i>
Notonectidae	<i>Anisops</i> sp. ( <i>evansi</i> ?)
<b>Coleoptera</b>	
Psephenidae	<i>Sclerocyphon lacaustris</i>
Dytiscidae	<i>Liodessus amabilis</i>
	<i>Necterosoma penicillatus</i>
	<i>Sternopricus maedfooti</i>
	<i>Sternopricus tarsalis</i>
	<i>Sternopricus tasmanicus</i>
Elmidae	<i>Simsonia tasmanica</i>
	<i>Kingolus auratus</i>
	<i>Kingolus</i> sp. ( <i>auratus</i> ?)
<i>Galaxias auratus</i> eggs	
<i>Galaxias auratus</i> juveniles	
<b>Terrestrial Items</b>	
<b>Coleoptera</b>	
Chrysomelidae	<i>Chrysophtharta</i> sp.
	<i>Paropsis</i> sp.
Cerambycidae	Sub F. Cerambycinae sp.
	Sub F. Prioninae sp.
Elateridae	<i>Elaterid</i> sp.
Scarabidae	Sub F. Aphodiinae sp.
	Sub F. Melolonthinae sp.
	Unidentified sp.
	Unidentified sp.
Bostrichidae	Unidentified sp.
Cicinelidae	Unidentified sp.
<b>Hemiptera</b>	
Eurymelidae	<i>Eurymeloides?</i> sp.
Psyllidae	<i>Psyllid</i> sp.
<b>Hymenoptera</b>	
Formicidae	<i>Camponotus</i> sp.
<b>Orthoptera</b>	
Acrididae	<i>Acridid</i> sp.
<b>Oligochaeta</b>	
Terrestrial earthworm	Unidentified sp.
<b>Acarina</b>	
(Spiders)	Unidentified sp.
	Unidentified sp.
<b>Diptera</b>	
	Unidentified sp. I
	Unidentified sp. II
	Unidentified sp. III
	Unidentified sp. IV

To analyse the feeding strategies of *G. auratus* populations diet item groups were arranged into three functional divisions along the horizontal axis (x axis) of dietary plots. The three functional divisions represent diet item groups that are:

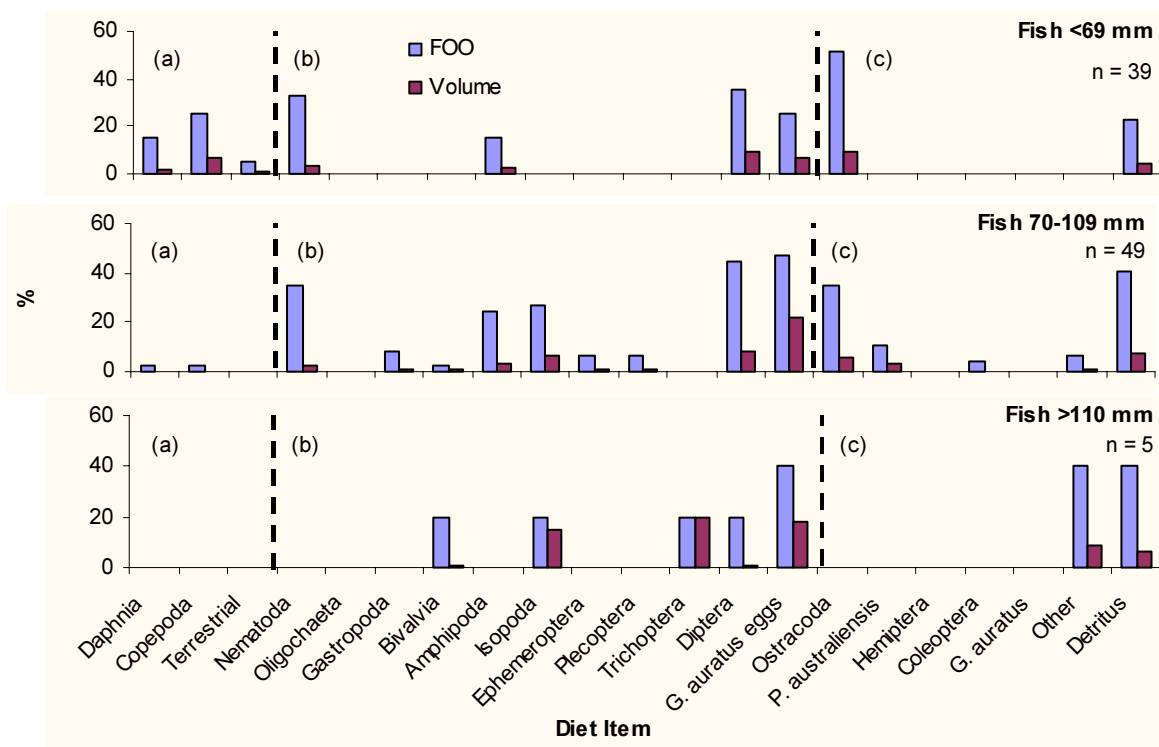
- (a) generally found in the water column or at the surface (pelagic),
- (b) generally found on or in close proximity to substrate (benthic), and
- (c) mobile and may be encountered near substrate or in the water column (mobile) including the two non specific groups, Other and Detritus.

Analysis of the three functional divisions provides information in regard to the location within the lake habitats where prey were captured and hence the feeding strategy being employed. To analyse the feeding strategies of different sized fish and seasonal trends in the diet of *G. auratus* populations, the populations were also separated into three length classes ( $\leq 69$  mm, 70-109 mm and  $\geq 110$  mm (TFL)) and data was analysed at seasonal intervals. The seasonal composition of the diet of the three different size classes of *G. auratus* populations in lakes Crescent and Sorell are shown in Figures 37-44 and Figures 45-52 respectively.

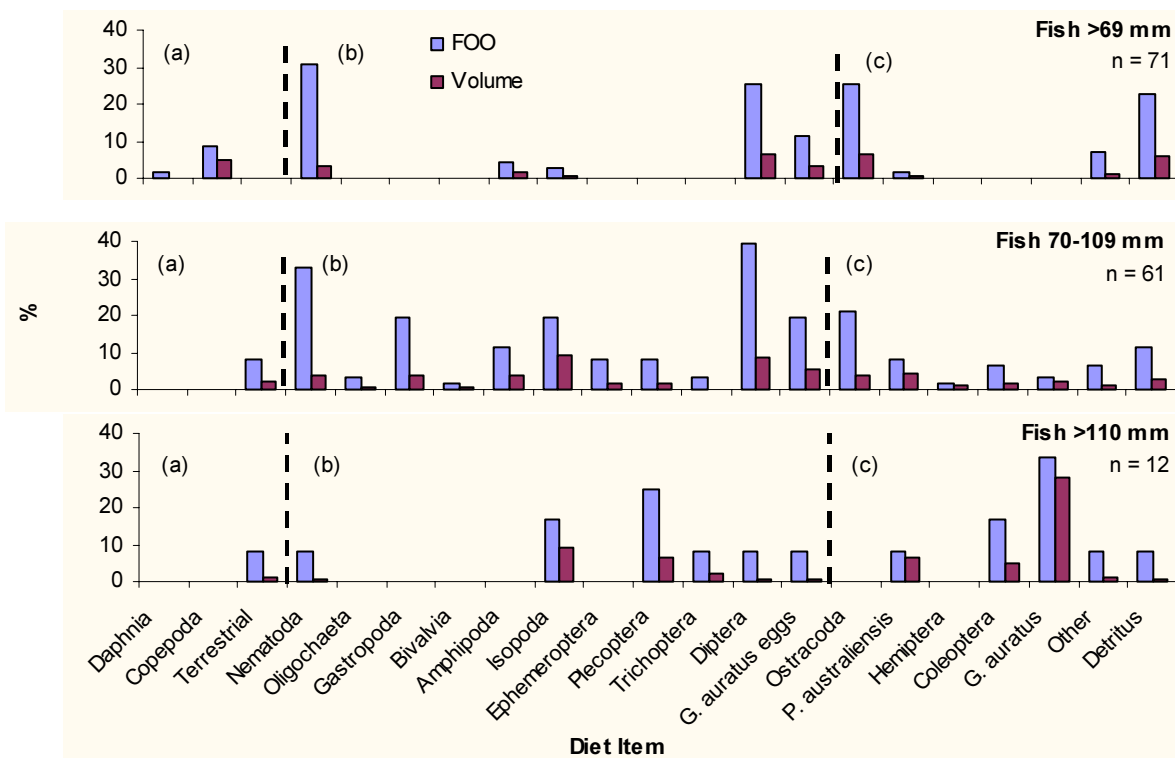
In Lake Crescent the diet of the entire *G. auratus* population (all three size classes) varied seasonally during the study period. *G. auratus* fed primarily on benthic prey items during winter and spring with their own eggs being a major diet item during this period (Figures 37, 38, 41 and 42). Pelagic and surface dwelling prey items become much more dominant in summer and autumn and to a lesser extent mobile prey were also important during this period (Figures 39, 40, 43 and 44).

Different size classes of *G. auratus* also have noticeable variations in their diet in Lake Crescent, with smaller juvenile fish ( $\leq 69$  mm (TFL)) generally preying upon smaller animals such as zooplankton (*Daphnia* and Copepoda) and some terrestrial invertebrates in the pelagic zone (Figures 37-44). Fish in the smallest size class were also found to feed on some benthic prey, but mobile prey (with the exception of Ostracoda) did not form a major component of their diet. The two larger size classes (70-109 and  $\geq 110$  mm (TFL)) had a similar diet, preying on the full range of diet items, with benthic animals being the most important. The largest size class also had a tendency to predate on larger and more mobile prey (ie heavy predation on *Paratya australiensis* and instances of cannibalism).

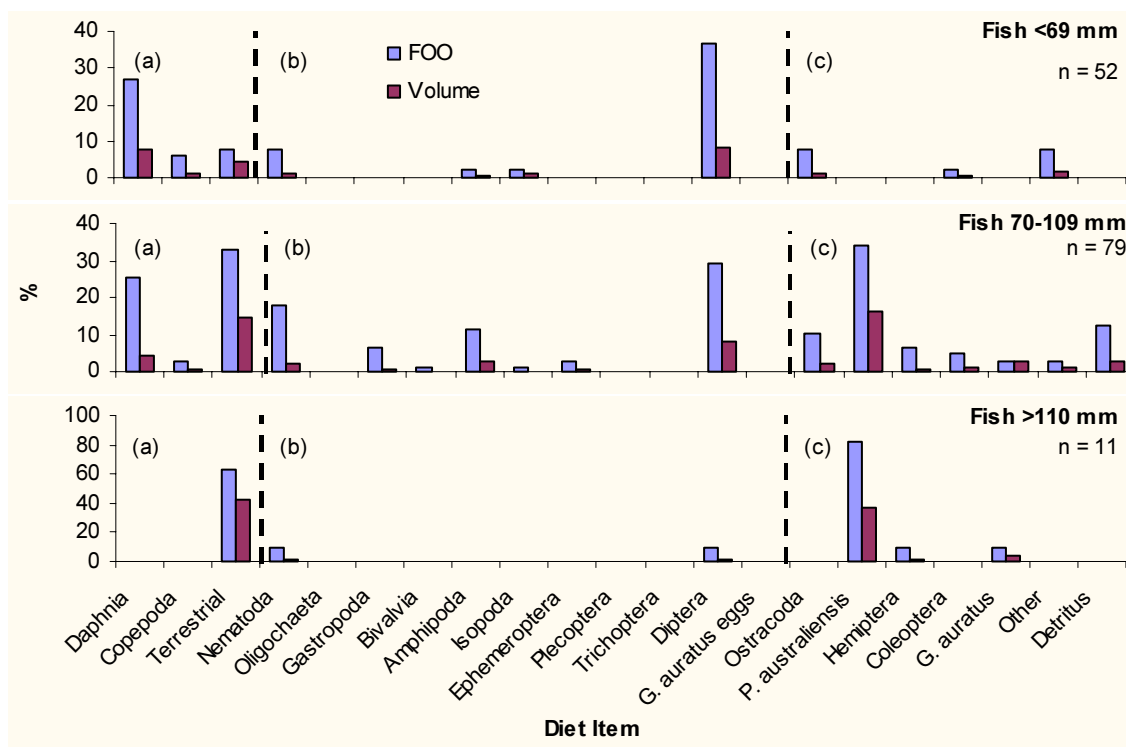
The diet of the *G. auratus* population in Lake Sorell was quite different to that of the population in Lake Crescent. This was primarily due to the dominance of *Daphnia* sp. in the diet of the entire population in Lake Sorell for most of the study (summer 2000/01 to autumn 2002) (Figures 45-52). This indicates that *G. auratus* in Lake Sorell had a preference for feeding in the pelagic zone. However, similar seasonal patterns in the diet and feeding strategies to those observed in Lake Crescent were also found in Lake Sorell. *G. auratus* in Lake Sorell also had a tendency to feed on benthic prey items during winter and spring (Figures 45, 46, 49 and 50), although during 2001, *Daphnia* sp. remained an important diet item (Figures 47-51).



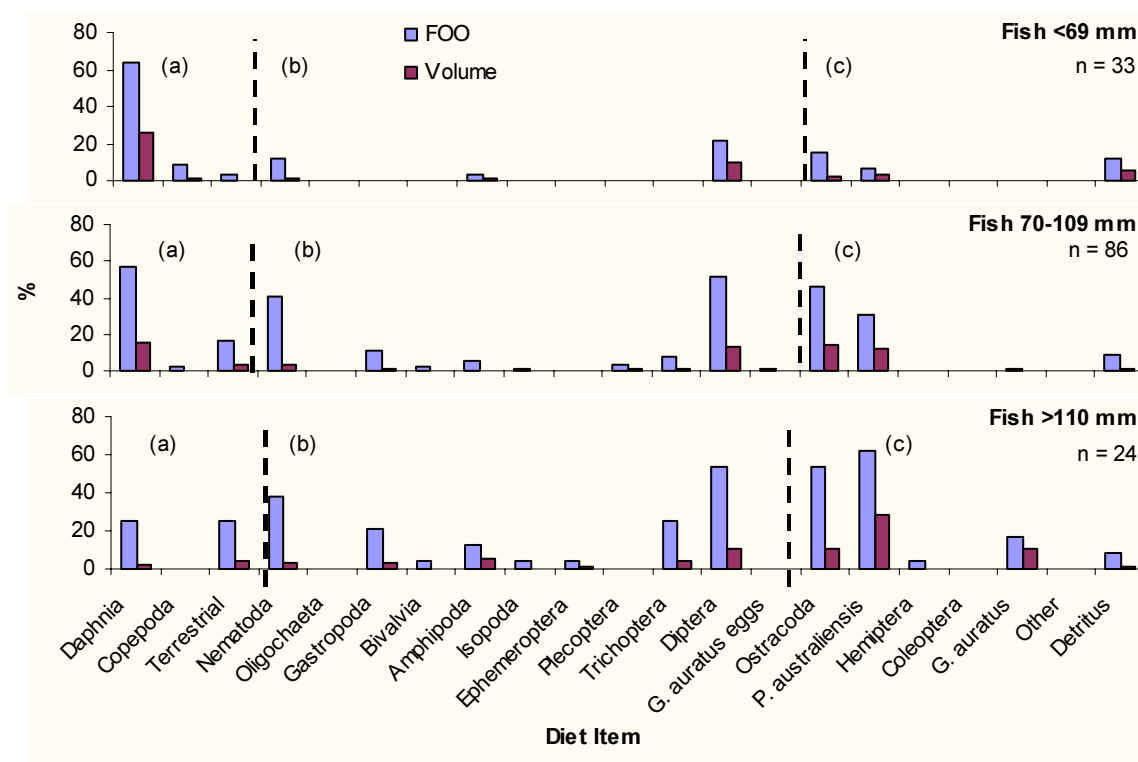
**Figure 37.** Diet of *Galaxias auratus* in Lake Crescent during winter 2000. Broken lines separate pelagic (a), benthic (b) and mobile (c) functional diet item divisions, n = number of fish and FOO = frequency of occurrence.



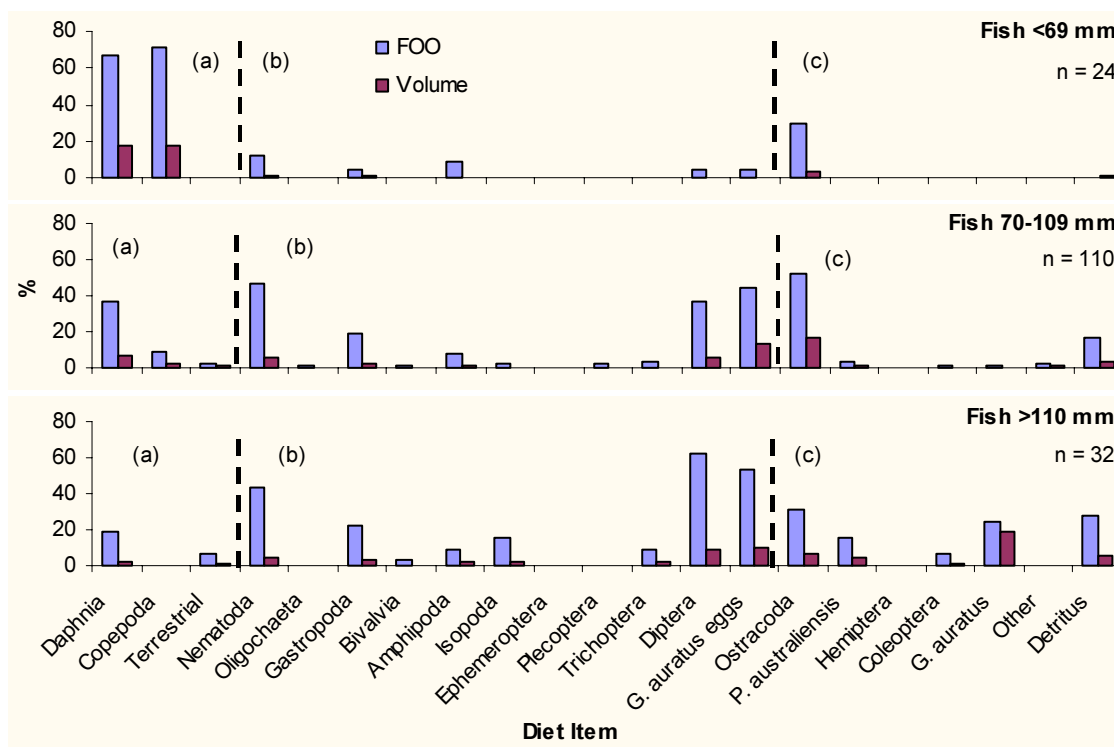
**Figure 38.** Diet of *Galaxias auratus* in Lake Crescent during spring 2000. Broken lines separate pelagic (a), benthic (b) and mobile (c) functional diet item divisions, n = number of fish and FOO = frequency of occurrence.



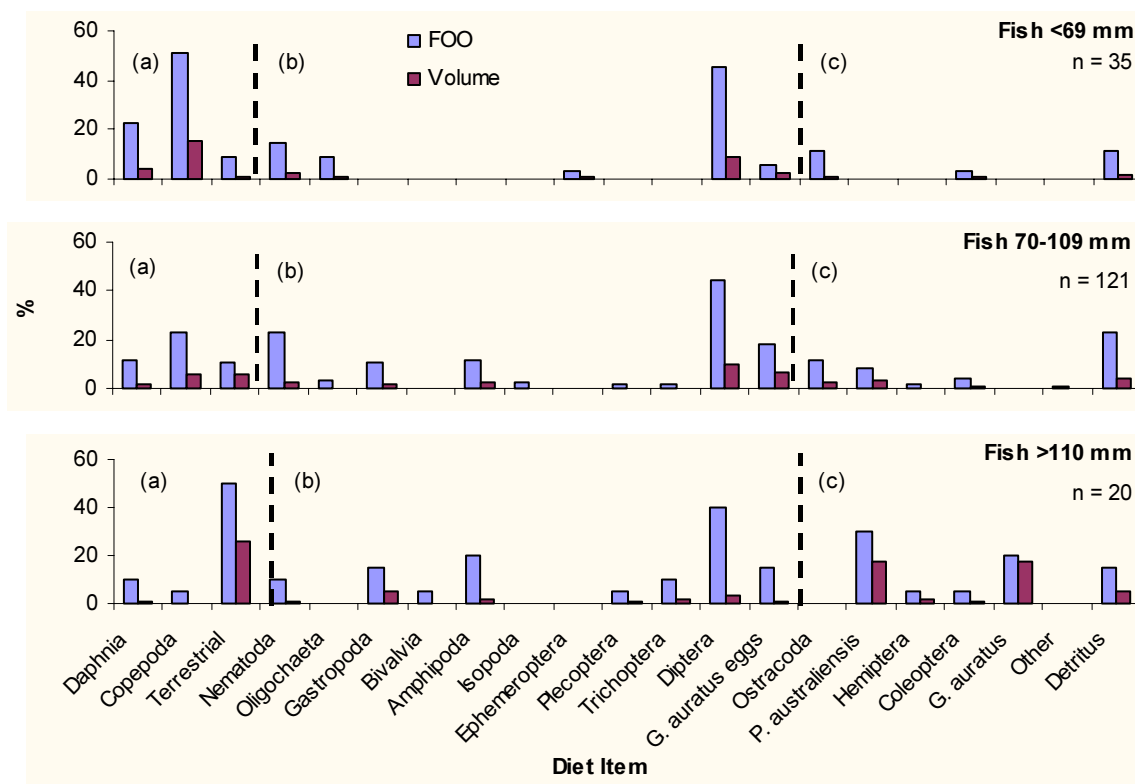
**Figure 39.** Diet of *Galaxias auratus* in Lake Crescent during summer 2000-2001. Broken lines separate pelagic (a), benthic (b) and mobile (c) functional diet item divisions, n = number of fish and FOO = frequency of occurrence.



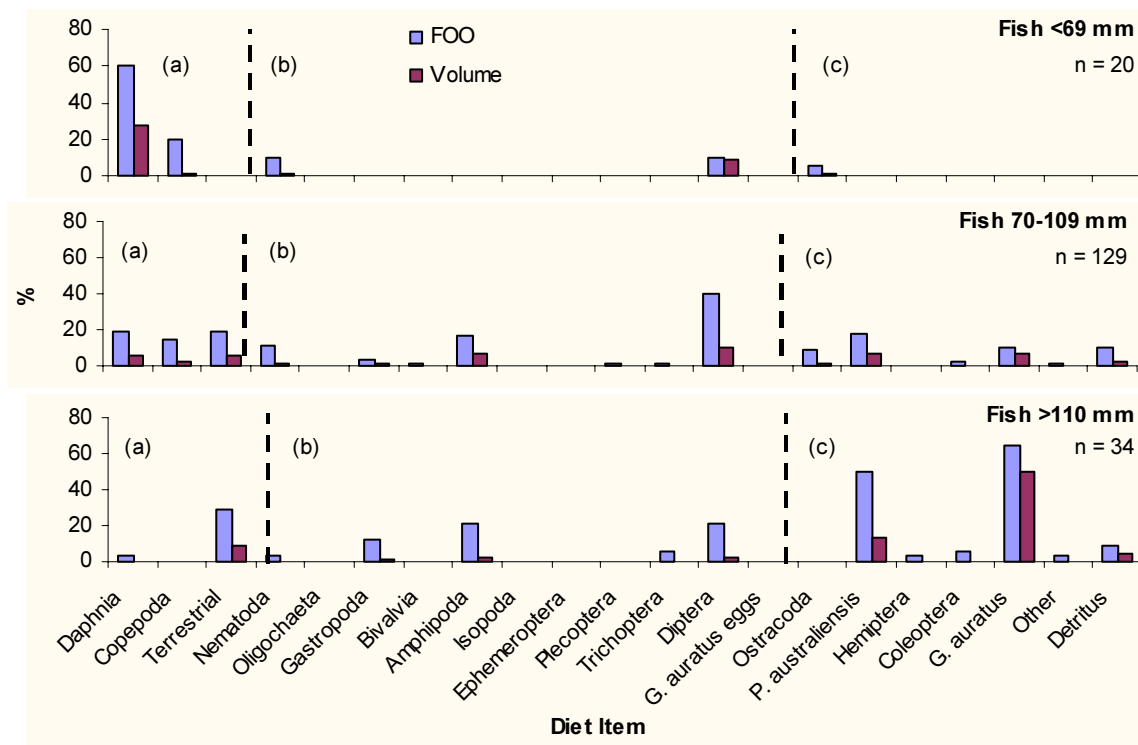
**Figure 40.** Diet of *Galaxias auratus* in Lake Crescent during autumn 2001. Broken lines separate pelagic (a), benthic (b) and mobile (c) functional diet item divisions, n = number of fish and FOO = frequency of occurrence.



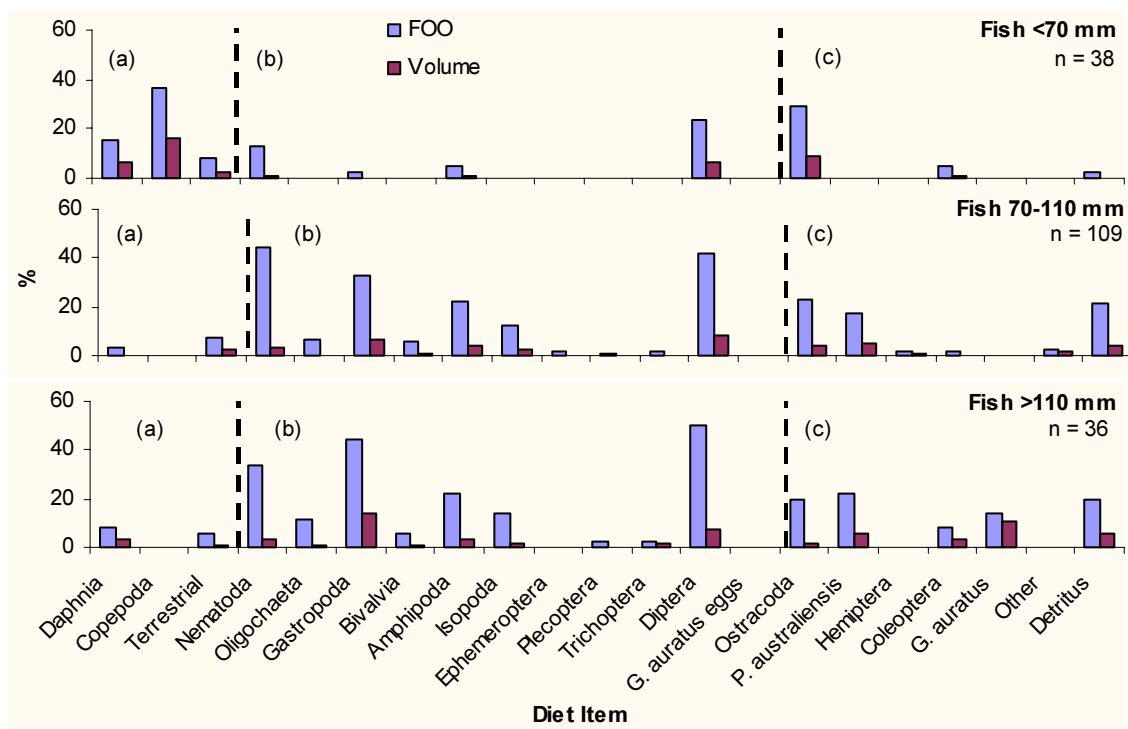
**Figure 41.** Diet of *Galaxias auratus* in Lake Crescent during winter 2001. Broken lines separate pelagic (a), benthic (b) and mobile (c) functional diet item divisions, n = number of fish and FOO = frequency of occurrence.



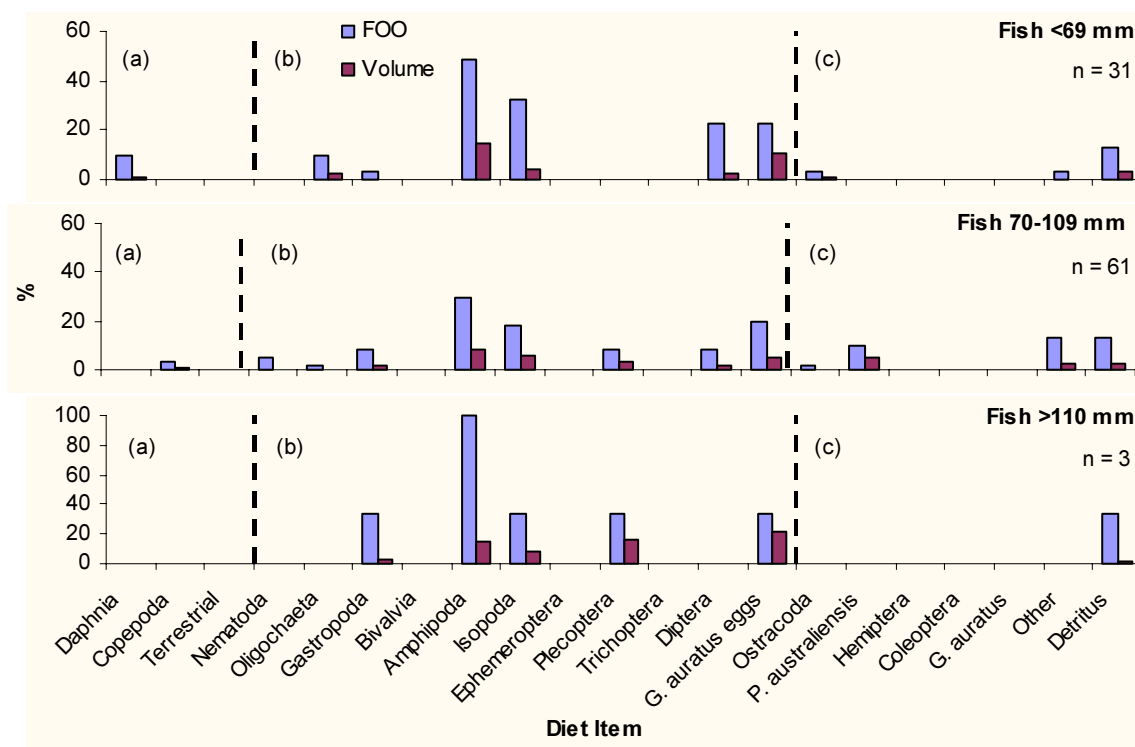
**Figure 42.** Diet of *Galaxias auratus* in Lake Crescent during spring 2001. Broken lines separate pelagic (a), benthic (b) and mobile (c) functional diet item divisions, n = number of fish and FOO = frequency of occurrence.



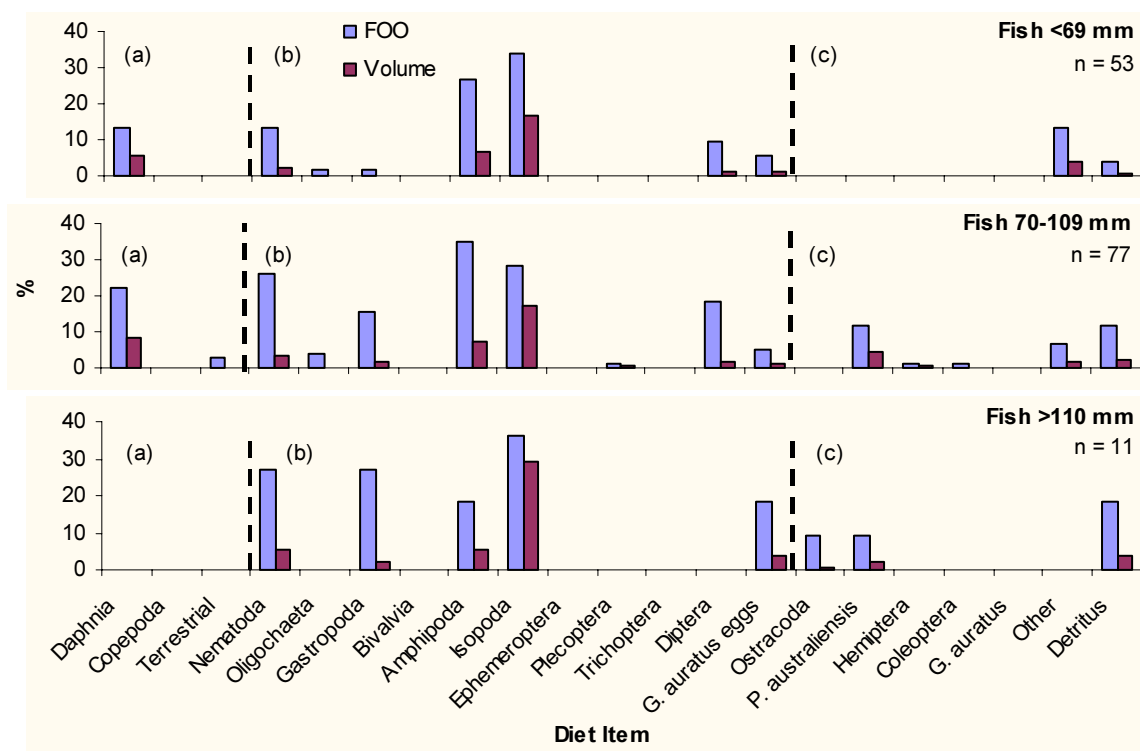
**Figure 43.** Diet of *Galaxias auratus* in Lake Crescent during summer 2001-2002. Broken lines separate pelagic (a), benthic (b) and mobile (c) functional diet item divisions, n = number of fish and FOO = frequency of occurrence.



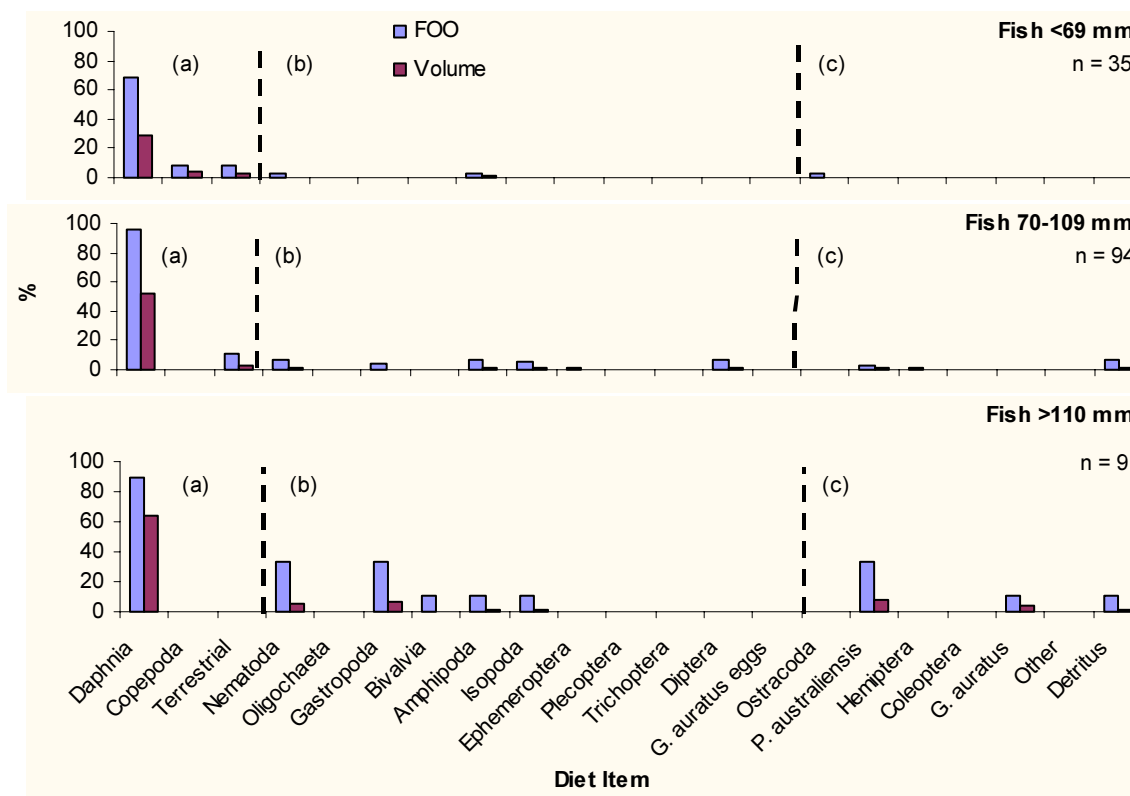
**Figure 44.** Diet of *Galaxias auratus* in Lake Crescent during autumn 2002. Broken lines separate pelagic (a), benthic (b) and mobile (c) functional diet item divisions, n = number of fish and FOO = frequency of occurrence.



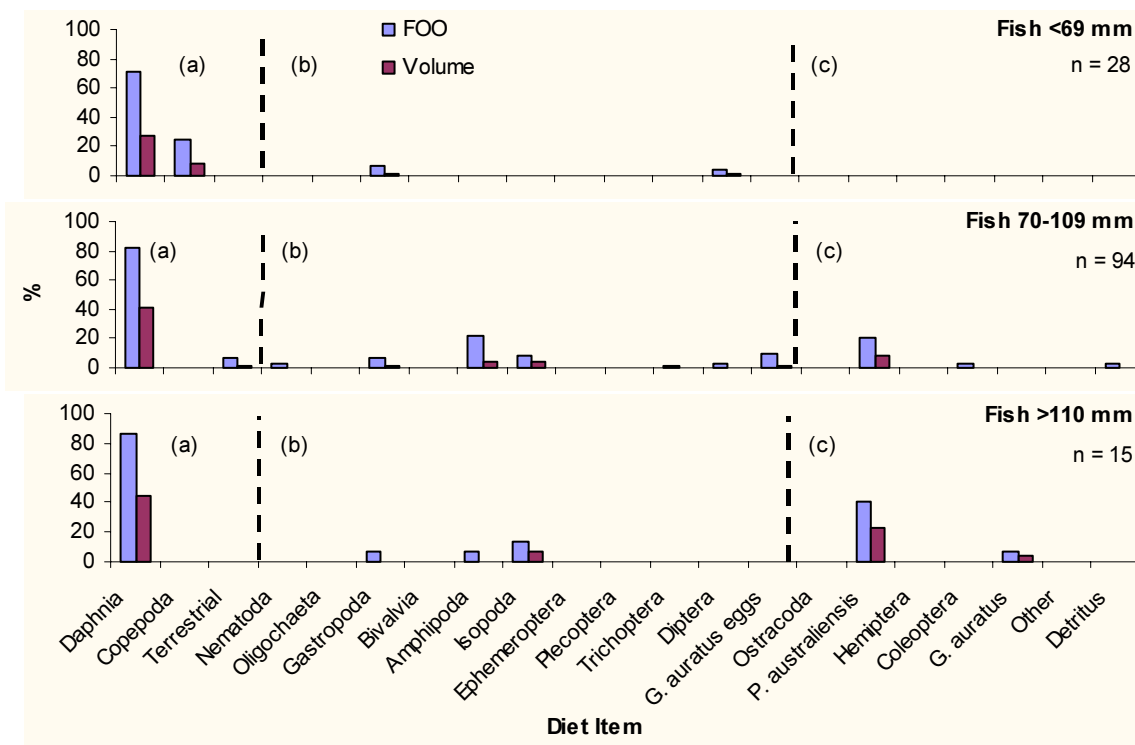
**Figure 45.** Diet of *Galaxias auratus* in Lake Sorell during winter 2000. Broken lines separate pelagic (a), benthic (b) and mobile (c) functional diet item divisions, n = number of fish and FOO = frequency of occurrence.



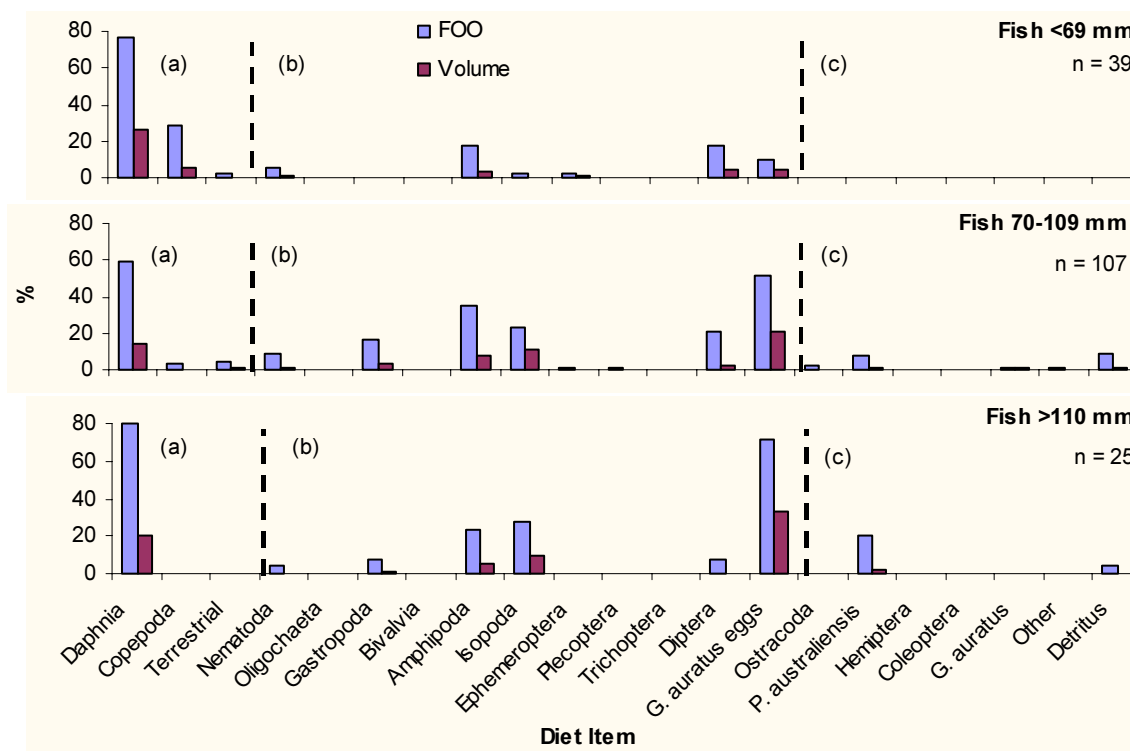
**Figure 46.** Diet of *Galaxias auratus* in Lake Sorell during spring 2000. Broken lines separate pelagic (a), benthic (b) and mobile (c) functional diet item divisions, n = number of fish and FOO = frequency of occurrence.



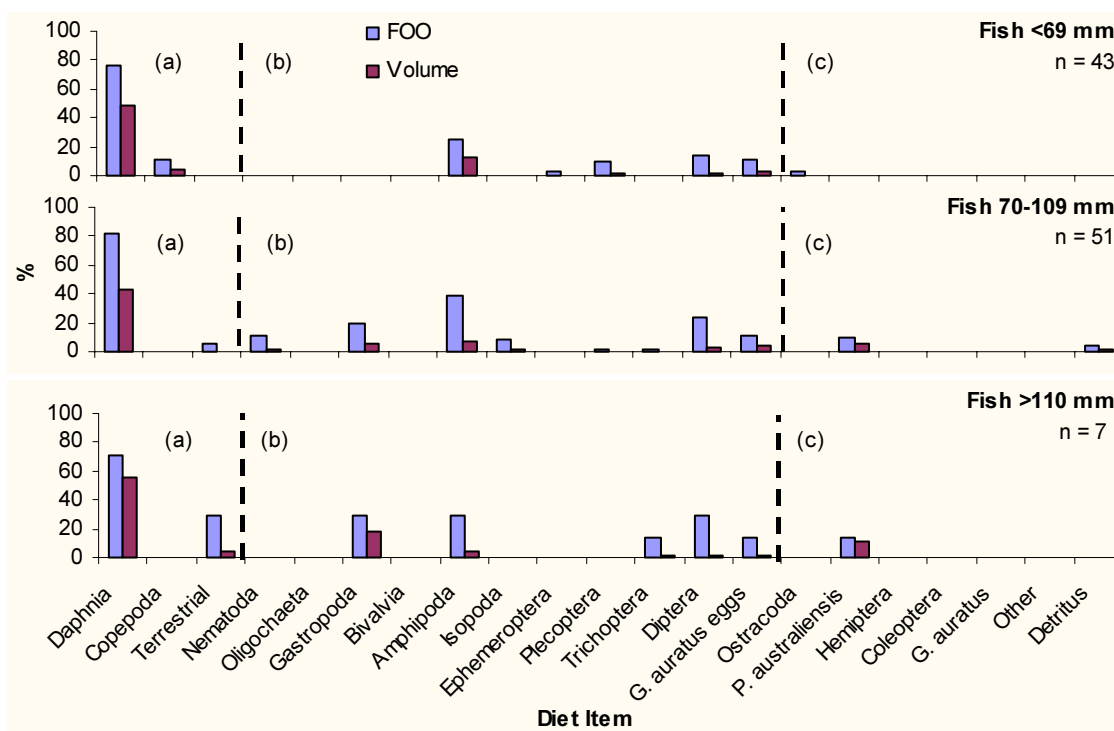
**Figure 47.** Diet of *Galaxias auratus* in Lake Sorell during summer 2000-2001. Broken lines separate pelagic (a), benthic (b) and mobile (c) functional diet item divisions, n = number of fish and FOO = frequency of occurrence.



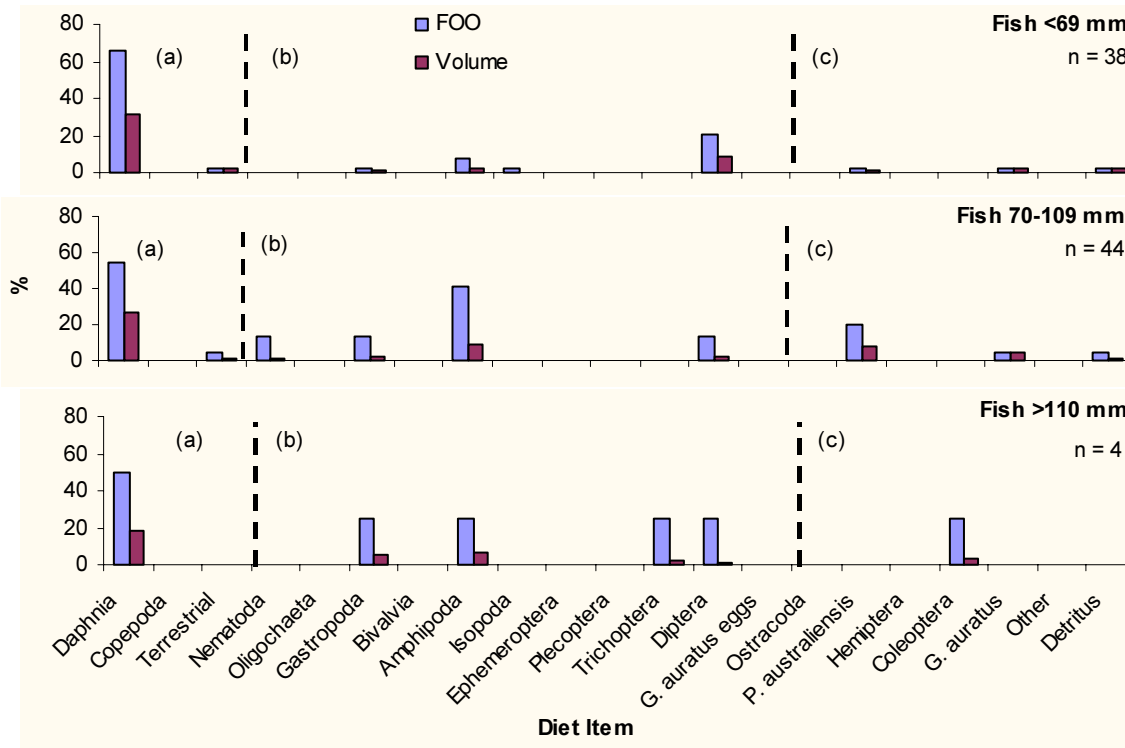
**Figure 48.** Diet of *Galaxias auratus* in Lake Sorell during autumn 2001. Broken lines separate pelagic (a), benthic (b) and mobile (c) functional diet item divisions, n = number of fish and FOO = frequency of occurrence.



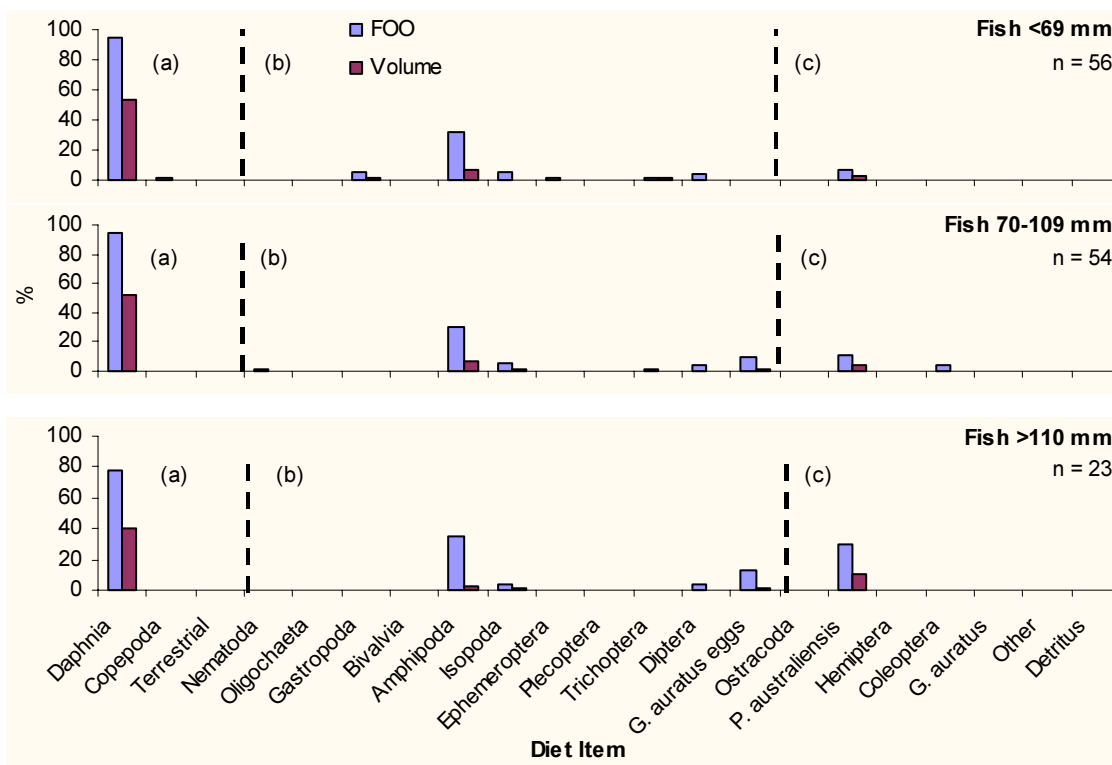
**Figure 49.** Diet of *Galaxias auratus* in Lake Sorell during winter 2001. Broken lines separate pelagic (a), benthic (b) and mobile (c) functional diet item divisions, n = number of fish and FOO = frequency of occurrence.



**Figure 50.** Diet of *Galaxias auratus* in Lake Sorell during spring 2001. Broken lines separate pelagic (a), benthic (b) and mobile (c) functional diet item divisions, n = number of fish and FOO = frequency of occurrence.



**Figure 51.** Diet of *Galaxias auratus* in Lake Sorell during summer 2001-2002. Broken lines separate pelagic (a), benthic (b) and mobile (c) functional diet item divisions, n = number of fish and FOO = frequency of occurrence.



**Figure 52.** Diet of *Galaxias auratus* in Lake Sorell during autumn 2002. Broken lines separate pelagic (a), benthic (b) and mobile (c) functional diet item divisions, n = number of fish and FOO = frequency of occurrence.

The composition of the diet and hence feeding strategies that were used in the three different size classes of the *G. auratus* population in Lake Sorell did not show significant variation. All three size classes were found to feed in the water column on *Daphnia* sp. for the majority of the study period (Figures 45-52). Although data on prey size was not collected, it is suspected that larger fish did have a tendency to predate on larger *Daphnia* individuals.

Seasonal variation in the fullness of *G. auratus* stomachs was also analysed, however no significant patterns were observed. It is suspected that feeding may become more intense in spring – summer during the significant growth period. Feeding intensity is also thought to decrease in autumn – winter prior to spawning.

Analysis of the diet of *G. auratus* populations in both Lake Crescent and Lake Sorell has enabled several aspects of the feeding ecology of this species to be identified. Although the diets varied between the two populations, similar trends were evident. It appears that *G. auratus* are opportunistic and aggressive feeders that have the ability to utilise prey items that are in greatest relative abundance, particularly during ecological events such as zooplankton blooms. Both populations also showed that during winter and spring, *G. auratus* have a tendency to feed on benthic prey. *G. auratus* then move into the water column during summer and autumn to take advantage of the increase in zooplankton, hatching aquatic insects and terrestrial insects that fall onto the water surface.

In summary, general trends in the dietary composition and feeding strategies of *G. auratus* populations in both Lake Crescent and Lake Sorell include the following:

- There is a progression increase in the size of prey items consumed with the growth of *G. auratus*.
- Juvenile *G. auratus* (<70 mm (TFL)) are primarily pelagic and feed on zooplankton and other small prey items found in the water column and surface.
- Once *G. auratus* reach 70 mm (TFL) they generally move inshore and feed on larger benthic prey items.
- *G. auratus* >70 mm (TFL) have the ability to change feeding strategies from predation upon larger benthic prey to predation on water column and surface based prey.
- Larger *G. auratus* (>110 mm (TFL)) have the ability to capture larger and more mobile prey.
- The diet of *G. auratus* varies seasonally, with benthic prey dominating during winter and spring and pelagic prey dominating during summer and autumn.
- The diet of *G. auratus* consists primarily of aquatic invertebrates, but terrestrial invertebrates are an important component of their diet during summer and autumn.
- *G. auratus* eggs are a major diet item of *G. auratus* (particularly fish >70 mm (TFL)) during the spawning season.

- *G. auratus* are an opportunistic and aggressive feeder.
- Cannibalism is common in *G. auratus* populations.

#### 3.4.4 Habitat Preferences

Golden galaxias (*Galaxias auratus*) is primarily a lake dwelling species that prefers still or gently flowing waters. The inability of this species to fully exploit the habitats provided by the in-flowing creeks of lakes Crescent and Sorell and their periodic habitation of adjacent wetland habitats when available, are indications of their preference for still waters. Historically, *G. auratus* moved downstream of Lake Crescent into the Clyde River (this was particularly so for juvenile fish (0+ and 1+ age classes). Fish are thought to have been continually washed downstream with the out-flowing water and hence their occurrence in the upper Clyde River was not a result of a true migration strategy.

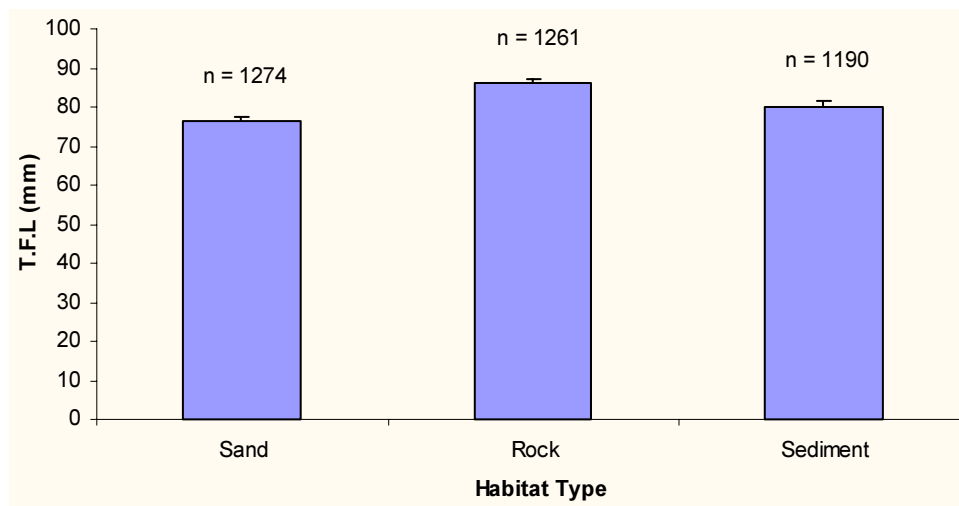
Larval and juvenile fish live in the water column until 4-5 months old (40 mm in length) and then they begin to move inshore seeking shelter and larger prey items. The majority of fish that are >70 mm (TFL) prefer littoral habitats, although they may feed in the water column of the main body of the lakes if food is present in sufficient abundance (see section 3.4.3). It is suspected that marsh areas when accessible, are also a preferred habitat of adult and juvenile fish and that these areas may provide an important nursery area for juvenile fish once they begin to move in-shore out of the water column.

The monthly adult *G. auratus* sampling regime in this study was conducted across the three dominant littoral habitats (sand, rock and sediment based shores) of lakes Crescent and Sorell. It is assumed that preferred lake habitats are occupied by either a greater number of fish and/or dominated by larger fish. This assumption has been used to determine which of the three habitats *G. auratus* populations in both lakes prefer.

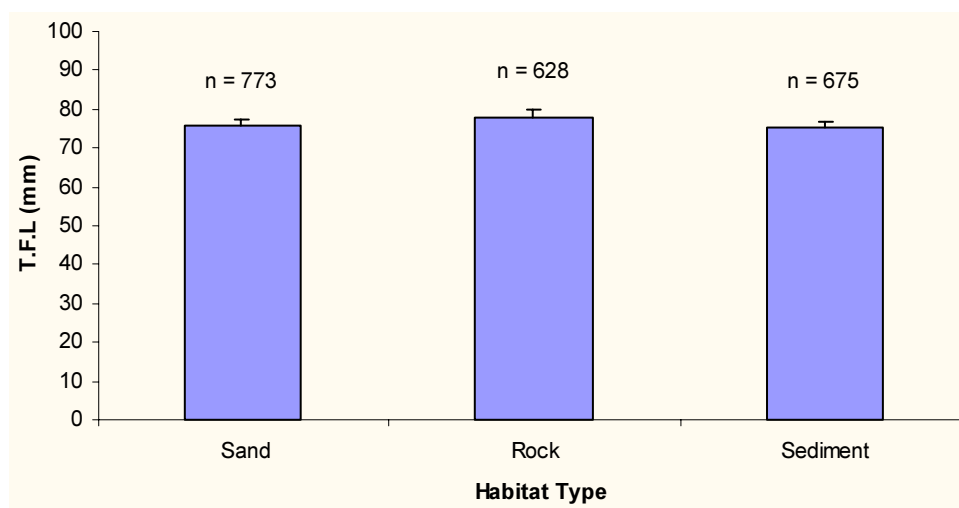
Adult *G. auratus* were found to prefer rocky lake shore habitat in Lake Crescent. Figure 53 shows a plot of the mean length of fish captured during the study in each habitat. Fish captured in the rock habitat have the largest mean length (TFL) (86 mm), followed by the sediment (80 mm) and sand (76 mm) habitats respectively. The difference between the mean lengths of the *G. auratus* sampled at each habitat were all found to be statistically significant ( $P < 0.0001$ ).

In Lake Sorell (Figure 54) no statistically significant differences were observed between the mean length of the *G. auratus* catch from each habitat. This is thought to be due to the different overall habitat composition of the shore-based substrate in Lake Sorell. In comparison to Lake Crescent, Lake Sorell is largely dominated by rocky substrate and hence the distribution of the full size range of the *G. auratus* populations is quite uniform across the lake (mean lengths 75-78 mm).

Catch data from both lakes was also analysed to determine if *G. auratus* populations vary in abundance across the three different habitats. However, no significant differences were found as catches varied at each habitat throughout the study period.



**Figure 53.** Mean length of *Galaxias auratus* in catch at different habitats in Lake Crescent 2000-2002. Length is measured as total fork length (TFL), n = number of fish and means are plotted with 95 % confidence limits.



**Figure 54.** Mean length of *Galaxias auratus* in catch at different habitats in Lake Sorell 2000-2002. Length is measured as total fork length (TFL), n = number of fish and means are plotted with 95 % confidence limits.

### 3.4.5 Behaviour

During this study, a significant amount of time and effort was directed towards sampling the wild populations of golden galaxias (*Galaxias auratus*) in lakes Crescent and Sorell and surveying the distribution of this species. From this work it is possible to make some general observations about the behaviour of *G. auratus* in their natural habitats.

Like many fish species, including other Galaxiidae species (Bonnett *et al.* 1989; Eldon 1979; Glova 1989; Glova & Sagar 1989; McDowall *et al.* 1996), *G. auratus* appear to be most active at night, possibly relating to feeding behaviour. Trials of various sampling techniques and the high catching efficiency of fyke nets, set over night for this species, indicate that *G. auratus* has a tendency to be most active in terms of their movement, between dawn and dusk. Large fish (ie >130 mm TFL), which are commonly captured in fyke nets over-night, are seldom caught by electro-fishing during the day. This indicates that larger *G. auratus* move inshore and are possibly more active at night.

The behaviour of *G. auratus* is, like all fish, governed by the variable conditions of their environment. During periods of rough weather (ie very strong winds) adult *G. auratus* appear to avoid exposed shorelines and seek refuge on sheltered shores. This preference for sheltered shores was common during monthly sampling, with catches varying dramatically at exposed sites. Juvenile sampling in the water column also indicated that larvae and juvenile fish migrate to a lower level in the water column during rough weather, with much lower catches in the upper water column during periods of strong wind.

Shoaling of juvenile *G. auratus* in open water of shallow margins was observed in translocated populations. This behaviour was not observed in wild populations in lakes Crescent and Sorell, due to the high water turbidity. It is suspected that this behaviour may be more pronounced in habitats where the threat of predation from other fish species is marginal or non-existent.

As discussed further in section 3.4.2, the spawning behaviour of *G. auratus* involves an increase in the abundance of fish on rocky shores during late autumn – winter.

### 3.4.6 Interactions with Introduced Fish

Six fish species currently inhabit lakes Crescent and Sorell. All species other than golden galaxias (*Galaxias auratus*) and short-finned eel (*Anguilla australis*) are introduced. During this study, interactions between *G. auratus* and all introduced species were investigated. The main focus of the investigation was the relationship between brown trout (*Salmo trutta*), especially juvenile trout, and *G. auratus*, as *S. trutta* are thought to be the second most abundant fish in these lakes.

The 2000 juvenile (0+) *S. trutta* cohort in Lake Sorell was found to have a strong preference for rocky shore habitat during monthly sampling over the first 11 months of their lake dwelling life (during 2000-2001). Juvenile *S. trutta* were found almost exclusively in this habitat.

The diet of juvenile *S. trutta* in Lake Sorell during their first year was found to be dominated by benthic invertebrates including small crustaceans (isopods and amphipods) and mayfly (ephemeroptera) and stonefly (plecoptera) nymphs (Figures 55-58).

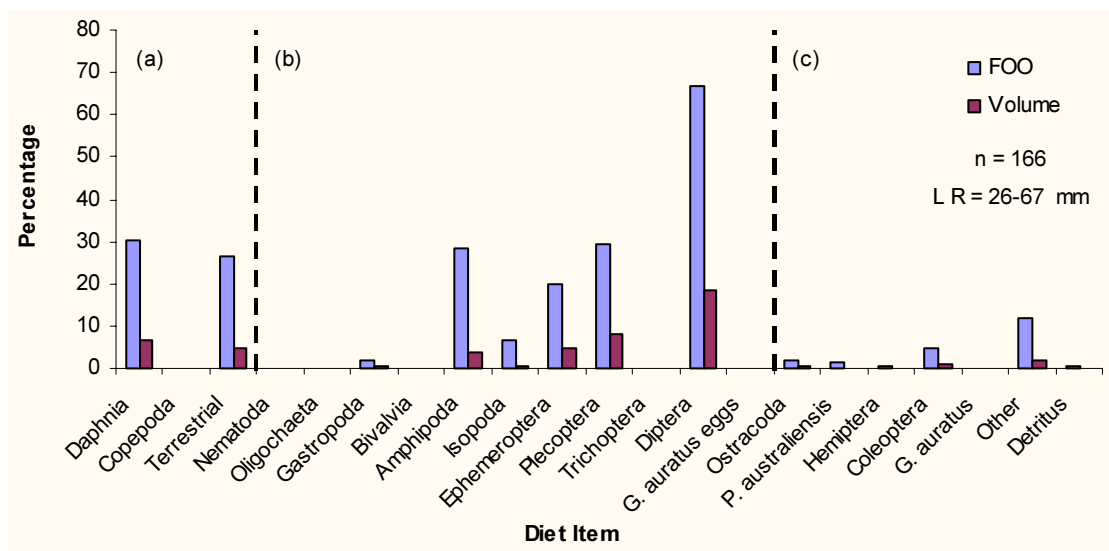
In contrast to juvenile *S. trutta*, adult *G. auratus* in Lake Sorell during the same period were primarily feeding in the water column on pelagic prey dominated by *Daphnia* spp. (Figures 47-50). *G. auratus* took some benthic prey items during winter 2001, where isopods and amphipods became more prevalent in their diet.

A clear difference between the diets of the two species is the importance of ephemeroptera and plecoptera nymphs in the diet of juvenile *S. trutta* and the almost complete absence of these orders in the diet of adult *G. auratus*. This difference in diet suggests that juvenile *S. trutta* feed selectively on these items on the rocky shores of Lake Sorell and it highlights the different feeding strategies utilised by both species. *S. trutta* appear to shelter and feed amongst the substrate of rocky shores, whereas *G. auratus* also like to shelter in rocky shore substrate but are not restricted to this habitat and are able to leave the shelter of the substrate to feed in the water column.

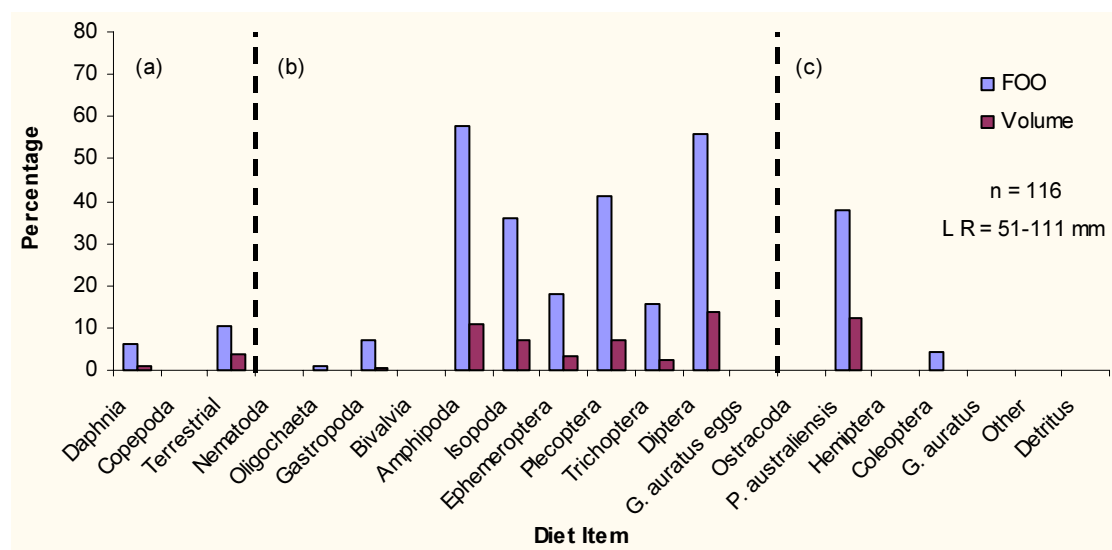
Juvenile *S. trutta* were found to compete for food and habitat resources with adult *G. auratus* in Lake Sorell, however differences in preferred prey were evident. Therefore, although both species prefer rocky shore habitat for feeding and shelter, *G. auratus* appear to be more adaptable to other habitats and feeding strategies. To some extent *G. auratus* may have been forced into other habitats and feeding strategies by direct competition with the more aggressive and dominant juvenile *S. trutta*.

Predation by adult *S. trutta* is also a significant interaction that is thought to shape the abundance and structure of *G. auratus* populations in lakes Crescent and Sorell. Historically, *S. trutta* have been found to feed almost exclusively on *G. auratus* in Lake Crescent (IFS unpublished data), whereas the diet of *S. trutta* in Lake Sorell is more varied, with *G. auratus* still being an important diet item (Stuart-Smith 2001).

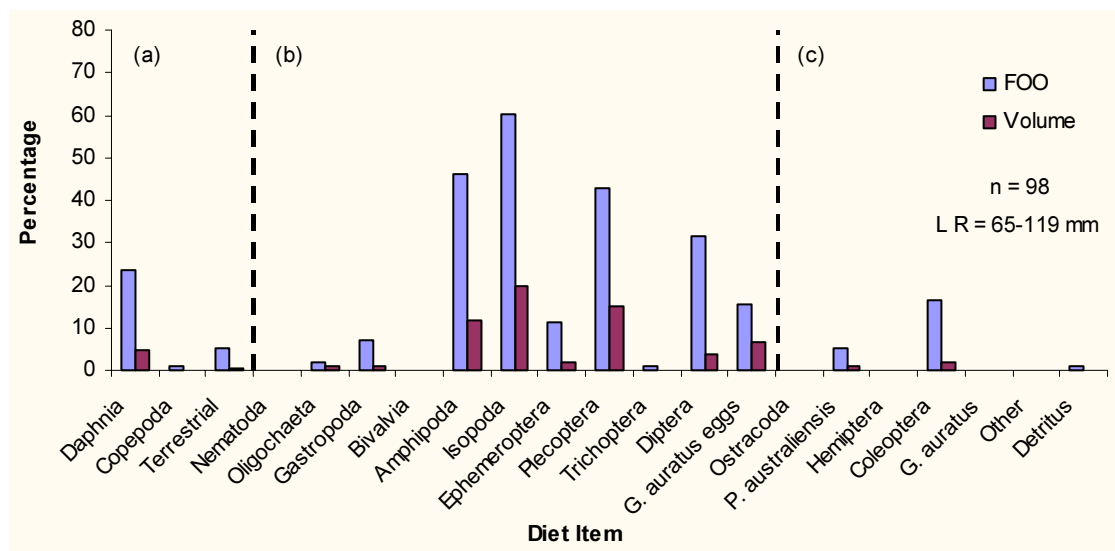
The difference in density between *G. auratus* populations in lake Crescent and Sorell is thought to be primarily due to different competition and predation pressures from the different sized *S. trutta* populations. With Lake Sorell having good annual recruitment of *S. trutta* and a large population of medium sized *S. trutta*, high competition pressure from juvenile *S. trutta* and predation pressure from adult *S. trutta* is likely to occur. In contrast, Lake Crescent has poor natural recruitment of *S. trutta* and a smaller population of larger *S. trutta*, resulting in low competition pressure from juvenile *S. trutta* and predation pressure from adults. The *S. trutta* populations appear to be controlling the size of *G. auratus* populations, however both species seem to be able to co-exist.



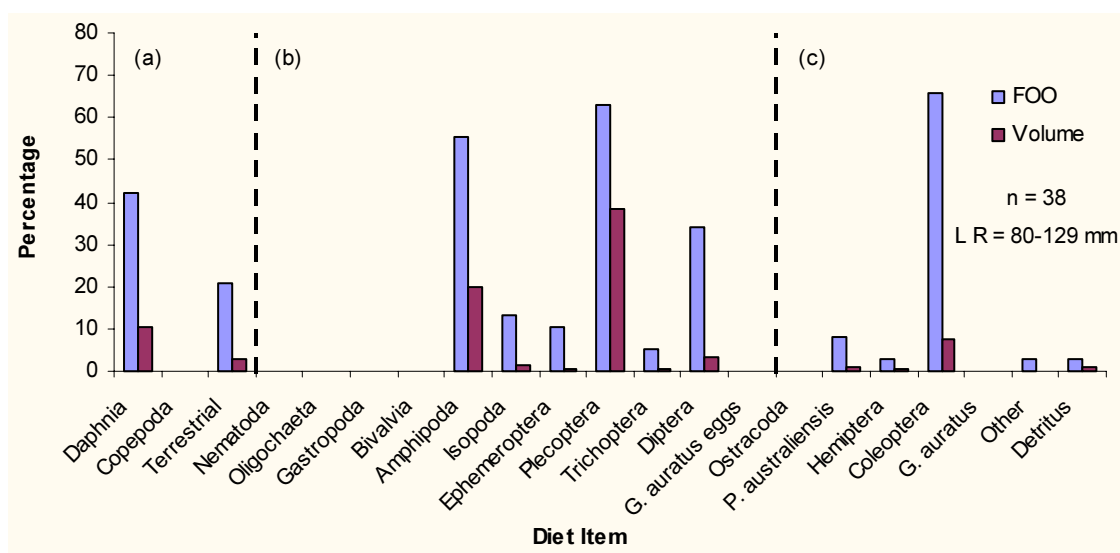
**Figure 55.** Diet of juvenile *Salmo trutta* in Lake Sorell during summer 2000-2001. Broken lines separate pelagic (a), benthic (b) and mobile (c) functional diet item divisions, n = number of fish and FOO = frequency of occurrence and LR = length range of examined fish.



**Figure 56.** Diet of juvenile *Salmo trutta* in Lake Sorell during autumn 2001. Broken lines separate pelagic (a), benthic (b) and mobile (c) functional diet item divisions, n = number of fish and FOO = frequency of occurrence and LR = length range of examined fish.



**Figure 57.** Diet of juvenile *Salmo trutta* in Lake Sorell during winter 2001. Broken lines separate pelagic (a), benthic (b) and mobile (c) functional diet item divisions, n = number of fish and FOO = frequency of occurrence and LR = length range of examined fish.

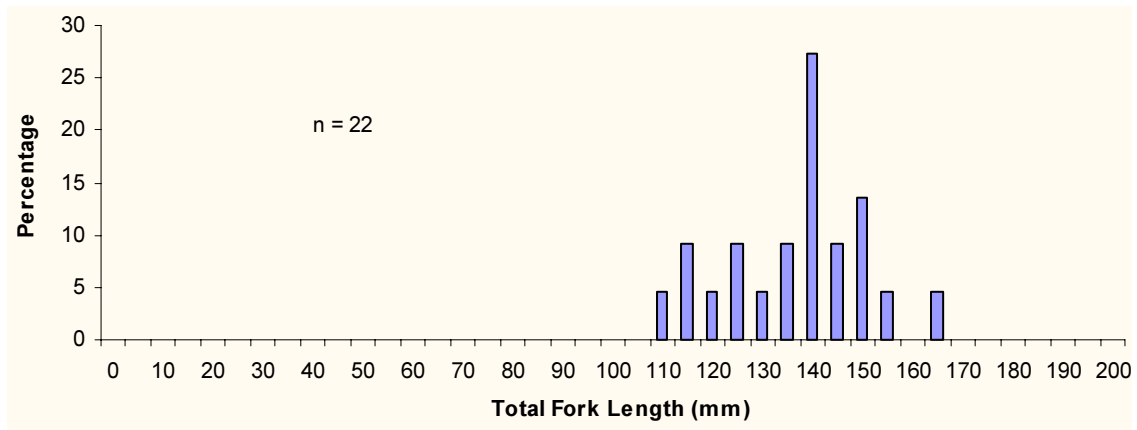


**Figure 58.** Diet of juvenile *Salmo trutta* in Lake Sorell during spring 2001. Broken lines separate pelagic (a), benthic (b) and mobile (c) functional diet item divisions, n = number of fish and FOO = frequency of occurrence and LR = length range of examined fish.

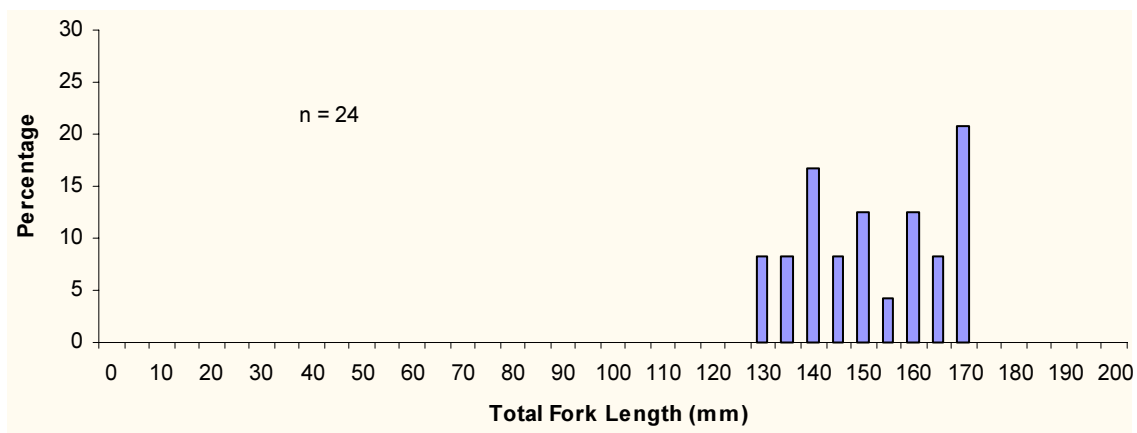
Other introduced fish populations are also thought to influence the status of *G. auratus* populations to varying degrees. Rainbow trout (*Oncorhynchus mykiss*) populations are currently not very abundant in either Lake Crescent or Lake Sorell. In the past, *O. mykiss* populations have formed a significant component of the trout populations in these lakes, especially in Lake Sorell. When in high abundance, *O. mykiss* are thought to interact with *G. auratus* in a similar way to the *S. trutta*. However, *O. mykiss* are not known to feed as aggressively on small fish as *S. trutta* and may not have as great an influence on the abundance of *G. auratus* populations.

European carp (*Cyprinus carpio*) populations are currently very small in both Lake Crescent and Lake Sorell (P. Donkers pers. com.) and are not thought to be having a significant impact on *G. auratus* populations. The different feeding strategies of *C. carpio* and *G. auratus* mean that *C. carpio*, a non-piscivorous (non-fish eating) species, do not pose a threat to *G. auratus* from direct predation on juveniles and adults, although some predation may occur on eggs. These two species are likely to utilise different niches of the food resources of lakes Crescent and Sorell. However, if the *C. carpio* populations were to become abundant and dominate the fish fauna of these lakes then competition for space and to lesser degree, food resources would occur with *G. auratus*. *C. carpio* have been found to alter habitats through their characteristic bottom feeding behaviour, hence increasing water turbidity, destroying aquatic macrophyte beds etc. (Harris 1995). Therefore if *C. carpio* populations were to become abundant, an indirect effect on *G. auratus* populations could result from habitat alteration.

The recent discovery of common galaxias (*Galaxias maculatus*) in lakes Crescent and Sorell is of concern. Populations have been monitored during this study with a total of 46 *G. maculatus* being captured (22 in Lake Crescent and 24 in Lake Sorell). At this stage there has been no evidence of this species establishing breeding populations with only adult fish being caught (>100 mm (TFL)) (Figure 59 and 60). *G. maculatus* are thought to be an opportunistic and adaptable species which would occupy a similar niche to that of *G. auratus* in the trophic structure of the fish communities of lakes Crescent and Sorell. If the species was to become established, direct competition for habitat and food resources with *G. auratus* is likely to occur.



**Figure 59.** Length frequency plot of all *Galaxias maculatus* captured in Lake Crescent, 2000-2001. Where n = number of fish.



**Figure 60.** Length frequency plot of all *Galaxias maculatus* captured in Lake Sorell, 2000-2001. Where n = number of fish.

### 3.4.7 Captive Breeding

The aim of the captive breeding trials was to determine suitable methods for rearing golden galaxias (*Galaxias auratus*) in captivity, so that appropriate methods are known if captive breeding becomes a necessary conservation measure. The captive breeding experiments also provided an opportunity to observe and quantify various aspects of the behaviour and reproductive cycle of *G. auratus*. A summary of the results of the captive breeding trials is shown in Appendix 6.

*G. auratus* captive breeding trials were conducted in conjunction with trials on Swan and Clarence galaxias (*G. fontanus* and *G. johnstoni*) performed by Jackson (2001). Jackson (2001) has reviewed and summarised previous galaxiid captive breeding studies.

#### *Adult Behaviour in Captivity*

Adult *G. auratus* were reasonably easy to maintain and appeared comfortable in the captive environment. Broodstock acclimatised quickly to the aquarium habitat and were feeding within a few hours of their release. It was important to keep the food supply plentiful, as there were instances of cannibalism between large and small fish.

*G. auratus* adults were observed feeding in the mid to lower water column and occasionally from the substrate during the day. Fish were thought to be most active at night although this was not quantified. Fish at rest generally stationed themselves under cover (ie under over hanging rocks or woody debris) with the large fish occupying the best positions. Fish would, at times, actively swim in all levels of the water column.

#### *Artificial Fertilisation*

Artificial fertilisation of *G. auratus* eggs by stripping eggs and milt from broodstock, was found to be an effective method. Several batches of eggs were fertilised and incubated until hatching occurred. The success rate of the fertilisation process was not accurately quantified, however visual estimates indicated that approximately 80% of the eggs in each batch (500-2000 eggs/batch) were fertilised. It was important to predetermine and separate the sexes of broodstock so that stripping and fertilising could be carried out quickly. One of the first batches of eggs was thought to have water hardened prior to milt being stripped in the petri dish and hence the fertilisation rate for this batch was very low and the batch was discontinued after only 4 weeks. It was noted during the selection of broodstock for stripping that most large fish (>130 mm (TFL)) were females but the sex of smaller fish could only be determined accurately by undertaking a small amount of stripping.

*G. auratus* eggs are slightly orange and adhesive upon extrusion from a ripe female and then turn clear and become more adhesive after fertilisation. Eggs are approximately 1.5 mm in diameter after fertilisation and water hardening.

### ***Natural Spawning***

No spawning took place in the aquarium holding the broodstock, however broodstock held in the outside pond spawned approximately 500 eggs during late September 2000. The water temperature during the period the eggs were spawned ranged between 5°C and 10°C. Eggs were found scattered over rocky substrate in a reasonably small area of approximately 0.1 m<sup>2</sup>. Eggs were generally positioned individually although a few clusters of 5-10 eggs were present. Rocks with adhered eggs were transferred to an inside aquarium for incubation where several larvae subsequently hatched proving that the eggs were in fact fertilised and not just deposited by a female.

The natural spawning trials were largely unsuccessful with only a small number of broodstock spawning. Several fish of both sexes also died during the natural spawning trials and when the trials ended in early November 2000, the remaining fish all retained large gonad masses, which appeared to be no longer viable. Remaining female broodstock appeared 'egg bound' with dissections revealing large volumes of disfigured and discoloured eggs. The remaining male broodstock retained large volumes of 'watery' testes which also appeared disfigured and discoloured in comparison to healthy ripe gonads.

It is assumed that the broodstock aquarium and outside pond did not possess all of the triggers required for spawning (ie rising water level and appropriate natural water temperature cycles). Because of this apparent lack of suitable spawning conditions, most fish retained their gonad masses and, in some cases, this caused mortality.

### ***Egg Incubation***

*G. auratus* eggs were incubated for 55-65 days at a water temperature of 4-5°C prior to hatching. The success rate of eggs from fertilisation to hatching was <20 % and generally <5 % during the captive trials.

Batches of fertilised eggs needed to be scattered, not clustered together, in order to survive the incubation period. Eggs appear to require some space around them, possibly to allow efficient transfers of nutrients and waste products across the egg membrane. Large clusters of eggs in incubation trays generally were the first of the eggs to die and develop a fungus-like covering. Eggs on the outside of clusters were often still viable but had a much lower success rate due to an encroaching cover of fungus over the egg mass. It is interesting to note that *G. auratus* eggs found in the wild during the study were never found in large clusters – usually scattered individually or in very small groups of <5 eggs (see section 3.4.2).

Basic observations on the development of *G. auratus* eggs were conducted on a weekly to bi-weekly bases during their incubation.

Post fertilisation the eggs developed a defined nucleus. Within 18 days the non-viable eggs began to develop fungus. Within 27 days a small embryo had formed around the outside of a portion of the nucleus. Within 35 days eggs became 'eyed' with the development of the head of the embryo. Within 42 days the embryo became well developed and there was an overlap in its coiled position around the nucleus. Some periodic movement was observed at this stage. Within 56 days some larvae were

hatching while the rest had very well developed embryos that were tightly coiled more than twice around nucleus with a small hint of yellow-green colouration along the back. Embryo's at this stage had a well developed head with pronounced eyes and were quite active inside the egg. Within 63 days the majority of larvae had hatched.

Some fully developed eggs that were disturbed by the handling of incubation trays and by the removal of dead eggs, appeared to be triggered into hatching. This may suggest that the stable environment of aquaria which lack the natural currents and water movement associated with wind action in the natural environments of *G. auratus*, also lack events which trigger eggs to hatch. However the fact that many eggs did hatch independently shows that eggs will hatch without these stimuli.

The hatching of a small number of larvae was observed both with the naked eye and under a dissecting microscope during the routine removal of dead eggs and assessment of stage development. Larval hatching is a very rapid process lasting only a few seconds. Larvae that are about to hatch convulse their body in wriggling movements and then break through the egg membrane with their tail. Once the membrane is broken, larvae quickly exit the egg membrane and swim actively.

There was a small difference between the water temperatures of the wild habitats of *G. auratus* - lakes Crescent and Sorell, and the aquaria and ponds of the captive breeding trials at Liawenee during the study period. Water temperature had greater variability in the wild habitats ranging 3-13°C (average of ~ 7°C) in lakes Crescent and Sorell, and 4-11°C (average ~ 6°C) in the inside aquaria and 2-15°C (average ~7°C) in outside ponds at Liawenee. The difference in water temperature is thought to be primarily due to the difference in altitude of both locations on Tasmania's Central Plateau. Lakes Crescent and Sorell are located at approximately 800 m AHD, while Liawenee is situated at approximately 1050 m AHD. The length of fish egg incubation is directly related to water temperature. Therefore it is suspected that, depending upon the time of year that *G. auratus* actually spawn, the incubation period may be comparable or slightly less in the wild than was observed in captivity (see section 3.4.2).

### ***Larval Behaviour in Captivity***

Newly hatched *G. auratus* larvae are 5-7 mm (TFL) and have a very elongated shape with a pronounced head and eyes. Larvae are basically transparent with a hint of yellow-green colouration on their back (visible only under a microscope) and are active swimmers in the mid to upper water column (Frijlink 1999). Larvae have some predator avoidance skills, with larvae being difficult to catch in a small dip net.

Larvae were found to be difficult to rear, with mortality in the majority of larvae within 21 days of hatching during this study. The lack of success in this stage of the trials was thought to be related to an inappropriate feeding regime, in terms of frequency, and size and quantity of food.

### **Summary of Findings**

Captive breeding of *G. auratus* was found to be feasible although larval rearing methods need further refinement. The results and significant outcomes of the captive breeding trials are as follows:

- *G. auratus* were found to be a hardy species and reasonably easy to keep in captivity.
- Artificial stripping of ripe *G. auratus* adults was found to be an effective method to fertilise eggs.
- *G. auratus* eggs were able to be collected in the wild, transported to aquaria and incubated until hatching.
- Mature *G. auratus* were found to spawn in an outdoor pond containing rocky substrate although this method did not appear to be as reliable as stripping.
- Results suggest that the length of the incubation period of *G. auratus* eggs is 55-65 days at a water temperature of 4-5°C.
- The difficult part of the trials was found to be rearing the newly hatched larvae with sufficient amounts of appropriately sized food. Cultures of suitable planktonic food are required.

## **3.5 Translocated Populations**

All actions undertaken in the golden galaxias (*Galaxias auratus*) translocation program to date are documented in this report. The initial stages of the program were carried out prior to this study, but have not been previously documented.

### **3.5.1 Site Selection and Translocations**

The site selection survey, which was carried out during 1996, found that most of the farm dams in the Clyde River catchment are relatively small (ie <0.15 ha) and shallow (<1.5 m deep), fed by direct precipitation and runoff and have direct stock assess. Some dams were also found to be dominated (choked) by aquatic macrophytes limiting the diversify of available habitats and potentially leading to low dissolved oxygen concentrations.

Due to the apparent lack of larger existing dams within the catchment, 3 sites on Alma property were inspected during 1996 and 2 were identified to be suitable for constructing purpose built dams. The sites were located in a natural marsh area, which receives a reliable supply of spring and runoff water. Although construction of the dams at these sites was recommended at the time and quotes were prepared, the proposal was not given financial support and no on-ground works were undertaken.

Although the many dams within the catchment were found to provide only marginal habitat, 17 dams were selected for translocation sites. It was assumed in all cases that the sites provided an equivalent, if not better, standard of environmental condition to that of lakes Crescent and Sorell at the time.

Seventeen farm dams in Clyde River catchment were stocked with golden galaxias (*Galaxias auratus*) from Lake Crescent between spring 1996 and winter 1998 (Table 11). The number of fish stocked into a dam varied from 50 to 3000 depending on the size of dam.

**Table 11.** *Galaxias auratus* translocations in the Clyde River catchment, 1996-1998.

Site Name	Property	Map	Grid Ref.	Surface Area (m <sup>2</sup> )	Translocations	
					Date	No.
Roadside	Interlaken	Interlaken	104 339	450	1/8/96	50+
Starkes Gate	Interlaken	Interlaken	094 332	625	1/8/96	50
Wet Marsh	Interlaken	Interlaken	077 345	225	1/8/96	50
Silver Plains	Interlaken	Interlaken	089 351	225	1/8/96	50
Homestead 1	Interlaken	Interlaken	097 338	5000	1/8/96	100+
Logging Rd 1	Serat	Table	064 236	700	1/8/96	50+
Logging Rd 2	Serat	Table	062 234	1125	1/8/96	50
Black Snake Rd 1	Serat	Table	092 284	400	1/8/96	50
Black Snake Rd 2	Serat	Table	085 285	1000	1/8/96	50
Homestead 2	Serat	Table	088 265	1000	2/8/96	100
Tiger Rise 1	Serat	Table	074 228	400	2/8/96	50+
Tiger Rise 2	Serat	Table	077 229	400	2/8/96	50+
Belles Marsh 1	Serat	Table	087 259	900	5/9/96	50+
Belles Marsh 2	Serat	Table	091 268	400	5/9/96	50+
Belles Marsh 3	Serat	Table	098 275	375	5/9/96	50+
Rotherwood	Rotherwood	Dennistoun	113 169	6000	8/7/98	700
Cluny	Cluny	Cluny	190 992	955800	6/8/98	3000

### 3.5.2 Follow-up Surveys

Of the 17 farms dams that were stocked, 11 were surveyed using fish sampling equipment, while the remaining 6 had dried-up and hence no longer contained suitable habitat for the golden galaxias (*Galaxias auratus*). The results of the follow-up surveys highlighted the difficulty in finding suitable habitat for *G. auratus* in the Clyde River catchment and hence establishing translocated populations. Of the 17 farm dams stocked with *G. auratus* only 2 populations were found to have established (Table 12), one on the 'Interlaken Estate' (Tasmap Interlaken, Grid Ref 097 : 338) (Appendix 2 – Picture 7) and another on the 'Rotherwood' property (Tasmap Dennistoun, Grid Ref 113 : 169) (Appendix 2 – Picture 8). A marginal population was also found in a dam on the 'Cluny' property (Tasmap Cluny, Grid Ref 190 : 992).

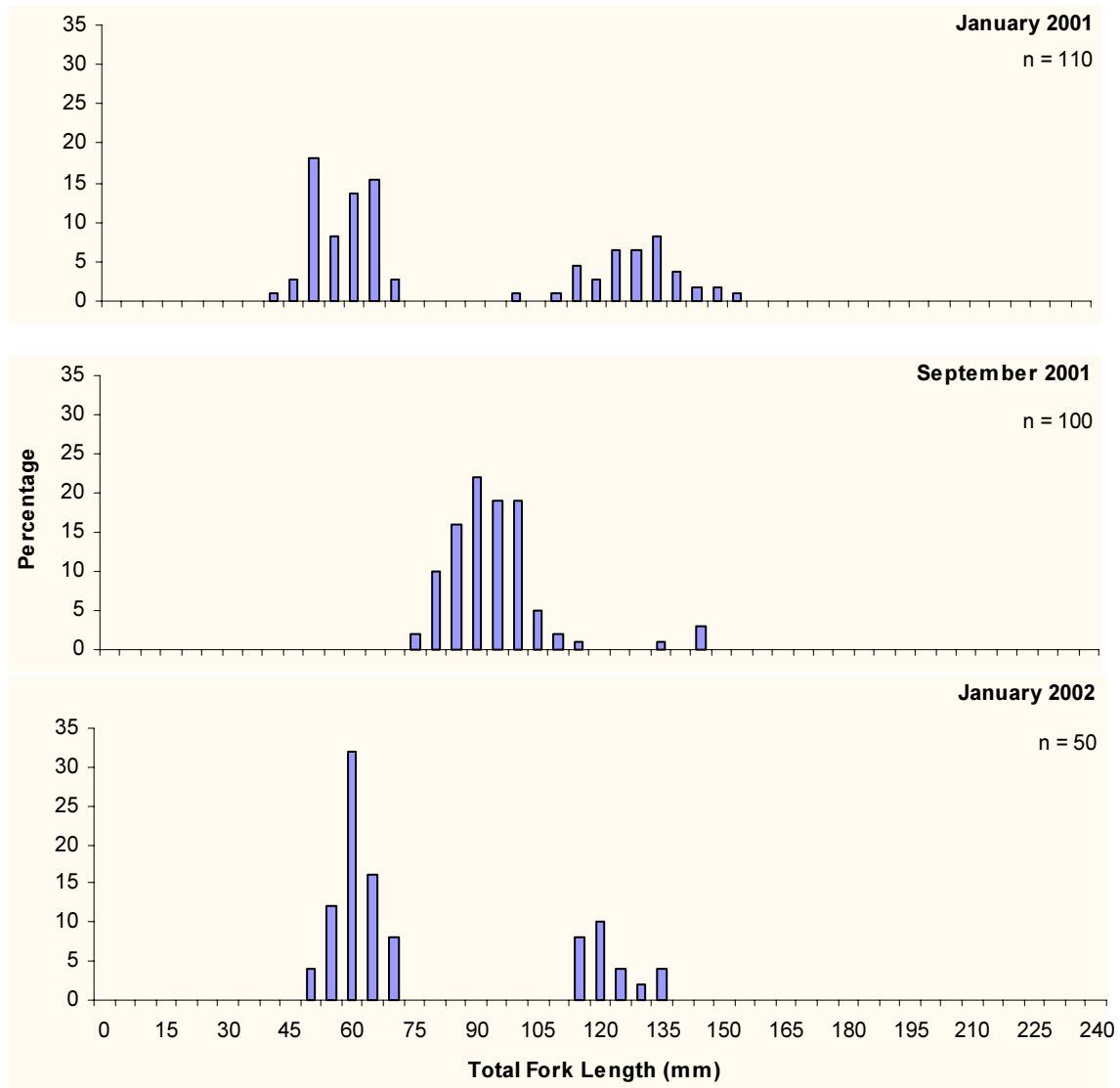
The limited success of the translocations also makes the 2 translocated populations that have established, highly significant, as they may be critical for the survival of this species in the future.

**Table 12.** Results of *Galaxias auratus* translocated populations survey, January 2001.

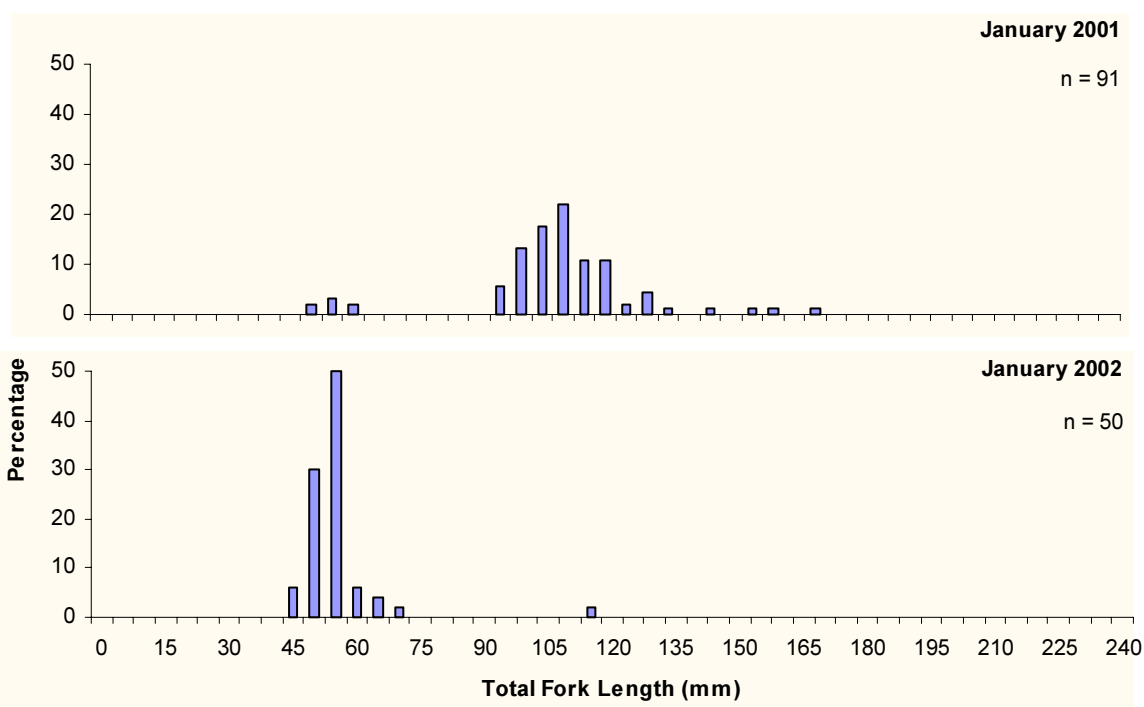
Site Name	Property	Grid Ref.	Survey Results		
			Date	Fishing Effort	Catch
Roadside	Interlaken	104 339	16/1/01	e-fish 5 min	Nil
Starkes Gate	Interlaken	094 332	Not surveyed*	-	-
Wet Marsh	Interlaken	077 345	Not surveyed*	-	-
Silver Plains	Interlaken	089 351	16/1/01	e-fish 5 min	Nil
Homestead 1	Interlaken	097 338	16-17/1/01	e-fish 10 min 6 fyke nets o/n	92 <i>G. auratus</i>
Logging Rd 1	Serat	064 236	16/1/01	e-fish 5 min	Nil
Logging Rd 2	Serat	062 234	16/1/01	e-fish 5 min	Nil
Black Snake Rd 1	Serat	092 284	Not surveyed*	-	-
Black Snake Rd 2	Serat	085 285	16/1/01	e-fish 5 min	Nil
Homestead 2	Serat	088 265	16/1/01	e-fish 10 min	Nil
Tiger Rise 1	Serat	074 228	16/1/01	e-fish 5 min	Nil
Tiger Rise 2	Serat	077 229	Not surveyed*	-	-
Belles Marsh 1	Serat	087 259	16/1/01	e-fish 5 min	1 <i>A. australis</i>
Belles Marsh 2	Serat	091 268	Not surveyed*	-	-
Belles Marsh 3	Serat	098 275	Not surveyed*	-	-
Rotherwood	Rotherwood	113 169	17-18/1/01	6 fyke nets o/n	~1500 <i>G. auratus</i>
Bowden	Cluny	190 992	24-25/1/01	15 fyke nets o/n	1 <i>G. auratus</i> 1 <i>S. trutta</i> 1 <i>A. australis</i> ~200 <i>T. tinca</i>

Species caught are: golden galaxias (*Galaxias auratus*), short-finned eel (*Anguilla australis*), brown trout (*Salmo trutta*) and tench (*Tinca tinca*) and \*indicates waterbodies that had dried-up.

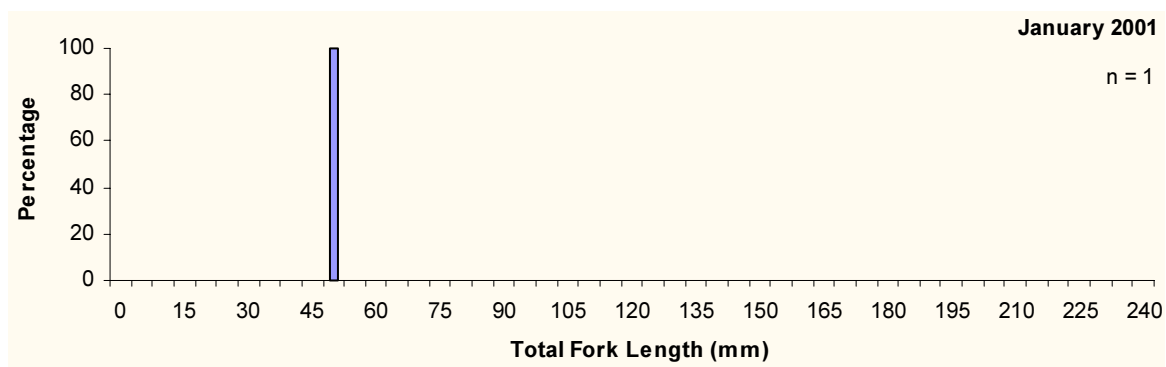
Length frequency plots for proportions of the catches collected during translocated population surveys illustrate the structure of these populations and indicate if recruitment is occurring (Figures 61-63). The presence of length classes 40-70 mm and also 90-130 mm in the length frequency plots for the Rotherwood and Interlaken populations (Figures 61 and 62) indicate that recruitment is occurring and that adult fish are also abundant. A comparison of the structure of the translocated populations with that of the wild populations, where age analysis had been undertaken (Figure 30), supports this assessment. Fish in the 40-70 mm length class are thought to be less than one - two years of age (0+ and 1+), while fish in the 90-130 mm length classes are thought to be 3 and 5 years old (2+ and 4+).



**Figure 61.** Length frequency plot for the *Galaxias auratus* population in the Rotherwood Dam, 2001-2002.



**Figure 62.** Length frequency plot for the *Galaxias auratus* population in the Interlaken Dam, 2001-2002.



**Figure 63.** Length frequency plot for the *Galaxias auratus* population in the Cluny Dam, January 2001.

The small catch of *G. auratus* in the Cluny dam (Figure 63) is thought to represent the marginal status of this population. The primary reason for this population not being able to establish is thought to be the large population of brown trout (*Salmo trutta*) present in the dam causing high competition and predation pressure on the relatively small number of translocated *G. auratus*.

### 3.5.3 Management of Translocated Populations

During this study the golden galaxias (*Galaxias auratus*) translocation sites were surveyed for the first time since the stockings were carried out. The results of the surveys identified which translocations were successful and gave an insight into the habitat requirements of *G. auratus* relevant to translocations.

The first steps towards formally managing the established translocated populations were also undertaken during this project. A Conservation Management Agreement was prepared for the Rotherwood dam and initial on-ground management works have been undertaken. A Management Brief has also been prepared for the Interlaken Estate owner/manager detailing management recommendations for the dam on this property.

The dam on the Rotherwood property is thought to provide the better habitat of the two dams which have established *G. auratus* translocated populations, as the dam's catchment is primarily native forest and the dam does not contain other fish species. The benefits of these differences in habitat has been illustrated by the Rotherwood population being more abundant, having a more complex population structure and fish generally being much healthier in condition than the population in the Interlaken dam. To further protect this population, the *Aquatic Fauna Sub-project* along with the property owner/manager Jim McShane, has set-up a formal reserve (referred to as Rotherwood Reserve) around the dam by fencing-off the dam and its catchment to exclude stock and protect native vegetation in the area. Fencing-off the area was thought to be a simple way of enhancing the dam's water quality by reducing nutrient inputs and soil disturbance by stock. It also aids in the protection of the ecosystem that surrounds the dam.

Site visits, discussions and negotiations with various interest groups and the land owner/manager were undertaken between December 2001 and May 2002. The majority of the on-ground works were also completed during this period, with weed control being an on-going management issue. On-ground works included clearing a fence line and erecting 1.4 km of stock proof fence, installing 450 m of water pipe and a stock watering trough and commencing a program to remove the noxious weed – European gorse (*Ulex europaeus*), from the reserved area.

Gorse removal work has been undertaken following the advice given by Greening Australia. Initial works have utilised the herbicide Roundup Bioactive® which contains the active constituent glyphosate. The ‘cut and paint’ method has been employed for the initial gorse work, where undiluted Roundup is painted onto freshly cut stumps of mature bushes. This method was identified by Greening Australia and the Department of Primary Industries Water and the Environment (DPIWE) as the most suitable way to remove gorse from the area given the close proximity of the patches of gorse to the dam and its main feeder creek.

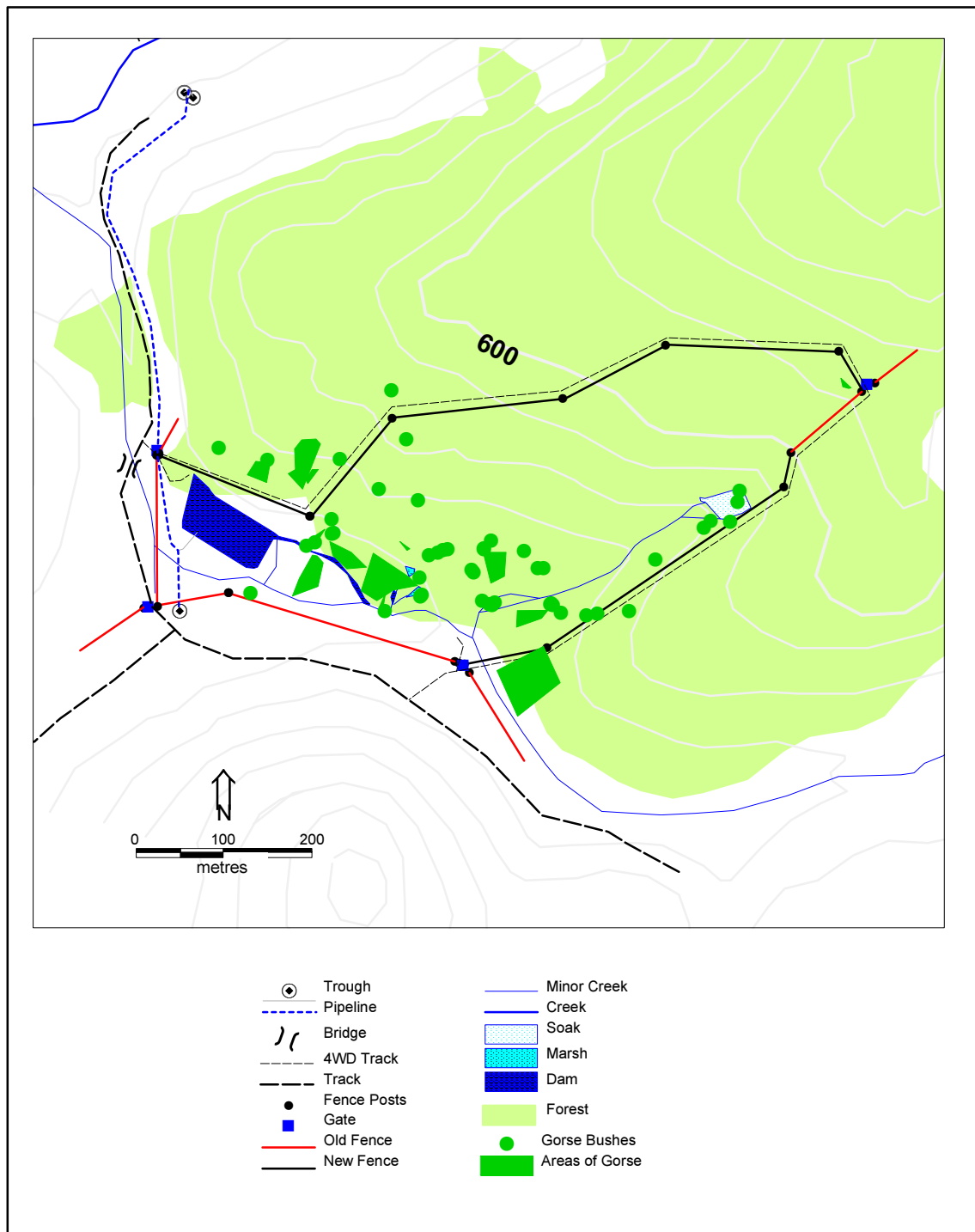
The result of these works is a 17 ha area of reserved native eucalypt forest and some pasture land which surrounds the dam and the catchment of a small creek which is the dam’s main water source (Figure 64). The total cost of the establishment of Rotherwood Reserve has been \$ 6,690.71 (Table 13) plus an equal amount of in-kind support in the form of labour and use of equipment from the Inland Fisheries Service (IFS) and Jim McShane (Rotherwood property owner and manager).

Several departments and organisations have been involved in the construction of the Rotherwood Reserve and, although some have previously been mentioned, all parties deserve formal recognition. Greening Australia’s ‘Fencing Incentive Scheme – Tasmania’ and ‘On-ground Rehabilitation of Remnant Vegetation’ projects funded the majority of the fencing, stock watering and weed control materials, with the IFS providing some additional funding as well as support for on-grounds works. The DPIWE gave specialist advice in relation to weed management. The Australian Bush Heritage Fund prepared the Conservation Management Agreement for the reserve.

**Table 13.** Costs involved in the initial on-ground works associated with the establishment of the Rotherwood Reserve. It should be noted that in-kind support through labour and use of equipment is not included.

On-ground Works	Cost <sup>1</sup>	
	Inland Fisheries Service	Greening Australia
Fencing Materials	\$ 924 - 66	\$ 2 392 - 50
Alternate Stock Watering Materials	\$ 193 - 55	\$ 500 - 00
Weed Eradication/Control	\$ 180 - 00	\$ 2 500 - 00
<b>Total Costs</b>	\$ 1 298 - 21	\$ 5 392 - 50
<b>Grand Total</b>		\$ 6 690 - 71

1 – costs are in Australian dollars calculated during January 2002 and include GST.



**Figure 68.** Map of Rotherwood Reserve: reserved area surrounding the dam on Rotherwood property that contains a translocated population of *Galaxias auratus*.

## 4. Discussion

### 4.1 Significant Findings of Population Monitoring and Ecological Research

During the *Aquatic Fauna Sub-project*, wild populations of golden galaxias (*Galaxias auratus*) in lakes Crescent and Sorell were monitored monthly over a 27 month period (June 2000 – August 2002) and the status and distribution of this species in the Clyde River catchment was investigated. Extensive research into the ecology of *G. auratus* was undertaken which clearly defined the life cycle of this species and provided insight into its habitat preferences, behaviour and general biology.

#### 4.1.1 Status of Populations

Historically the golden galaxias (*Galaxias auratus*) has had a very restricted natural distribution being confined to lakes Crescent and Sorell and their associated creeks and wetlands. The natural distribution of this species is currently further restricted by low rainfall and spasmodic rainfall patterns and newly developed IFS carp management infrastructure. The current climatic conditions have created low lake levels and inconsistent flows in in-flowing creeks prohibiting this species from utilising associated creek and wetland habitats. Due to these alterations to their habitat, the natural distribution of *G. auratus* is currently confined to the main bodies of lakes Crescent and Sorell. This reduced and limited distribution of *G. auratus* is a major concern for the management of this endemic and unique species, particularly given the current degraded state of lakes Crescent and Sorell.

During the study period lakes Crescent and Sorell were in a very degraded state, with extremely low water levels causing a significant decrease in water quality (primarily high turbidity) and decreases in habitat diversity and availability. The low water levels were thought to be primarily due to the drought conditions that the Interlaken area had been experiencing during the 3 years prior to, and during, the study period.

The poor environmental condition of lakes Crescent and Sorell was found to be threatening *G. auratus* populations through decreases in water quality and habitat diversity and availability. Rocky shoreline habitat was found to be critical to *G. auratus* populations during this study. Rocky shores were the preferred habitat of *G. auratus* being used for feeding, shelter and the only habitat used for spawning.

The importance of macrophyte dominated habitat to *G. auratus* could not be formally investigated during the study, as this form of habitat was not present in the Crescent-Sorell system. It is suspected that when they are available, in-lake macrophyte beds and adjacent wetlands are also important habitats used by *G. auratus* populations in lakes Crescent and Sorell for feeding, shelter and possibly spawning. The macrophyte habitat in Kemps Marsh was found to contain a diverse and abundant macroinvertebrate community during the study period, with several species not being confined to this habitat (Hardie 2003). Therefore in-lake macrophyte beds are suspected to provide a significant food resource for *G. auratus* when available.

Macrophytes dominate the habitat present in the two farm dams that contain translocated populations of *G. auratus*. It is suspected that these populations have benefited from the presence of this habitat.

Abundant populations of *G. auratus* were found in lakes Crescent and Sorell, however abundance differed significantly between the two lakes. The *G. auratus* population in Lake Crescent was approximately 10 fold greater in abundance than the population in Lake Sorell. The reason for the difference is thought to be primarily due to the difference in abundance of the trout populations in each lake, resulting in different competition and predation pressures.

Although *G. auratus* populations in both Lake Crescent and Lake Sorell appear to be abundant, it is difficult to compare the current status of these populations to their historical status as baseline data is purely anecdotal. It is suspected that the abundance (density) of fish is similar (probably slightly reduced), but the actual size of the populations is much less due to the reduction in the amount and diversity of available habitat.

As a result of the translocation program that was undertaken by the Inland Fisheries Service (IFS) between 1996 and 1998, two translocated populations of *G. auratus* also occur in farm dams in the Clyde River catchment. The translocated populations appear to be well established.

In summary, *G. auratus* is a species whose natural distribution is confined to a very small area where it's habitat is in a very degraded state. Wild populations are facing several threatening processes but as yet it is difficult to quantify if population sizes have been reduced. Translocated populations offer some protection for the survival of this species in the event of significant declines in wild populations.

Given the restricted distribution and threats that *G. auratus* populations are facing, this species has significant conservation status. *G. auratus* is currently listed as 'rare' under the Tasmanian *Threatened Species Protection Act 1995* and 'endangered' on the IUCN Red List (ASFB 2001).

#### **4.1.2 Summary of the Ecology of Golden Galaxias**

Prior to this project very little was known of the ecology of the golden galaxias (*Galaxias auratus*). This study has been able to accurately define the age, growth, population structure, reproductive cycle and diet of this species. Additional to this information, is an evaluation of sampling methods for *G. auratus* and observations on behaviour and habitat preference.

#### ***Sampling Techniques***

Fyke netting was found to be the most effective technique for sampling *G. auratus*, particularly for collecting samples for biological analysis. The fyke net sampling regime detected variation in the relative abundance of *G. auratus* in different habitats during the study. This was particularly evident during spawning seasons when *G. auratus* congregated on rocky shores. However, it is difficult to quantify fyke net catches to determine population estimates. A sampling regime involving in-lake seine

netting in combination with shore based fyke netting was found to be the best option for performing quantitative population estimations of *G. auratus*.

### ***Habitat and Behaviour***

*G. auratus* is primarily a lake dwelling species that prefers still or gently flowing waters. Larval and juvenile fish are pelagic while adults are more benthic and prefer the shelter of rocky shore and possibly macrophyte dominated habitat. Adult fish also feed in the water column, particularly if food is abundant. Juvenile fish occasionally shoal in shallow lake margins. *G. auratus* appear to be most active at night (between dusk and dawn), but are not solely nocturnal.

### ***Reproduction***

Male fish sexually mature in their first year (>50 mm TFL) and females in their second (>70 mm TFL). Adult *G. auratus* begin to develop gonad mass in early summer with the development period following decreases in lake level, photo period and water temperature. Male fish develop their gonads faster than females. Gonadosomatic index (GSI) values of both sexes generally peak between 15 and 30 % prior to spawning. Females have a relatively high fecundity: the relationship between fish length (L) and fecundity (F) for *G. auratus* can be described by the equation:

$$F = 0.0029L^{3.0305} \quad (n = 87, R^2 = 0.729)$$

Mature females produce 1,000–15,000 eggs depending on the size of fish, with most female fish having 1,100–5,800 eggs. Spawning takes place in late autumn – winter on rocky shores and possibly wetland habitat when available. Rocky shore spawning habitat consists of cobble rock (10-200 mm diameter) at a depth of 300–600 mm. Spawning occurs at approximately 4°C (range 2-7°C) and appears to be triggered by rising lake levels and either a slight decrease or more likely, slight increase, in water temperature. Fertilised eggs are 1.5 mm in diameter and are transparent with a visible nucleus. Spawned eggs adhere to rocky substrate. Eggs are thought to incubate for 30-45 days in the wild with artificially fertilised eggs taking 55-65 days at 5°C.

### ***Recruitment***

The hatching period of *G. auratus* larvae may extend over 3-4 months depending on the time of year at which spawning commenced. Larval hatching peaks in late winter-spring. Newly hatched larvae are 5-7 mm (TFL), transparent and have a very elongated body shape with a defined head and pronounced eyes. Larvae are active swimmers upon hatching and are pelagic living in the mid to upper water column. Larvae grow slowly for the first 2-3 months reaching around 10 mm (TFL) by the end of this period. Larvae then grow rapidly with growth rates approaching 0.5 mm/day when approximately 100-120 days old. The growth rate then gradually decreases until the end of autumn. Juvenile fish recruit into the adult proportion of populations at 5-6 months of age at lengths >40 mm (TFL). By the end of their first year *G. auratus* reach approximately 60 mm (TFL).

### ***Age, Growth and Population Structure***

Once *G. auratus* have reached their second year, growth is more weight related. The relationship between length (L) and weight (W) for *G. auratus* can be described by the equation:

$$W = 1 \times 10^{-6} L^{3.4883} \quad (n = 2376, R^2 = 0.966)$$

Wild populations of *G. auratus* are dominated by cohorts 0+, 1+, 2+, 3+ and 4+. Most fish live for 3-4 years with some reaching greater than 6 years of age. Female fish grow larger and possibly live longer than males. Female fish are also more abundant than male fish with sex ratios (male:female) 1:1.88 and 1:1.72 being observed in lakes Crescent and Sorell respectively.

### ***Diet***

*G. auratus* larvae feed on zooplankton and small insect larvae in the water column. Once juvenile fish reach around 60-70 mm (TFL) they generally move inshore and feed on larger benthic prey. Juvenile and adult fish feed on aquatic and terrestrial insects, small crustaceans (including zooplankton) and molluscs. Cannibalism is common amongst larger fish. *G. auratus* have the ability to change feeding strategies depending on the availability of food resources. Terrestrial invertebrates from nearby eucalypt forests account for a significant proportion of the diet of *G. auratus* during summer and autumn.

#### **4.1.3 Discussion of the Ecology of Golden galaxias**

Several aspects of the biology and life cycle of the golden galaxias (*Galaxias auratus*) are typical of galaxiid species, however this study has also revealed that this species has some interesting and unique life history strategies. The following is a comparison of the ecology of *G. auratus* to that of other Galaxiidae species and findings of interest are discussed.

### ***Habitat and Behaviour***

The preferred habitats of adult *G. auratus* and the way in which these habitats are utilised is similar to other Galaxiidae species. *G. auratus* was found to prefer rocky shore habitat and is also suspected to favour macrophyte dominated in-lake and marsh habitat when available.

The preference of this species for the shelter and food resources provided by these complex habitats is not unusual. All lake dwelling Tasmanian endemic galaxiid species prefer rocky shores. These include *Paragalaxias* species Shannon (*P. dissimilis*), Great Lake (*P. electroides*), Arthurs (*P. mesotes*) and western (*P. julianus*) (Fulton 1982), and *Galaxias* species Pedder (*G. pedderensis*), Clarence (*G. johnstoni*) and saddled (*G. tanycephalus*) (IFS unpublished data). Landlocked populations of the closely related non-endemic spotted galaxias (*G. truttaceus*) are also known to prefer this habitat (IFS unpublished data). Of these species, *G. johnstoni*, *G. tanycephalus* and *G. truttaceus* are also known to utilise macrophyte dominated habitat where it is available (B. Mawbey pers. comm.).

The behaviour of *G. auratus* appears similar to other galaxiids. Juvenile *G. auratus* were found to shoal in shallow margins which is a common behavioural characteristic amongst Galaxiidae species (McDowall 1970). The increase in activity (possibly feeding related) of *G. auratus* nocturnally has also been recorded for stream dwelling galaxiids, climbing galaxias (*G. brevipinnis*) (Glova & Sagar 1989) and common river galaxias (*G. vulgaris*) (Glova 1989), and is a behavioural characteristic of the translocated population of *G. pedderensis* in Lake Oberon, south-west Tasmania (IFS unpublished data). This behaviour is thought to be common amongst other galaxiid species both riverine and lake dwelling, although data in this area is limited.

The daily home range of larger *G. auratus* individuals appears to be reasonably extensive given that they move in-shore over-night. The home range of lake-dwelling galaxiids has not been formally studied. The suspected extensive home range of large *G. auratus* may be a common behavioural characteristic of large individuals of lake dwelling galaxiid species.

### **Reproduction**

Most aspects of the reproductive biology of *G. auratus* are similar to other galaxiid species, however the timing of the spawning period is unusual for a non-diadromous species. In general, diadromous (sea ↔ freshwater migratory) galaxiids produce large numbers of small eggs and breed in late autumn to early winter, whereas non-diadromous (freshwater landlocked) species generally have smaller numbers of larger eggs and breed in late winter to early spring (McDowall 1970; McDowall & Frankenberg 1981). Humphries (1989) examined this theory in regard to diadromous and non-diadromous populations of *G. truttaceus*, a species closely related to *G. auratus*, and found that the diadromous populations spawn in autumn while the non-diadromous populations spawn in spring. The late autumn-winter spawning of the non-diadromous *G. auratus* observed during this study, is an exception to this theory.

Pen & Potter (1991) summarised the spawning time, diameter of eggs and fecundity of various galaxiid species. In comparison to this summary, *G. auratus* has medium sized eggs and a reasonably high fecundity, which are indicative of a landlocked derivative of diadromous species (ie. comparable to landlocked *G. truttaceus*). However, the timing of spawning period of *G. auratus* is not consistent with the similarity of other aspects of the reproductive biology of this species to that of other non-diadromous galaxiids.

The gonad development period was similar and consistent in the Lake Crescent and Lake Sorell populations over the three breeding seasons that were studied. However, a difference in the timing of the spawning period was observed between the populations. The *G. auratus* population in Lake Sorell was found to spawn earlier than the population in Lake Crescent during 2001 and 2002, while both populations spawned progressively earlier between 2000 and 2002. Reasons for the earlier spawning period in Lake Sorell compared to Lake Crescent and the progression towards earlier spawning and hence larval hatching in both lakes are unclear.

It is suspected that *G. auratus* populations may have progressed towards an earlier spawning period in response to a number of environmental pressures. The recent low water levels in lakes Crescent and Sorell and the disconnection of their associated wetlands may have altered the reproductive cycle of *G. auratus* populations. If macrophyte dominated wetland habitat is used for spawning when available, then the disconnection of this habitat along with the de-watering of rocky shores in Lake Crescent, may have delayed spawning in recent years due to a lack of suitable habitat availability. After a number of consecutive years of this occurring, the reproductive cycle of the populations may have altered towards a later spawning in Lake Crescent compared to Lake Sorell, where low water levels do not greatly effect the availability of rocky shore habitat.

It is also speculated that the *G. auratus* population in Lake Sorell may be spawning earlier than the Lake Crescent population in an effort to reduce the risk of predation from trout. Currently the reproductive cycle of the *G. auratus* population in Lake Sorell is very similar to that of the brown trout (*Salmo trutta*) population and hence the spawning periods of *G. auratus* and *S. trutta* are coinciding. During this period, a large proportion of the *S. trutta* population in Lake Sorell, is congregating in and around the mouth of tributaries that are used for spawning, primarily Mountain Creek and to a lesser degree Silver Plains Creek, while *G. auratus* are spawning on rocky shores. Alternatively, if *G. auratus* in Lake Sorell were to spawn in spring, then *S. trutta* that have finished spawning and are lacking condition would be able to target congregations of *G. auratus* on rocky shores and predate heavily on this vulnerable prey.

Spawning during late autumn - early winter is not thought to be advantageous for successful reproduction and recruitment. Eggs that have been spawned earlier in the season have a much longer incubation period due to colder water temperatures, which increases their vulnerability to predation and disturbance. Larvae that hatch during winter also have to contend with much colder water temperatures and less abundant food resources and hence their growth is much slower, once again decreasing their chance of survival. The larval hatching period that follows early spawning is thought to be extended due to intermittent spawning caused by marginal conditions. This means that larvae are not as abundant in the water column as occurs after a major spawning event. This is also thought to impact on the success of recruitment.

In contrast to Lake Sorell, the *G. auratus* population in Lake Crescent contends with much less predation pressure from *S. trutta*, as the trout population is significantly less abundant in comparison to that in Lake Sorell. Therefore, *G. auratus* in Lake Crescent are not forced into earlier spawning and are able to utilise conditions that are more favourable towards successful reproduction and recruitment. This may also contribute to the difference in abundance between the two *G. auratus* populations.

The evolutionary progression of non-diadromous species/populations that have been derived from diadromous species, such as *G. auratus*, from autumn spawning to spring spawning has been previously investigated on the closely related *G. truttaceus* (Humphries 1989). The variation in the timing of the spawning period of *G. auratus* populations and their tendency towards autumn - winter spawning compared to the spring spawning of other non-diadromous galaxiid species, may be an evolutionary trait.

The reproductive cycle of the closely related saddled galaxias (*G. tanycephalus*) which occurs in the nearby Woods Lake and Arthurs Lake on the Tasmanian Central Plateau, has also been found to vary from the general trend of a non-diadromous galaxiids. *G. tanycephalus* has an extended spawning period which appears to peak in autumn and spring (IFS unpublished data). Therefore the reproductive biology of the species complex that contains *G. auratus*, *G. tanycephalus* and diadromous and non-diadromous *G. truttaceus*, that has evolved from the ancestral *G. truttaceus*, may vary from the general trend of other non-diadromous galaxiid species.

Most other aspects of the reproductive biology of *G. auratus*, including size at sexual maturity, fecundity, size of eggs and larvae, closely resemble those recorded for the closely related non-diadromous *G. truttaceus* (Humphries 1989). The reproductive biology of *G. auratus* is also similar to other non-diadromous galaxiid species/populations (Pen & Potter 1991; Pollard 1971).

The diversity of available habitats in lakes Crescent and Sorell during this study was very low, with rocky substrates being the only stable substrate available to *G. auratus* on which to adhere their eggs. Although data is limited, it is suspected that most non-diadromous galaxiid species in Tasmania also utilise rocky substrates for spawning. It is thought that *G. auratus* may also use macrophyte dominated habitat for spawning when it is available, as this habitat would also provide a stable surface for the adhesion of eggs. Non-diadromous populations of the closely related *G. truttaceus* have been found to use macrophytes for spawning (Humphries 1989).

The length of the incubation period of *G. auratus* eggs, observed during this study, is thought to be longer than that recorded for most galaxiid species. The longer incubation period is likely to be due to the cold water temperatures that occur in lakes Crescent and Sorell after the unusual late autumn-winter spawning period of this highland, landlocked species.

### **Recruitment**

Several Galaxiidae species have small pelagic larvae, which is indicative of the relatively small size of adult galaxiids and the marine ancestry of this family. The length and age of juvenile *G. auratus* upon their recruitment into the adult population is similar to other galaxiid species. Most galaxiids utilise adult habitats by the end of their first year and generally reach sexual maturity in either their first or second year. Examples of other non-diadromous galaxiid species and populations with similar recruitment patterns include *G. truttaceus* (Humphries 1989), *P. dissimilis* (Fulton 1982) and *G. tanycephalus* (IFS unpublished data).

### ***Age, Growth and Population Structure***

The relative abundance of the *G. auratus* population in Lake Crescent is thought to be quite high in comparison to other populations of galaxiids in lakes on Tasmania's Central Plateau. The high abundance of *G. auratus* in Lake Crescent is suspected to be due to the relatively low abundance of the trout population and hence may be representative of the abundance of this species in both lakes Crescent and Sorell prior to the introduction of trout. The abundance of the *G. auratus* population in Lake Crescent may also simulate the abundance of other galaxiid species in other lakes on the Tasmanian Central Plateau before human induced alterations to their habitats occurred (ie introduction of trout and water level alterations).

The growth patterns and structure of the *G. auratus* populations in lakes Crescent and Sorell are similar to those of non-diadromous populations of *G. truttaceus* on Tasmania's Central Plateau (Humphries 1989). Humphries (1989) found that the population structure of non-diadromous populations of *G. truttaceus* had diverged significantly from their diadromous ancestors to populations that are dominated by older fish (> 2+ years). Given the common ancestry of *G. auratus* and non-diadromous populations of *G. truttaceus* (both derived from diadromous *G. truttaceus*), this trend of domination of older fish in non-diadromous populations is also evident in *G. auratus* populations.

### ***Diet***

The diet of *G. auratus* and feeding strategies that this species uses, are similar to other galaxiid species. Larvae and juveniles of other non-diadromous galaxiid species including *P. dissimilis* (Fulton 1982) and *G. tanycephalus* (IFS unpublished data), have also been found to feed in the pelagic zone on insect larvae and plankton. The diet of adult *G. auratus* was found to vary seasonally, particularly in Lake Crescent. Dominant diet items during winter and spring included benthic prey such as small crustaceans and gastropods, as well as aquatic insect larvae and their own eggs, while terrestrial insects and zooplankton made more significant contributions during summer and autumn. The diet of the Lake Sorell population was, however, dominated by *Daphnia* spp. for the majority of the study period.

Similar seasonal feeding patterns to those observed in the Lake Crescent *G. auratus* population, have been recorded for Paragalaxias species (Fulton 1982) and non-diadromous common galaxias (*G. maculatus*) (Pollard 1973). Terrestrial insects also make significant contributions, particularly during summer, to the diet of stream dwelling galaxiid species, mountain galaxias (*G. olidus*) (Cadwallader *et al.* 1980), shortjawed kokopu (*G. postvectis*) (McDowall *et al.* 1996) and *G. vulgaris* (Cadwallader 1975). Galaxiid eggs have also been found to make a significant contribution to the diet of *P. eleotroides* and *P. dissimilis* (Fulton 1982).

The dominance of the pelagic feeding strategy, primarily on *Daphnia* spp., in the *G. auratus* population in Lake Sorell is interesting given that the population in the neighbouring Lake Crescent is not utilising this strategy to the same extent. It is suggested that this feeding strategy is a reflection of the persistent high abundance of *Daphnia* spp. in Lake Sorell and may also be due to competition with juvenile *S. trutta* causing food resources partitioning between the two species. The ability of *G. auratus* to utilise different feeding strategies in lakes Crescent and Sorell illustrates the adaptive feeding habits of this species.

## 4.2 Threatening Processes

### 4.2.1 Lake Levels

Low water levels in Lake Crescent and Lake Sorell have been identified as a major threat to golden galaxias (*Galaxias auratus*) populations. The recent persistent low water levels were found to have degraded lakes Crescent and Sorell, the only habitat available to wild populations of this species. A general decrease in water quality, in particular high turbidity, as well as a decrease in habitat diversity and loss of habitat in both lakes was observed during this study as a result of low water levels. This degradation of habitat affects *G. auratus* populations by decreasing shelter and spawning habitat and is also thought to limit available food resources. Higher water levels are thought to provide greater habitat diversity, availability and stability.

Prolonged low lake levels are the major threat facing the *G. auratus* populations in lakes Crescent and Sorell and hence the survival of this species.

### *Water Quality*

High turbidity is thought to be a serious threat to *G. auratus* populations. High turbidity has been found to cause large fish kills of *G. auratus* in the past (IFC 1994). Fine sediments suspended in the water column were found to cause abrasion of gills which disrupts respiration and increases the chance of infection. Although fish kills have not been noticed recently, prolonged high turbidity levels and/or sudden increases in turbidity, are still considered a significant threat.

The effect that high turbidity has on the entire aquatic ecosystem associated with lakes Crescent and Sorell has not been fully examined. However the aquatic invertebrate communities in both lakes were studied as a part of the *Aquatic Fauna Sub-project* (Hardie 2003). Invertebrates provide the majority of the food resource for *G. auratus* and are therefore critical for the survival of this species. The diversity and abundance of the invertebrate communities in lakes Crescent and Sorell is suspected to have decreased in recent years (Hardie 2003). High turbidity may have contributed to the change in structure of the invertebrate communities.

Processes associated with water turbidity that may directly and indirectly influence invertebrates include increased light attenuation which, in turn, reduces algal and plant growth and hence decreases food resources and habitat for invertebrates. The siltation of rock and sand shores associated with an increase in turbidity also may have degraded these habitats and rendered them unsuitable for habitat specific invertebrate species.

### ***Reduced Habitat Availability***

Low water levels in lakes Crescent and Sorell have the potential to reduce the amount and diversity of habitat that is available to *G. auratus* populations. The prolonged low lake levels that were observed during this study, had de-watered and disconnected the extensive adjacent wetland areas from the main bodies of the lakes. This has made access to in-flowing creeks and their associated wetlands more difficult for *G. auratus*. Low water levels have also decreased the diversity of in-lake habitats, particularly in Lake Crescent, by de-watering sandy and rocky shores. The increase in turbidity, associated with low lake levels also decreased the abundance of in-lake macrophytes in Lake Sorell by inducing light attenuation into the water column.

The cumulative reduction in habitat associated with low water levels removes areas of important habitat that *G. auratus* utilise for shelter, feeding and spawning.

### ***Effect on Golden Galaxias Reproductive Cycle***

Rocky shores were found to be the only habitat which *G. auratus* used for spawning during this study. Data collected on the reproductive cycle of *G. auratus* populations in lakes Crescent and Sorell during the 2001 spawning season illustrates that a significant reduction in the amount of submerged rocky shore habitat may delay spawning.

As previously discussed, low water levels in Lake Crescent can significantly reduce the amount of submerged rocky shore habitat. Results of the rocky shore survey showed that lake levels <801.50 m AHD in Lake Crescent de-water basically all of the rocky shore habitat. It is not until the water level is >802.20 m AHD that a significant proportion of rocky substrate suitable for *G. auratus* spawning is inundated and therefore available for spawning.

Examination of the gonadal cycle of *G. auratus* showed that populations in both lakes rapidly develop gonad mass during late summer – autumn and are ready to spawn in late autumn-early winter. Spawning events appear to be triggered by suitable water temperatures and rising lake level, given that suitable habitat is available. In the 2001 spawning season, the spawning in Lake Crescent occurred later than in Lake Sorell, despite there being suitable environmental conditions. The mean gonadosomatic index (GSI) of *G. auratus* in Lake Crescent (Figure 33) remained high between May – July during 2001 (while lake levels were <802.20 m AHD), whereas in Lake Sorell (Figure 36) it decreased as a result of spawning.

The delay in spawning is verified by the presence/absence of *G. auratus* eggs on fyke nets and the results of eggs searches on rocky shores during this period (Tables 7 and 8). During the project, fyke nets were found to provide a suitable spawning substrate for *G. auratus*. Therefore when fish are ripe and conditions are favourable, fish will spawn inside fyke nets, leaving eggs adhered to the nets. During the 2001 spawning season, *G. auratus* eggs were present on fyke nets from June to September in Lake Crescent and from May to September in Lake Sorell. However, eggs were not found at the spawning monitoring site in Lake Crescent until late July (when lake level reached 802.20 m AHD), with a peak in the abundance of eggs occurring in late August. In comparison, eggs were found at the spawning monitoring site in Lake Sorell in early June with a peak in abundance in early July.

Data collected on the 2002 spawning season shows a similar trend between the two lakes despite higher lake levels in Lake Crescent compared to 2001. The delay in spawning during 2002 is thought to be due to a combination of two factors: 1) Fish may have been lagging in their gonad development as a result of the delay in spawning during 2001, with the resting stage of development of fish in Lake Crescent being much less than fish in Lake Sorell; 2) Although lake levels were higher and more spawning habitat was inundated in Lake Crescent, a high proportion of the rocky substrate was smothered in a fine layer of sediment – possibly decreasing the suitability of this substrate for spawning.

#### 4.2.2 Competition and Predation from Introduced Fish Species

Of the six fish species present in lakes Crescent and Sorell (brown trout (*Salmo trutta*), rainbow trout (*Oncorhynchus mykiss*), European carp (*Cyprinus carpio*), common galaxias (*Galaxias maculatus*), short-finned eel (*Anguilla australis*) and golden galaxias (*Galaxias auratus*)), only *G. auratus* and *A. australis* are indigenous to the lakes. The fish fauna of lakes Crescent and Sorell is both typical and unique in terms of other lakes on Tasmania's Central Plateau. Both lakes contain an endemic galaxiid species that is co-existing with introduced salmonid species. This is typical of many lake systems on the Central Plateau such as Woods Lake, Arthurs Lake, Great Lake, Shannon Lagoon and various lakes in the Western Lakes area. What makes lakes Crescent and Sorell unique is the presence of European carp (*Cyprinus carpio*) which is only found in these two water bodies in Tasmania.

Understanding the interactions between *G. auratus* and the introduced species in the fish communities of lakes Crescent and Sorell is a critical component of the knowledge base required to manage *G. auratus* as a threatened species. The interactions between *G. auratus* and all 4 introduced fish species in lakes Crescent and Sorell were examined during the study. Particular focus was directed towards the interaction between *G. auratus* and juvenile *S. trutta*, with *S. trutta* dominating the trout populations (ie *O. mykiss* are in relatively small numbers).

Juvenile *S. trutta* competed for both food and habitat resources with adult *G. auratus* in Lake Sorell. Both fish prefer rocky shore habitat for feeding and shelter, although *G. auratus* appear to be more adaptable to other habitats and feeding strategies.

The difference in density between *G. auratus* populations in lake Crescent and Sorell is thought to be primarily due to different competition and predation pressures from the different sized *S. trutta* populations. With Lake Sorell having high annual recruitment and a large population of medium sized *S. trutta*, high competition from the juveniles and predation from adults is likely to occur. Lake Crescent has poor natural recruitment and a smaller population of larger *S. trutta*, resulting in low competition pressure from the juveniles and low predation from adults. This inverse relationship between the abundance of salmonid and galaxiid fish may be compounded by the historic difference in water turbidity between lakes Crescent and Sorell. Increased turbidity has been found to have a negative effect on the ability of salmonids to seek prey (Vogel & Beauchamp 1999). Historically, Lake Crescent is more turbid and this inhibits the ability of *S. trutta* to predate on highly mobile prey, such as *G. auratus*.

*S. trutta* populations appear to be controlling the size of *G. auratus* populations, however both species are currently able to co-exist. This inverse relationship between the abundance of salmonid and galaxiid fish is also thought to be common to other lakes on the Central Plateau. Another example of this relationship is the difference in relative abundance between saddled galaxias (*G. tanycephalus*) populations in Woods Lake and Arthurs Lake. Arthurs Lake have a larger population of *S. trutta* and a smaller population of *G. tanycephalus*, and the reverse occurs in Woods Lake (IFS unpublished data). Similarly, this relationship is thought to be compounded by the difference in turbidity between these lakes, with Woods Lake being more turbid.

The population sizes of European carp (*Cyprinus carpio*) and common galaxias (*Galaxias maculatus*) are currently very small in lakes Crescent and Sorell and are not likely to be having an impact on *G. auratus* populations. If either species were to become abundant then competition for habitat and food resources would occur with *G. auratus*. Direct predation on juvenile and adult *G. auratus* is not a threat as neither species is piscivorous, although some predation on eggs may occur. Both species will compete for food resources and habitat, with *G. maculatus* occupying a similar niche to *G. auratus*. *C. carpio* also have the potential to degrade habitat and reduce water quality through their bottom feeding behaviour.

The two farm dams in the Clyde River catchment containing the translocated populations of *G. auratus* are currently free of other fish species. It is critical that these dams remain undisturbed by fish introductions particularly predatory species such as *S. trutta*, *O. mykiss* and redfin (*Perca fluviatilis*). If large numbers of any of these piscivorous species were introduced into the dams then it is likely that *G. auratus* would not be able to co-exist, given the relatively small size of these dams and limited refuge habitat available for *G. auratus*.

### 4.2.3 Other Threats

Other threatening processes faced by wild populations of golden galaxias (*Galaxias auratus*) include the alteration of associated wetland habitats through draining and grazing and the potential for reductions in water quality caused by run-off from forestry operations and the Lake Crescent subdivision.

Draining and grazing of associated wetlands threatens *G. auratus* populations by reducing the condition and amount of wetland habitat available to this species. An example of the impact these land management practices can have is the current state of the Agnews system associated with Lake Crescent. The recent draining of Agnews Marsh and the channelisation of Agnews Creek has severely degraded the habitat this system once provided to the *G. auratus* population in Lake Crescent. The physical alteration of the water-holding capacity and flow regime of the marsh and creek, respectively, has converted the wetland into an area of sodden sediment and marginal pasture and has caused flows in the creek to become more variable and inconsistent. In recent years, the combination of low flows in the creek and low water levels in Lake Crescent have caused the mouth of the creek to become undefined – hence creating an impassable barrier for *G. auratus* seeking to move upstream into the Agnews system. These alterations of the Agnews system have further restricted the distribution of *G. auratus*.

The quality of the water into Lake Crescent from Agnews Creek was found to be poor during the study period with high concentration of nutrients, particularly nitrogen (Uytendaal 2003). Uytendaal (2003) found that the Agnews system was contributing significantly to the nitrogen loading of Lake Crescent. This situation has the potential to cause water quality conditions suitable for algal booms to occur in Lake Crescent.

The Agnews system is an extreme example of the damage that can be caused by draining and grazing a wetland. However, all alterations (such as draining and grazing) to other wetlands associated with lakes Crescent and Sorell, are thought to have impacted upon the hydrology and ecology of these areas. Although the impacts of these land management practices may not be obvious, they have the potential to significantly alter habitat utilised by *G. auratus* and further restrict the distribution of this threatened species.

Forestry operations in the catchment of lakes Crescent and Sorell have the potential to degrade the water quality and cause the siltation of tributaries through run-off. The Lake Crescent subdivision also has the potential to influence the water quality of Lake Crescent through seepage from un-maintained or faulty septic systems.

The main recreational activities that occur at lakes Crescent and Sorell are fishing and, to a lesser extent, duck shooting. These activities have the potential to introduce exotic aquatic flora and fauna into the lakes Crescent and Sorell area through transfers via unclean equipment (ie boats and waders) and/or accidental releases through bait fishing. A major concern is the potential for the introduction of other fish species that would predate on and/or compete with *G. auratus*. The recent introduction of European carp (*Cyprinus carpio*) into lakes Crescent and Sorell is an example of this threatening process. *C. carpio* are thought to have been introduced by fishermen using this species for bait. However, the risk of fish introductions has been

significantly reduced since 1996, when the use of fish and fish products for angling was made illegal for all inland waters, except tidal waters, in Tasmania.

Since the discovery of *C. carpio* in lakes Crescent and Sorell in 1995, Lakes Crescent has been closed to fishing and when re-opened it will be managed as an 'artificial lure only' water (ie no bait fishing). Lake Sorell was managed as an 'artificial lure only' water prior to the introduction of *C. carpio* and will continue to be managed in this manner in the future.

Another example of the hazards associated with the introduction of exotic fish species is the scenario that could arise if redfin (*Perca fluviatilis*) were introduced into lakes Crescent and Sorell. *P. fluviatilis* are widespread in Tasmania, particularly lowland lakes and streams, including the Clyde River 30 km downstream of Lake Crescent. They are a very aggressive piscivore that would predate heavily on *G. auratus* if they were introduced into lakes Crescent and Sorell and most likely cause the extinction of the wild populations of this species.

*G. auratus* has a very restricted distribution with only two natural populations. This limited distribution means that survival of this species is at high risk. These risks include fish kills (caused by disease and climatic events), human induced alterations to their environment and pressure from exotic fauna invading their habitat. The restricted distribution of *G. auratus* means that all of the threats which have been outlined are highly significant as they have the potential, not only to impact upon the populations of this species, but also directly threaten the survival of this species.

#### 4.2.4 Summary of Threatening Processes

The main threats to wild populations of golden galaxias (*Galaxias auratus*) are associated with low water levels in lakes Crescent and Sorell. These threats include:

- decrease in the diversity of in-lake habitat
  - loss of rocky shore habitat, particularly Lake Crescent (critical spawning habitat)
  - loss of in-lake macrophyte habitat, particularly in Lake Sorell
  - loss of sandy shore habitat
- reduction in available habitat, particularly in Lake Crescent
  - disconnection and de-watering of adjacent wetlands
  - disconnection of tributary streams and their associated wetlands
  - reduction of lake volume
- decrease in water quality
  - high to very high water turbidity
    - potential to cause fish kills through 'gill erosion'
  - siltation of rock and sand shores

- reduced habitat diversity and availability increases competition with other fish species and the risk of predation from salmonids
- alteration to habitats impacts on invertebrate communities (food resources)

Other general threats to *G. auratus* include:

- competition and predation from introduced fish,
  - salmonid populations cause competition and predation pressure
    - control size of *G. auratus* populations
  - European carp (*Cyprinus carpio*) and common galaxias (*Galaxias maculatus*) populations have the potential to cause competition pressure
- draining and grazing of adjacent and associated wetlands
  - further restrict distribution by decreasing available habitat
- recreational use of lakes
  - potential for introduction of flora and fauna particularly other fish species

## 5. Management of Golden Galaxias

Given the significant conservation status of the golden galaxias (*Galaxias auratus*) and the fact that lakes Crescent and Sorell are the only locations where natural populations of *G. auratus* occur, all management actions should be undertaken in a cautious and conservative manner. The management of lakes Crescent and Sorell needs to provide suitable habitat for the health and long-term survival of *G. auratus* populations.

In light of the significant findings of the ecological research that has been undertaken on *G. auratus* and the threatening processes that have been identified, several management issues have been highlighted. Management issues are briefly discussed and recommendations for management are detailed.

### 5.1. Lakes

The Inland Fisheries Service (IFS) currently manages lakes Crescent and Sorell under the *Inland Fisheries Act 1995* in conjunction with the Department of Primary Industry, Water and Environment (DPIWE) and the Clyde Water Trust. There are several issues associated with the management of these lakes including water level regimes, recreational fisheries, carp control and eradication, commercial fisheries and recreational activities, all of which may impact on golden galaxias (*Galaxias auratus*) populations.

#### 5.1.1 Water Level Regime

Water level management needs to take into account the effect that this physical parameter has on the unique ecosystems associated with lakes Crescent and Sorell, that in turn support golden galaxias (*Galaxias auratus*) populations. Several water level dependant processes have been identified in lakes Crescent and Sorell during the *Lakes Sorell and Crescent Rehabilitation Project*. Some of these processes indirectly effect *G. auratus* populations while others have direct impacts.

Prolonged low water levels were found to degrade water quality (particularly by increasing turbidity) and also reduce the availability and diversity of in-lake habitats in lakes Crescent and Sorell. Lake Crescent was found to be more susceptible than Lake Sorell, to decreases in habitat diversity during periods of low water levels. Significant proportions of rocky shore habitat, a critical refuge and spawning habitat for *G. auratus*, can be de-watered as a result of low lake levels in Lake Crescent.

The water level regimes of lakes Crescent and Sorell have been artificially manipulated over the past 150 years. As a consequence of these alterations, the lakes are thought to be quite different from their natural, pre-disturbed state. In order to protect the aquatic ecosystems, and hence the *G. auratus* populations, the Crescent-Sorell system should not undergo further alterations to its water holding capacity and/or significant variations from its historical water level regimes.

Recommendations for the management of the water levels in lakes Crescent and Sorell include:

- Maintaining both lakes at mid to high levels to protect habitat diversity and ensure good water quality.
- Historical seasonal cycles in water level regimes should be retained and altered as little as possible.
- Maintaining water levels in Lake Crescent above 802.20 m AHD, the level above which rocky shore habitat becomes inundated. This is particularly critical during late autumn - winter.
- The absolute minimum frequency for Lake Crescent to have a water level above 802.20 m AHD during late autumn – winter, is 1 in every 3 years. This is, however, a high risk strategy which may have long term impacts on the structure and abundance of the *G. auratus* population.
- Sudden decreases in water level, >600 mm, between June and September should not occur in either Lake Crescent or Lake Sorell, as this will de-water incubating *G. auratus* eggs.
- The recommendations of the *Wetlands Sub-project* regarding lake level regimes should be implemented to ensure the adjacent wetlands remain healthy (ie. protect *G. auratus* habitat).
- The recommendations of the *Water Quality Sub-project* regarding lake level regimes should be implemented to ensure the water quality in lakes Crescent and Sorell improves and is maintained in a healthy state (ie. protect *G. auratus* habitat).

### 5.1.2 Recreational Fisheries Management

The Inland Fisheries Service (IFS) is responsible for managing the recreational trout fishery in lakes Crescent and Sorell. In the past, brown and rainbow trout (*Salmo trutta* and *Oncorhynchus mykiss*) have been regularly stocked into Lake Crescent while the trout fishery in Lake Sorell has been sustained by natural recruitment. The golden galaxias (*Galaxias auratus*) appears to be able to co-exist with these salmonid species although the size of *G. auratus* populations is thought to be controlled by salmonid populations.

In the past, salmonid stockings into Lake Crescent have varied in terms of number and size of stocked fish and no formal consideration has been given to the management of the *G. auratus* population. It is recommended that the relationship between the abundance of salmonid and *G. auratus* populations in lakes Crescent and Sorell be investigated and quantified. Future salmonid stockings should be based upon the findings of this research, to ensure *G. auratus* populations remain abundant. This research could also be expanded to other waters stocked with salmonids containing threatened native species (particularly Galaxiidae species).

The findings of this study indicate that the *G. auratus* population in Lake Sorell is approximately 10 fold less abundant than the Lake Crescent population. It is suggested that the main reason for the difference in abundance is the greater predation and competition pressure associated with the more abundant salmonid population in Lake Sorell.

A relatively simple way of controlling the size of the salmonid population in Lake Sorell is to limit the access salmonids have to spawning habitat in in-flowing creeks. If the *G. auratus* population in Lake Sorell was to suffer a serious decline in abundance in the future, limiting salmonid spawning could be an option to decrease one of the threats this population is facing.

Recommendations for the management of the recreational trout fisheries in lakes Crescent and Sorell include, that the IFS:

- Examine the relationship between the abundance of salmonid and *G. auratus* populations and develop a formal stocking strategy for Lake Crescent.
- Protect the *G. auratus* population in Lake Crescent by instigating appropriate salmonid stocking rates designed to limit salmonid populations in the lake to historical levels.
- Consider limiting salmonid spawning runs in Mountain Creek and Silver Plains Creek as a strategy to increase the abundance of the *G. auratus* population in Lake Sorell, if a serious decline in the abundance of the *G. auratus* population occurs in the future.

### 5.1.3 Carp Control/Eradication Program

The Inland Fisheries Service (IFS) has been conducting a program to control/eradicate European carp (*Cyprinus carpio*) in lakes Crescent and Sorell since 1995 when this species was first discovered in Lake Crescent. Some of the activities that are undertaken as part of this program have the potential to impact upon golden galaxias (*Galaxias auratus*) populations. The main impacts are associated with the screening of water between the two lakes and at the outflow of Lake Crescent. The screen systems at both of these locations restrict the movement of *G. auratus* between the two lakes and downstream into the upper Clyde River by acting as impassable barriers.

There is also potential for *G. auratus* bi-catch during carp eradication sampling. However, due to the large net meshes that are generally used during carp sampling, the risk posed by bi-catch is minimal.

Although *C. carpio* populations in lakes Crescent and Sorell are currently in very low abundance, this species still poses a significant threat to *G. auratus*. If *C. carpio* populations were to become abundant then competition with *G. auratus* could cause a reduction in the size of the only two wild populations of *G. auratus*.

Recommendations for the management of the Carp Control/Eradication Program in lakes Crescent and Sorell include:

- Where possible, *G. auratus* entering carp containment screens in the Interlaken Canal and the Clyde River outflow are to be trapped and relocated back into the respective lakes.
- Consider relocating some *G. auratus* into the upper Clyde River at an appropriate time of year.
- If the Carp Control/Eradication Program does remove all carp from the Crescent-Sorell system then the containment screens should be removed to allow *G. auratus* to move downstream of Lake Crescent and between the two lakes.
- Carp eradication work should continue to use methods that minimise the risk of *G. auratus* bi-catch.
- The Carp Control/Eradication Program should be continued until eradication has been achieved or to at least ensure carp populations remain in low abundance.

#### 5.1.4 Commercial Eel Fishery

The Inland Fisheries Service (IFS) currently manages a commercial eel (*Anguilla australis*) fishery in lakes Crescent and Sorell, which is worked by a single licence holder. The IFS maintains the eel fishery by annual elver stockings. Elver stockings pose a considerable risk of introducing fish species other than *A. australis*. The risk of introductions should be minimised through regular quality control checks on elver stockings.

Although golden galaxias (*Galaxias auratus*) have evolved to co-exist with *A. australis*, predation by *A. australis* on *G. auratus* is thought to occur and this interaction could become more significant if *A. australis* populations were to become extremely abundant.

Eel fishing primarily involves the use of fyke nets although a migratory trap is periodically used in the Interlaken Canal. The introduction of flora and fauna to lakes Crescent and Sorell via contaminated fishing equipment that has been used in other waters poses a significant threat to *G. auratus*. Eel fishermen need to ensure that all equipment is properly cleaned prior to use in lakes Crescent and Sorell.

Recommendations for the management of the eel fishery in lakes Crescent and Sorell include:

- Elver stockings should be monitored and quality control checks performed to minimise the risk of introducing other fish species.
- Elver stocking rates for lakes Crescent and Sorell should protect *G. auratus* populations by not creating a larger *A. australis* population than the lakes are thought to have historically maintained.
- The need for use of clean equipment (boats and nets) by eel fishermen in lakes Crescent and Sorell to reduce risk of introducing flora and fauna (especially fish) be publicised and enforced.

### 5.1.5 Recreational Activities

Lakes Crescent and Sorell are used for recreational fishing and duck shooting. Both activities pose threats to golden galaxias (*Galaxias auratus*) populations. Anglers and shooters using lakes Crescent and Sorell need to ensure that their equipment (ie waders and boats) is clean to minimise the risk of introducing flora and fauna from other waterways. Recreational users also need to be made aware of the significance of *G. auratus*.

The accidental introduction of non-indigenous fauna through the use of fishing bait poses a significant risk to *G. auratus* populations. Since the discovery of European carp (*Cyprinus carpio*) in lakes Crescent and Sorell, the Inland Fisheries Service (IFS) has managed this issue by eliminating the use of fish as bait in all non-tidal waters in Tasmania and by closing Lake Crescent to the public. It is recommended that the 'artificial lure only' regulation should apply to both lakes Crescent and Sorell fisheries in order to minimise the risk of introducing additional non-indigenous fauna.

Recommendations for the management of the recreational activities which lakes Crescent and Sorell support, include:

- Educate anglers and shooters about the risk of introducing flora and fauna in lake Crescent and Sorell by using unclean equipment.
- Educate anglers and shooters about the significance of *G. auratus* and enforce its protection (ie no disturbing or possession without a permit).
- Regulate lakes Crescent and Sorell as 'artificial lure only waters' (ie no bait fishing).

## 5.2 Surrounding Land Use

The catchment of lakes Crescent and Sorell is used for agricultural and forestry practices and there is also some adjacent residential land. These activities have the potential to impact on golden galaxias (*Galaxias auratus*) populations.

### 5.2.1 Agriculture

Agricultural activities within the catchment primarily involve the grazing of sheep and cattle. Four of the five major adjacent wetlands to lakes Crescent and Sorell are currently grazed. Some of the adjacent wetlands have also been channelised (drained) to maximise their grazing potential. Alterations to the hydrology of the wetlands and the grazing of these areas by domestic stock, have the potential to further restrict the distribution of the golden galaxias (*Galaxias auratus*) and damage their habitat.

The use of fertilisers on surrounding pasture land also has the potential to increase the nutrient concentrations of the water in lakes Crescent and Sorell and degrade water quality.

Education and involvement of land owners/managers in the Crescent-Sorell catchment in regard to management issues, is thought to be a priority to improve the condition of the wetland habitats and ensure their protection in the future.

Recommendations for the management of agricultural activities in the catchment of lakes Crescent and Sorell include:

- Informing landowners and residents of the findings of the *Lakes Sorell and Crescent Rehabilitation Project* and of the significance of the Crescent-Sorell system.
- Develop partnership approaches with landholders for managing the wetlands and adjacent agricultural areas.

### 5.2.2 Forestry

Forestry operations in the catchment of lakes Crescent and Sorell, particularly in close proximity to in-flowing creeks and wetlands, have the potential to degrade the water quality of the lakes. Siltation of tributaries caused by erosion related to forestry operations may also damage golden galaxias (*Galaxias auratus*) habitat if the Forest Practices Code is not adhered to.

The native eucalypt forests surrounding lakes Crescent and Sorell provide important food resources for *G. auratus*, with several species of terrestrial forest dwelling invertebrates making significant contributions to the diet of *G. auratus* during summer and autumn.

Recommendations concerning forestry operations that occur in the catchment of lakes Crescent and Sorell include:

- Forestry operations should comply with the *Forest Practices Act 1985* and works should be undertaken in accordance with the Forest Practices Code 2000 (FPB 2000).
- Forestry operators (via the Forestry Practices Board) should seek advice from the IFS of the potential impacts associated with forestry operations within the catchment of lakes Crescent and Sorell, particularly those that are in close proximity to waterbodies.

### 5.2.3 Residential

Residential buildings are located in the Lake Crescent subdivision and Jacks Point at Lake Crescent and Dago Point at Lake Sorell (including a camp ground) and an extensive camp ground on Silver Plains Rd adjoining Lake Sorell. The main threat to golden galaxias (*Galaxias auratus*) populations that is associated with the residential use of the surrounding land, is seepage from un-maintained or faulty septic systems. Sewage effluent has the potential to increase nutrient concentrations in lakes Crescent and Sorell and lead to a degradation of water quality.

It is important that residents are informed of the findings of the *Lakes Sorell and Crescent Rehabilitation Project* and are aware of the significance of the *G. auratus* populations.

Recommendations related to residential use of land within the catchment of lakes Crescent and Sorell include:

- Provide information to local residents about the potential impacts of un-maintained septic systems.
- Inform residents of the findings of the *Lakes Sorell and Crescent Rehabilitation Project* and about the significance of the *G. auratus* populations in lakes Crescent and Sorell.

### 5.3 Protection

The golden galaxias (*Galaxias auratus*) has significant conservation status due to its restricted distribution and the threats that the species is facing in the wild. *G. auratus* is currently listed at both state and international levels and a nomination has recently been submitted by the Inland Fisheries Service (IFS) for listing at the Commonwealth level.

In order to protect this unique species and ensure its long-term survival, the formal reservation of *G. auratus* habitat should be encouraged. Interest groups and the general public should be informed of the significance of this species and other threatened freshwater fish species in Tasmania.

#### 5.3.1 Reservation

The main bodies of lakes Crescent and Sorell are currently areas of Crown land. The adjacent wetlands are a mixture of Crown land (Clyde Marsh, Robertsons Marsh and the Interlaken Lakeside Reserve) and private land (Kemps/Kermodes Marsh and Silver Plains Marsh). The Interlaken Lakeside Reserve currently listed as a 'public reserve' under the *Crown Lands Act 1976*. The Tasmanian Parks and Wildlife Service (PWS) manages the wetlands on Crown land, while the main bodies of lakes Crescent and Sorell are currently managed by the Inland Fisheries Service (IFS) due to the presence of European carp (*Cyprinus carpio*).

A proposal has recently been prepared by the IFS, for all Crown Land wetlands to be listed as Conservation Areas under the Tasmanian *National Parks and Wildlife Act 1970* (Heffer 2003). If this proposal is accepted, then it will be an important step towards protecting areas of *G. auratus* habitat.

Significant areas of foreshore and adjacent wetlands to lakes Crescent and Sorell are privately owned. These areas need to be appropriately managed to protect *G. auratus* populations and their habitat. Land owners/managers should be provided with information about suitable management practices.

Recommendations regarding the reservation of land in the lakes Crescent and Sorell area include:

- The formal reservation of all wetlands located on Crown land associated with lakes Crescent and Sorell.
- Land owners in the catchment, particularly owners of wetland and/or lake shore areas, be encouraged to reserve these areas of land.

### 5.3.2 Education

The Inland Fisheries Service (IFS) has recently commenced an education campaign to raise the public's awareness of the issues associated with the protection of threatened freshwater fish in Tasmania. The golden galaxias (*Galaxias auratus*) should be included in this campaign, particularly as it is one of the few threatened species that now has an accurately defined life cycle. This program should not only inform the public of the threats facing freshwater fish, but also explain the ecology of these species, so that the public has a true understanding of the significance of individual freshwater fish species in Tasmania. This education program should target schools, anglers, naturalist groups and local residents of the areas where threatened species occur.

Recommendations regarding the education of users of the lakes Crescent and Sorell area and the broader community include:

- Install signs at lakes Crescent and Sorell to promote the significance of the *G. auratus* populations in these lakes.
- Include *G. auratus* in a public information and education campaign to increase the profile of Tasmania's threatened freshwater fish.
- The ecological findings of this study be used to describe the life cycle of this unique Tasmanian species to interest groups and the general public.

## 5.4 Monitoring

This study has provided an extensive base-line data set on the status of golden galaxias (*Galaxias auratus*) populations and has also defined the ecology and life cycle of this species. To guarantee the survival of *G. auratus* and ensure that populations remain abundant, a monitoring program should be implemented on both the wild and translocated populations. The aim of the monitoring program should be to detect changes in the distribution and abundance of this species. In the event of a serious decline in either of the wild populations, the cause should be determined and appropriate action taken to prevent the loss of the population.

Given the significant threat posed by the establishment of common galaxias (*Galaxias maculatus*) populations in lakes Crescent and Sorell, strategies designed to monitor the abundance of this species are also important.

### 5.4.1 Golden Galaxias

#### *Wild Populations*

Wild populations of golden galaxias (*Galaxias auratus*) only occur in lakes Crescent and Sorell. Both of these populations need to be monitored, as a serious decline in either population would dramatically reduce (up to 50 %) the distribution of this species.

Over the next five years, it is expected that the condition of lakes Crescent and Sorell will improve and that all issues associated with the management of these lakes will be addressed. Wild populations of *G. auratus* should be monitored annually over the next 5 years to ensure management practices are not harming the wild populations of *G. auratus*. If and/or when the water levels in lakes Crescent and Sorell do increase and stabilise at higher levels, then the effect this has on *G. auratus* populations should also be investigated.

The monitoring regime should replicate the qualitative adult (fyke netting) and juvenile (tow netting) sampling techniques that were employed monthly during this study (see section 2). Quantitative techniques for monitoring *G. auratus* populations should also be investigated. Based on the findings of the monitoring program, the conservation status of *G. auratus* should be up-dated if necessary.

Recommendations for the future monitoring of *G. auratus* populations in lakes Crescent and Sorell include:

- Monitor *G. auratus* populations in both Lake Crescent and Lake Sorell on an annual basis over the next five years (until 2008).
- Monitor *G. auratus* populations in both Lake Crescent and Lake Sorell more frequently in the event of a significant decrease in the condition of either or both lakes. Examples being:
  - If lake levels reach record lows in either lake.
  - If water levels in Lake Crescent are below 802.20 m AHD for an extended period.
  - If a large fish kill of *G. auratus* is observed.
- The monitoring program should replicate the adult (fyke netting) and juvenile (tow netting) sampling techniques that were employed during this study (see section 2).
- Monitoring should occur in early summer (December) each year.
- Monitoring results should be compared to the data collected during this study to determine the status of the wild populations.
- Methods to quantitatively estimate the size of *G. auratus* populations in Lakes Crescent and Sorell be developed and then applied to other lake dwelling threatened galaxiid species in Tasmania.
- The conservation status of *G. auratus* be appropriately updated in the event of any changes in the status of the wild populations in lakes Crescent and Sorell.

### ***Translocated Populations***

There are currently two translocated populations of golden galaxias (*Galaxias auratus*) in the Clyde River catchment, one on Interlaken Estate and the other on the Rotherwood property. These populations need to be monitored as they may be critical to the survival of this species in the future.

The translocated populations of *G. auratus* should be monitored annually over the next five years. Monitoring of these populations should follow the regime used for the 2002 survey during this study (ie setting of 6 fyke nets over night in each dam).

The Tasmanian State Government has entered into a Management Agreement with the owner/manager of the Rotherwood property, Jim McShane. It is important that regular communication is maintained between the two parties. The State Government needs to direct greater effort towards the co-operative management of the Rotherwood dam and its newly established reserve (Rotherwood Reserve) with the property owner to ensure that the reserve and its flora and fauna are managed appropriately. The control and eradication of the noxious weed, European gorse (*Ulex europaeus*), from the Rotherwood reserve will be an on-going management issue for both the State Government and the property owner.

Recommendations for the future monitoring and management of translocated *G. auratus* populations in Clyde River catchment include:

- Monitor the two translocated *G. auratus* populations in the farm dams on Interlaken Estate and the Rotherwood property on an annual basis over the next five years (until 2008).
- Monitoring should be performed by setting 6 fyke nets in each dam over night during early summer (December).
- Monitoring results should be compared to data collected during this study to determine the status of the translocated populations.
- The State Government should communicate regularly with the owners/managers of Interlaken Estate and the Rotherwood property, to ensure the translocated populations on these properties are managed appropriately.
- The Sate Government should direct effort towards the management of the Rotherwood Reserve and the control and eradication of European gorse (*Ulex europaeus*) from the reserved area.

#### **5.4.2 Common Galaxias**

Common galaxias (*Galaxias maculatus*) populations in lakes Crescent and Sorell are currently very small and at this stage, this species does not appear to have become fully established. However, if *G. maculatus* was to become fully established in lakes Crescent and Sorell, then this species would pose a significant threat to the wild populations of golden galaxias (*Galaxias auratus*).

Since the discovery of *G. maculatus* in lakes Crescent and Sorell in 2000, the Inland Fisheries Service (IFS) has collected and analysed all specimens that have been captured as bi-catch during routine work in the Crescent-Sorell system. The number of *G. maculatus* present in both Lake Crescent and Lake Sorell appears to be too small to warrant any specific sampling effort. The status of this introduced species in the Crescent-Sorell system needs to be regularly monitored.

Recommendations for the future monitoring of *G. maculatus* populations in lakes Crescent and Sorell include:

- All *G. maculatus* bi-catch be collected and preserved by freezing or placing in 70% ethanol and analysed in accordance with the methods used for biological analysis of *G. auratus* during this study (see section 2).
- A database of capture and biological information should be maintained for all *G. maculatus* captured in lakes Crescent and Sorell.
- Specific sampling for *G. maculatus* should be undertaken if this species does become established, as a part of a study to examine the interaction between *G. auratus* and *G. maculatus*.

## 5.5 Further Research

This study has been able to define the status, life cycle and several aspects of the ecology of the golden galaxias (*Galaxias auratus*). However, the research that was undertaken during this study was conducted during a period of low to very low water levels in lakes Crescent and Sorell, with adjacent wetlands being de-watered and low flows in in-flowing tributaries.

During wet periods, when water levels are relatively high in lakes Crescent and Sorell and the in-flowing creeks and associated wetlands are connected to the lakes, a larger area of more diverse habitat will be available to *G. auratus*. The way in which *G. auratus* utilises these habitats and the impact this increase in habitat has on the abundance and size of *G. auratus* populations is largely unknown. It is suspected that the reproductive cycle of *G. auratus* may vary during wet periods, so that marsh habitat can be utilised for spawning.

The status of wild *G. auratus* populations and their ecology needs to be examined during wet years when water levels in the Crescent-Sorell system are relatively high. This research will help determine the significance of the adjacent wetlands and in-flowing creeks and their associated wetlands.

During this study, brown trout (*Salmo trutta*) populations were thought to be controlling the abundance of *G. auratus* in lakes Crescent and Sorell. The contrasting abundance of the *S. trutta* and *G. auratus* populations in the neighbouring lakes Crescent and Sorell could provide an ideal opportunity to examine the relationship between the abundance of co-existing trout and galaxiid populations. The outcomes of this research will assist in the management of both the recreational fisheries and native fish fauna of lakes Crescent and Sorell and may help define conservative trout stocking rates for other waters which contain both trout and threatened native fish.

Primarily, the questions that remain unanswered regarding the impacts of higher water levels upon *G. auratus* populations are:

- Do higher water levels cause an increase in the abundance of *G. auratus* populations?
- How important are adjacent wetlands to *G. auratus* and how do populations utilise these areas?
- How important are the in-flowing creeks and their associated wetlands to *G. auratus* populations?
- Do higher water levels influence the reproductive cycle of *G. auratus*?
- Is aquatic vegetation used by *G. auratus* as a spawning substrate when available?

Other questions that are worth investigating include:

- What is the relationship between water turbidity and the size of *G. auratus* populations?
- What is the inter-relationship between the size of trout and *G. auratus* populations?

Recommendations for future research on *G. auratus* include:

- Seasonal sampling of the *G. auratus* populations in lakes Crescent and Sorell during a year of relatively high water levels.
  - Sampling should replicate the monthly regime of adult (fyke net) and juvenile (tow net) sampling undertaken during this study.
  - Sampling should include replication of the in-lake sampling effort in marsh habitat (ie 12 fyke nets and 4 larval tows in marsh habitat in each lake).
  - Searches for *G. auratus* eggs in marsh habitat should be performed during winter and spring.
  - Replication of the biological analysis of a proportion of the adult catch of *G. auratus* should be undertaken on each sampling occasion.
- Research to investigate the inter-relationship between the abundance of trout and *G. auratus* populations in lakes Crescent and Sorell.

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## 7. Appendices

### 1. Fish Descriptions

All descriptions are taken from McDowall (1996).

#### **Short-finned eel (*Anguilla australis*)**

The short-finned eel (*Anguilla australis*) belongs to the family Anguillidae which contains just one genus, *Anguilla*. *A. australis* is present in south-eastern Australia from the Caboolture River in Southern Queensland to the south, and west to the vicinity of Mount Gambier in South Australia. This species occurs primarily in coastal wetlands draining south and east from the mountain ranges, though a few fish have been reported from the inland Murray-Darling drainage system. It occurs in streams on Flinders and Vansittart Islands in Bass Strait, and is widespread in coastal and lowland rivers in Tasmania. It is also widespread in the western Pacific, occurring on Norfolk and Lord Howe Islands although has not been recorded from Fiji and Tahiti. *A. australis* is also present in New Zealand and the Chatham Islands. *A. australis* remains abundant across its range, although numbers have declined through the development of commercial eel fisheries.

*A. australis* is known to occur in a variety of wetland habitats, but is essentially a still-water species. It migrates to sea to spawn, possibly near the Coral Sea. Larvae are known as leptocephali, which because of their compressed gumleaf shape, drift back from spawning grounds by the East Australian current. On nearing the coast they metamorphose into glass eels and enter into freshwater where development of pigment rapidly occurs and they are then known as elvers. Migration upstream follows during spring and summer penetrating the upper reaches of rivers, lakes, lagoons and swamps. Eels may take 10-20 years to reach maturity and begin their migration to the sea to spawn. *A. australis* feeds on a variety of aquatic fauna including insects, crustaceans, molluscs and fish.

#### **Common galaxias (*Galaxias maculatus*)**

Common galaxias (*Galaxias maculatus*) belong to the family Galaxiidae which is one of the largest families in the Australian freshwater fish fauna. *G. maculatus* occurs at low elevations in streams draining to the coast in southern Queensland, New South Wales and Victoria, south and west to about Adelaide; it is also widespread on all coasts of Tasmania, including King and Flinders Islands. It is also known from southern parts of Western Australia and in Lord Howe Island, New Zealand, Chatham Islands, Patagonia, South America (Chile and Argentina) and the Falkland Islands. *G. maculatus* appears to remain widespread and abundant throughout its range and is able to withstand predation and habitat degradation better than most galaxiids.

The reproductive cycle of *G. maculatus* has been well researched. Spawning mostly in autumn with fish migrating downstream on new or full moons; the eggs are small (about 1 mm in diameter) and number several thousand. Spawning occurs amongst terrestrial vegetation on the margins of river estuaries when inundated at high spring tides, where eggs become exposed for 2 or more weeks, until a later set of spring tides. After hatching the larvae go to sea and spend 5-6 months, until they return in huge schools as transparent juveniles and move upstream into adult habitats to feed and grow. Landlocked stocks also occur in many lakes in Victoria and there are some in Tasmania. Landlocked populations use in-flowing creeks to spawn in spring and rely on flood events to expose and inundate eggs during incubation. *G. maculatus* feed on a wide range of aquatic insects, crustaceans, molluscs and terrestrial insects. They form a significant component of the annual whitebait runs, which were once a commercial operation in Tasmania. The fishery was re-opened in 1990 under strict conditions as a recreational fishery.

### **Brown trout (*Salmo trutta*)**

Brown trout (*Salmo trutta*) belong to the family Salmonidae. Although a relatively small family, Salmonidae contains some of the worlds most important angling and aquaculture fishes. *S. trutta* is native to Europe, from Iceland and Scandinavia south to Spain and Northern Africa, and eastward to the Black and Caspian Seas. *S. trutta* were introduced into Australia in the 1860s and spread by a combination of stocking and migration. In Australia it is mostly found in the highlands above about 600m from northern New South Wales to the south coast of Victoria descending to lower regions where the waters remain cool. In Tasmania it is widespread and abundant down to sea level in most major catchments.

*S. trutta* spawn in autumn and winter (April-August). Spawning fish migrate upstream into tributaries with gravel beds but may spawn in a river or on a gravel lake shore with sufficient water movement. Female fish make a series of depressions in the gravel with their tail, males then join females above the depression and eggs and milt is released and eggs settle in the depressions. Females then cover the eggs by dislodging gravel upstream, the mound is then known as a redd. Redds may contain between 500 and 3000 eggs. The eggs take several weeks to develop and hatch and the newly hatched fish (alevins) then stay in the gravel for some time, absorbing their yolk. *S. trutta* feed on a wide variety of animals including aquatic crustaceans, molluscs, insects, small fishes and terrestrial insects.

### **Rainbow trout (*Oncorhynchus mykiss*)**

Rainbow trout (*Oncorhynchus mykiss*) like Brown trout (*Salmo trutta*) belong to the family Salmonidae. They are native to the pacific coast of North America from Alaska to North America to Mexico, primarily in rivers draining in to the Pacific Ocean; also along the Pacific Coast of north eastern Siberia. Australian *O. mykiss* are derived from stocks obtained from New Zealand in the 1890s. The species now occurs in higher regions from northern New South Wales to Victoria, South Australia, and in Tasmania. Their range is similar to *S. trutta* but they are more restricted in distribution and abundance. *O. mykiss* populations are often maintained by stocking.

The life history of this species is essentially similar to that of *S. trutta*. Spawning is somewhat later, in winter and early spring (August-October). Eggs are smaller and develop more quickly than those of *S. trutta*. *O. mykiss* feed on a wide range of aquatic insects, crustaceans, molluscs, fishes and terrestrial insects. Where *S. trutta* and *O. mykiss* occur together *S. trutta* are more dominant.

### **European carp (*Cyprinus carpio*)**

European carp (*Cyprinus carpio*) belong to the family Cyprinidae which is one of the largest of all fish families, with more than 1700 species found in temperate and tropical waters of Europe, Africa, Asia and North America. *C. carpio* is a native of Asia, from where it was spread by humans through Europe. It has now spread to all continents except Antarctica and can be considered as the worlds most widely distributed freshwater fish. Three strains of *C. carpio* have been introduced into Australia; an ornamental strain, a Singaporean strain of Koi and a Boolara strain. *C. carpio* now occur throughout the large inland Murray-Darling system, including all its impoundments. It has also spread into Queensland and occurs in New South Wales and the Gippsland lakes. It was introduced into Tasmania during the mid 1990s, where it is now located and contained in lakes Crescent and Sorell in the lower central highlands.

*C. carpio* has a great tolerance of low oxygen levels, which enables it to live in stagnant waters from which other fish are excluded. Fecundity is very high, with a large female containing up to 1.5 million eggs. Spawning depends on water temperature, occurring in spring (September-December) at about 17-25°C. Eggs are deposited on any fibrous plant matter in shallow water. They hatch over a few days and rapidly grow in warm waters with prolific plankton. Diet is highly varied and includes diverse aquatic animals such as molluscs, crustaceans, insect larvae and seeds. Food is taken in by suction, filtered out by the long, fine gill rakers and crushed and shredded by the molar-like pharyngeal teeth.

## 2. Pictorial of Work Undertaken on Golden Galaxias



**Picture 1.** Golden galaxias (*Galaxias auratus*) captured by fyke netting in Lake Sorell. Fish is approximately 180 mm (TFL).



**Picture 2.** De-watered rocky shore habitat in Lake Crescent, May 2000.



**Picture 3.** De-watered sandy shore habitat in Lake Crescent summer 2001. Shore at mouth of Agnews Creek.



**Picture 4.** De-watered marsh habitat in Lake Crescent, winter 2001. View east over Bullies Marsh.



**Picture 5.** Golden galaxias (*Galaxias auratus*) eggs on fine mesh fyke net, Lake Crescent, winter 2002.



**Picture 6.** De-watered golden galaxias (*Galaxias auratus*) spawning habitat (rocky shore substrate) at Boat House Shore in Lake Crescent, winter 2001. Silver pocket knife (length 100 mm) in bottom right corner indicates size of substrate.



**Picture 7.** Farm dam on ‘Interlaken Estate’ that contains a translocated population of golden galaxias (*Galaxias auratus*), January 2002.



**Picture 8.** Farm dam on Rotherwood property that contains a translocated population of golden galaxias (*Galaxias auratus*), January 2002.

### 3. Conservation Status of Tasmanian Threatened Freshwater Fish

Species	Endemic	Conservation Status		
		Tasmania <sup>1</sup>	Commonwealth <sup>2</sup>	IUCN <sup>3</sup>
Golden galaxias ( <i>Galaxias auratus</i> )	Yes	rare	-	endangered
Swan galaxias ( <i>Galaxias fontanus</i> )	Yes	endangered	endangered	critically endangered
Clarence galaxias ( <i>Galaxias johnstoni</i> )	Yes	endangered	endangered	critically endangered
Pedder galaxias ( <i>Galaxias pedderensis</i> )	Yes	endangered	endangered	critically endangered
Swamp galaxias ( <i>Galaxias parvus</i> )	Yes	rare	-	data deficient
Dwarf galaxias ( <i>Galaxiella pusilla</i> )	No	rare	vulnerable	vulnerable
Saddled galaxias ( <i>Galaxias tanycephalus</i> )	Yes	endangered	vulnerable	vulnerable
Shannon paragalaxias ( <i>Paragalaxias dissimilis</i> )	Yes	vulnerable	-	vulnerable
Great Lake Paragalaxias ( <i>Paragalaxias eleotroides</i> )	Yes	vulnerable	-	vulnerable
Arthurs Paragalaxias ( <i>Paragalaxias mesotes</i> )	Yes	endangered	-	vulnerable
Western Paragalaxias ( <i>Paragalaxias julianus</i> )	Yes	rare	-	-
Australian Grayling ( <i>Prototroctes maraena</i> )	No	vulnerable	vulnerable	vulnerable

Listing categories are in relation to:

- 1 - Tasmania *Threatened Species Protection Act 1995*
- 2 - The Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*.
- 3 - International Union for Conservation of Nature and Natural Resources (IUCN) Red List, 2000 (ASFB 2000)

#### 4. Gonad Development Stages

Gonad development stages are modified from Fulton (1982).

Stage	Volume of Development (%)	Description
1	<25	Resting stage and small amount of development. Lobes of testes translucent, not meeting each other. Eggs transparent, small to indistinct.
2	26 – 50	Testes with vermicular appearance, expanded to fill about half of the abdominal cavity. Eggs distinct, and variable in size, some white, some yellow.
3	51 – 75	Testes with vermicular appearance, filling three-quarters of the abdominal cavity. All eggs yellow but small, variable size.
4	>76	Ripe stage. Testes a white colour, occupying most of the body cavity, body wall slightly distended. Eggs uniform in size, filling the body cavity and may be visible externally through body wall.
5	Variable	Spent stage. Lobes of testes slack instead of tight appearance with flaccid membrane. Colour of testes may have turned grey colour. An obvious decrease in the amount of ripe eggs present in abdominal cavity. Remaining eggs may be disfigured and more pale in colour than viable ripe eggs. This stage also includes fish with newly formed resting stage gonads with residual eggs and testes still present.

**5. Stomach Fullness and Volumetric Analysis Parameters.**

Parameters used to performed the 'points' method of dietary analysis.

<b>Stomach Fullness</b>		<b>Volumetric Points</b>
<b>Rank</b>	<b>Volume (%)</b>	
0	empty	0
1	<25	5
2	26-50	10
3	51-75	15
4	>76	20

## 6. Summary of Captive Breeding Experiment Results

Date	Broodstock		Larvae			
	Outside Pond	Inside Tank	Tank 1	Tank 2	Tank 3	Tank 4
11-14/7/00	Set-up					
27/7/00	Food: Lake Sorell (Inverts)					
	Transfer 14 fish	Transfer 8 fish				
4/8/00	Transfer ~20 fish	Transfer 10 fish	<i>Tray 1</i> <i>Eggs off fyke nets</i>	<i>Tray 2</i> <i>Stripped</i> 3 females 4 males	<i>Tray 3</i> <i>Stripped</i> 1 female 1 male	
17/8/00	Water Temperature: Lab 5°C Food: Lake Sorell (inverts) Changed water					
	Fish good	Fish good	<i>Tray 1</i> 30% eggs 'off', others clear/defined nucleus	<i>Tray 2</i> 20-30% eggs 'off', others clear/defined nucleus	<i>Tray 3</i> <10% eggs 'off', others clear/defined nucleus	<i>Tray 4</i> <i>Stripped</i> 2 female 2 male 20 min. after fert. 90% clear/defined nucleus
23/8/00	Water Temperature: Lab 4-5 °C					
	Fish good	Fish good	<i>Tray 1</i> Eggs dev. fungus	<i>Tray 2</i> Eggs dev. fungus	<i>Tray 3</i> Eggs dev. fungus	<i>Tray 4</i> Eggs dev. fungus <i>Tray 5</i> <i>rocks + eggs from Sorell</i>
1/9/00	Water Temperature: Lab 5°C, Pond 6°C (5-10°C)					
	<i>Approx. 500 eggs spawned on rocks</i>	Fish good	<i>Tray 1</i> 30% eggs 'off'/picked, others clear/small embryo visible	<i>Tray 2</i> 90% 'off', tray removed and <b>Trial Ended</b>	<i>Tray 3</i> 20% 'off'/picked, others clear/small embryo visible. <i>Rocks and eggs from outside pond transferred</i>	<i>Tray 4</i> <20 eggs 'off'/picked, others clear/defined nucleus <i>Tray 5</i> <10 eggs 'off'/picked, others clear/well dev. embryo/colour/movement

**Appendix 6. Continued...**

<b>6/9/00</b>						2 larvae observed
<b>8/9/00</b>	Water Temperature: Lab 4°C Food: Camerons Lagoon (plankton and inverts)					
	1 dead female	13 fish observed feeding and healthily	<i>Tray 1</i> 5% 'off', others eyed	<i>Tray 3</i> 60% covered in fungus many 'off', others eyed	<i>Tray 4</i> 20% covered in fungus many 'off', others eyed.  Eggs on rocks from outside pond eyed, some 'off'	<i>Tray 5</i> Mostly clear/very well dev./ movement Eggs on rocks at same stage of dev. as tray 2 larvae observed
<b>15/9/00</b>	Water Temperature: Lab 4°C, Pond 7°C Food: Camerons Lagoon and Lake Sorell (plankton and inverts) Changed water					
	1 female removed (fungus)	2 females removed (fungus) 1 male removed (fungus)	<i>Tray 1</i> 10 % 'off', others clear/well dev. embryo. 1 larvae observed in tray	<i>Tray 3</i> 50% 'off' and/or covered in fungus, others clear/well dev embryo/ coil overlap/ movement	<i>Tray 4</i> 20% 'off', others clear/eyed/s mall embryo/½ coiled.  Many eggs on rocks 'off' some clear/defined nucleus	<i>Tray 5</i> 99% eggs clear/very well dev. embryo/ colour/ movement. 5 larvae in tray. Serval larvae observed hatching in tray upon examin. 20 larvae observed
<b>20/9/00</b>	Water Temperature: 6°C, Pond 8°C Food: Lake Sorell and Camerons Lagoon (plankton and inverts)					
		1 female removed (fungus)	<i>Tray 1</i> Fungus spreading but many viable eggs remain	<i>Tray 3</i> Fungus spreading but many viable eggs remain	<i>Tray 4</i> Fungus spreading but many viable eggs remain	<i>Tray 5</i> Fungus spreading but many viable eggs remain. 30-40 larvae observed

## Appendix 6. Continued...

<b>29/9/00</b>	Water Temperature: 7°C, Pond 8°C Food: Lake Sorell and Camerons Lagoon (plankton and inverts) Changed water					
	3 dead females	1 female removed (egg-bound)	<b>Tray 1</b> 80% 'off', others clear/well dev. embryo/colour/movement/tightly coiled in egg. 4 larvae observed in tank	<b>Tray 3</b> 80% 'off', others clear/well dev. embryo/colour/movement/tightly coiled in egg. 4 live and 10 dead larvae in tray. 18 larvae observed in tank	<b>Tray 4</b> 70% 'off', others clear/well dev. embryo. 1 larvae observed swimming in tank. Eggs on rocks eyed/dev. embryo/coiled once in egg	<b>Tray 5</b> < 5 viable eggs left in tank. 3 larvae in tray. <i>Tray emptied into tank.</i> 2-30 larvae observed in tank. Some viable eggs still adhered to rocks
<b>6/10/00</b>	Water Temperature: Lab 9°C, Pond 18°C					
	2 dead females removed	6 fish appear healthy feeding well	20 larvae observed in tank	250 larvae observed in tank	1 larvae observed in tank	1 larvae observed in tank
<b>9/10/00</b>		Large fish preying on small fish				
<b>13/10/00</b>	Water Temperature: Lab 8°C (3-8°C), Pond 7°C (4-7°C) Food: Lake Sorell and Camerons Lagoon (plankton and inverts) Water changed, egg searches					
	No eggs found. 1 dead female removed	No eggs found. 6 adult fish remaining (2 male, 2 female)	<b>Tray 1</b> 90% of 300-400 remaining eggs 'off', approx 20 viable eggs left. 1 larvae observed in tray. 20 larvae observed in tank	<b>Tray 3</b> 95% of 500 remaining eggs 'off'. A few appear viable. 2 live and 3 dead larvae in tray. ~200 larvae observed in tank	<b>Tray 4</b> 90% of eggs 'off'. Small number still viable. 5 viable eggs on rocks. 6 larvae observed in tank	No larvae observed. <i>Tank drained</i> , no eggs found on rocks. Small number of dead larvae observed

## Appendix 6. Continued...

<b>19/10/00</b>	Water Temperature: Lab 10°C (10-10°C), Pond 10°C (8-10°C) Food: Camerons Lagoon and green culture (plankton and inverts)					
	1 dead female removed	6 fish good	4 larvae observed in tank	150 larvae observed in tank	30 larvae observed in tank	
<b>27/10/00</b>	Water Temperature: Lab 10°C (10-10°C), Pond 7°C (7-9°C) Food: Camerons Lagoon and green culture (plankton and inverts) Water changed					
	2 dead females and 1 dead male removed	1 dead male removed	<i>Tray 1</i> <10 viable eggs left in tray.  No larvae observed	<i>Tray 3</i> <10 viable eggs left in tray.  17 larvae observed	<i>Tray 4</i> <10 viable eggs left in tray.  80 larvae observed	
<b>3/11/00</b>	Water Temperature: Lab 10°C (10-11°C), Pond 11°C (9-15°C)					
	1 dead male removed.  No eggs found.  <b>Trial Ended</b>	No eggs found.  <b>Trial Ended</b>	<i>Tray 1</i> containing 200 'off' eggs.  No larvae observed.  <b>Trial Ended</b>	<i>Tray 3</i> containing 200 'off' eggs.  2 larvae observed.  <b>Trial Ended</b>	<i>Tray 4</i> containing 500 'off' eggs.  No eggs on rocks.  5 larvae observed.  <b>Trial Ended</b>	