South Esk – Great Lake Water Management Review

Scientific Report on Woods Lake

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Hydro Tasmania

Table of Contents

WOODS LAKE

1. ASSESSMENT OF ISSUES AND STATUS

Development History

Woods Lake is an artificial impoundment, which inundated a smaller natural lake. The impoundment was created initially in 1911 by the construction of a levee. The regulated water was initially used to help power the Duck Reach Power Station, near Launceston.

The impoundment was expanded further in 1962 by the construction of the present Woods Dam. This enabled water to be stored for irrigation purposes along the downstream reaches of the Lake and Macquarie Rivers.

In 1974, a set of three siphons was installed straddling the dam wall at Arthurs Lake. This infrastructure, in combination with a small riparian valve, facilitates the occasional release of water from Arthurs Lake into the upper Lake River, where it flows along the natural stream channel to Woods Lake.

Additional inflow to Woods Lake is also available from the Ripple Canal diversion, which is operated by Hydro Tasmania to provide water for both Woods Lake and the Lagoon of Islands (see Figure 1).

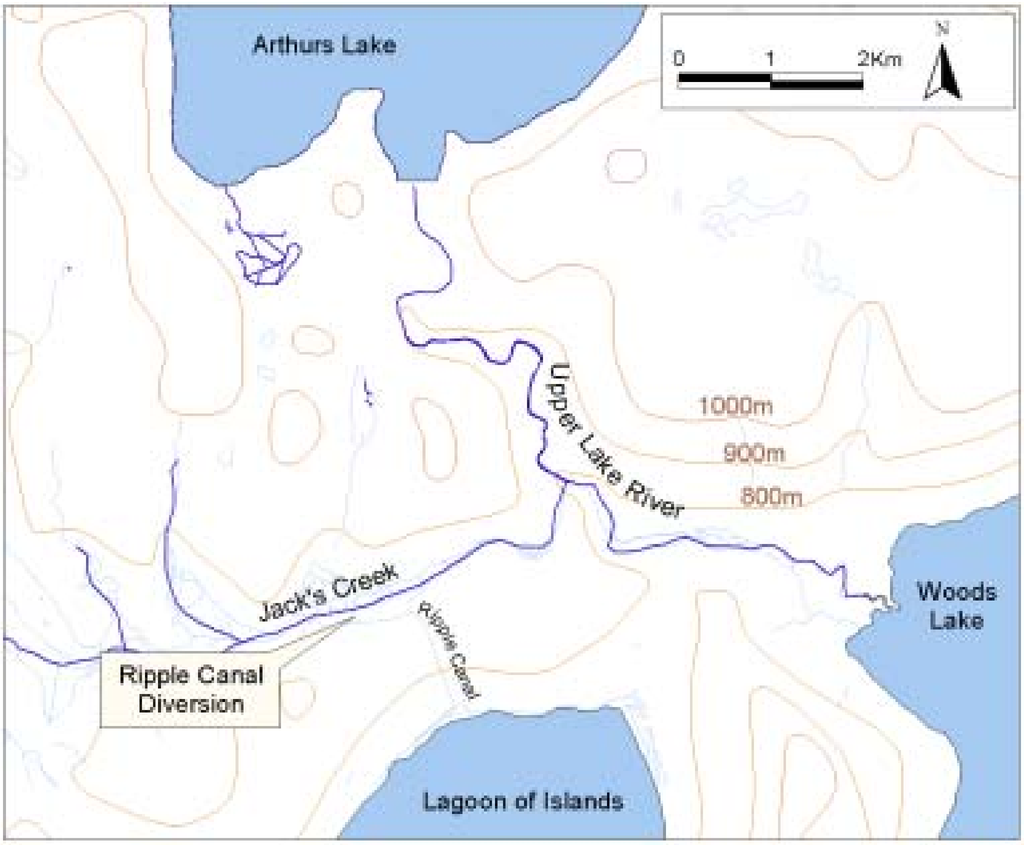


Figure 1: Map of the major inflows to Woods Lake

Irrigation Water Supply

Woods Lake is used to store inflows during the wetter months for later release to downstream users for irrigation and riparian uses. Table 1 lists the maximum and minimum water levels and the volume of water these drawdowns represent for each irrigation season since 1990 - 91. While the volumes given in Table 1 are gross values, which include water released for all purposes, they give some estimate of the amount of water used under the range of climatic conditions experienced in the catchment since 1990. The active storage volume of Woods Lake is approximately 43.49 Mm^3, with a maximum operating range of about 3.8m. The maximum and normal minimum operating levels are 737.77 m above sea level and 733.96 m above sea level respectively.

The mean annual release volume over the past 11 years, including 1995 - 96 when no release was made, was 13 Mm^3. The largest release occurred in 1997 - 98 (20.4 Mm^3), when the minimum lake level reached 735.6 m above sea level. The median release volume was 14.2 Mm^3, recorded in 1990 - 91.

Irrigation year	Max level (m)	Date of max	Min level (m)	Date of min	Volume Released (Mm^3)
1990-91	736.54	1/11/90	735.35	6/6/91	14.2
1991-92	736.31	7/1/92	735.38	28/4/92	11.1
1992-93	736.57	28/10/92	735.96	4/6/93	7.4
1993-94	736.84	12/1/94	735.25	11/5/94	19.0
1994-95	736.25	27/10/94	734.7	22/4/95	17.8
1995-96	n/a (flood year)				0.0
1996-97	737.93	21/10/96	736.6	15/4/97	16.6
1997-98	737.28	29/10/97	735.6	5/5/98	20.4
1998-99	736.55	10/11/98	735.94	24/3/99	7.4
1999-2000	736.55	18/10/99	734.99	30/4/00	18.4
2000-01	736.68	23/11/00	735.8	16/3/01	10.7

Table 1: Annual water level extremes and released water volume for Woods Lake from 1990 to 2001

Water Quality

Turbidity and Lake Levels

Woods Lake has historically been described as a 'naturally turbid' lake, although whether this applies to conditions before initial impoundment (1911), or those, which developed afterwards, is unknown. The lake was classified as a turbid oligotrophic system as early as the 1960s by P. Tyler (pers. comm.), although work carried out in the early 1990s indicated that it would be more appropriately classified as meso-eutrophic (Sanger 1993). The lake has been subject to considerable water quality monitoring since 1989.

Woods Lake is broad but shallow and surrounded by relatively high ridges that tend to funnel the prevailing winds. The morphology of the lake, combined with a muddy substrate produced by the effects of impoundment, means that wind-generated sediment resuspension is the primary cause of high turbidity levels.

The main water quality issue identified for Woods Lake is the management of high turbidity levels, which have periodically produced complaints from downstream water users and have the potential to adversely affect threatened native fish species as well as the recreational trout fishery. Woods Lake is the source of irrigation water for agriculture downstream on the Lake and Macquarie Rivers. These irrigators have access to 'reasonable' quantities of Woods Lake water. In the past, irrigation demand, which is closely associated with dry weather, has led to the lake being drawn down to low levels (see Table 1), with consequent increases in turbidity and occasional algal blooms.

A study carried out in 1995 analysed the relationships between wind velocity and direction, fetch (the uninterrupted distance the wind blows over the water), and water depth and demonstrated that water depth in Woods Lake was a critical factor in managing extreme turbidity levels (Crook, 1995), following windy periods. The model developed from these data indicated that, at a level of 734.7 m above sea level, a westerly wind of 15 $m.sec^{-1}$ would resuspend sediments over 80 % of the lakebed. At a level of 735.4 m above sea level, the same wind strength would result in less than 10 % of the lakebed area being resuspended.

Taking into account sediment particle size (as an indicator of settlement rate), the model used to predict wind-generated sediment resuspension produced three conclusions regarding water level in the lake (Crook 1995):

- at a level of 734.7 m above sea level, turbidity extremes (>40 NTU) are likely to be continual under normal wind conditions;
- at a level of 735.4 m above sea level, turbidity extremes are likely to be rare, short-lived, and associated with extreme wind conditions;
- at a level of 735.9 m above sea level, turbidity extremes are unlikely to occur at any time.

The operating procedures for Woods Lake were subsequently adjusted to keep the lake level above 735.4 m above sea level. This water level was exceeded from 1996 to 1999, but fell below its target in 2000. Water released from Arthurs Lake was used to restore the lake level above the agreed minimum and these levels were maintained through the 2000 - 01 irrigation season. Present levels (June 2001) are similar to those recorded in 1999. Figure 2 illustrates the lake levels recorded for Woods Lake since 1995.

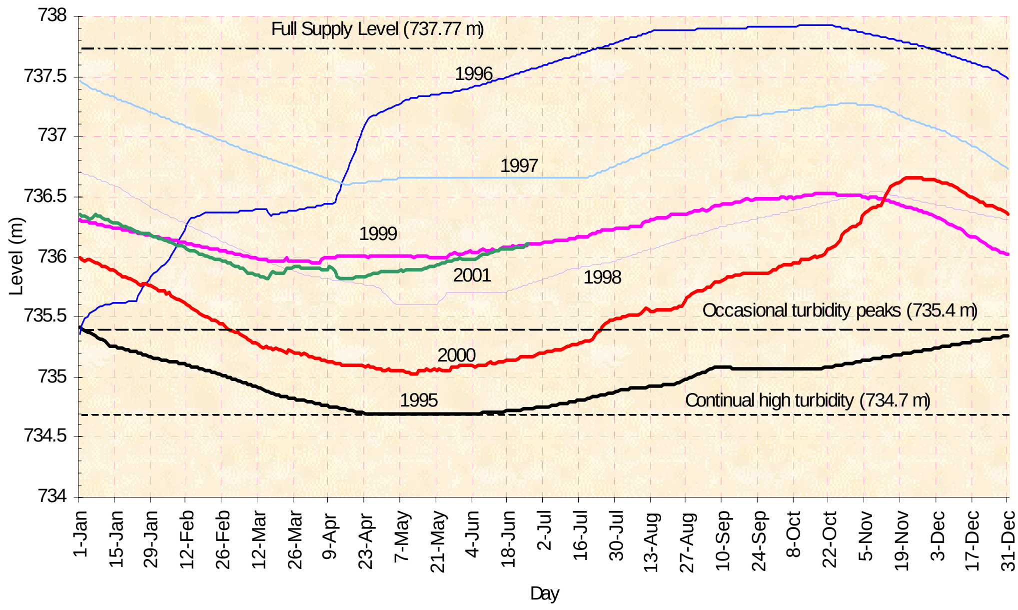


Figure 2: Woods Lake water levels for the period 1995-2001. Two indicator levels for turbidity management, as derived by Crook 1995, are marked.

Figure 3 shows the average turbidity values recorded in Woods Lake during a similar period, plotted against water level. Turbidity reached very high values during 1995 (>90 NTU) and higher values were again recorded during 2000. Bobbi *et al*. (2000) reported that the excessive values found in June 2000 followed very strong winds in late May.

A further pattern that is evident in Figure 3 is the slow recession of turbidity in the lake. Following a peak event, turbidity continues to decline until the next peak event occurs. Even over the 2-year period between the end of the 1995 event and the start of the 1998 peak, turbidity values continued to slowly decline. This indicates the fineness of the particle sizes entrained during a turbidity event and demonstrates the lengthy period needed for the lake to recover from a period of very high turbidity.

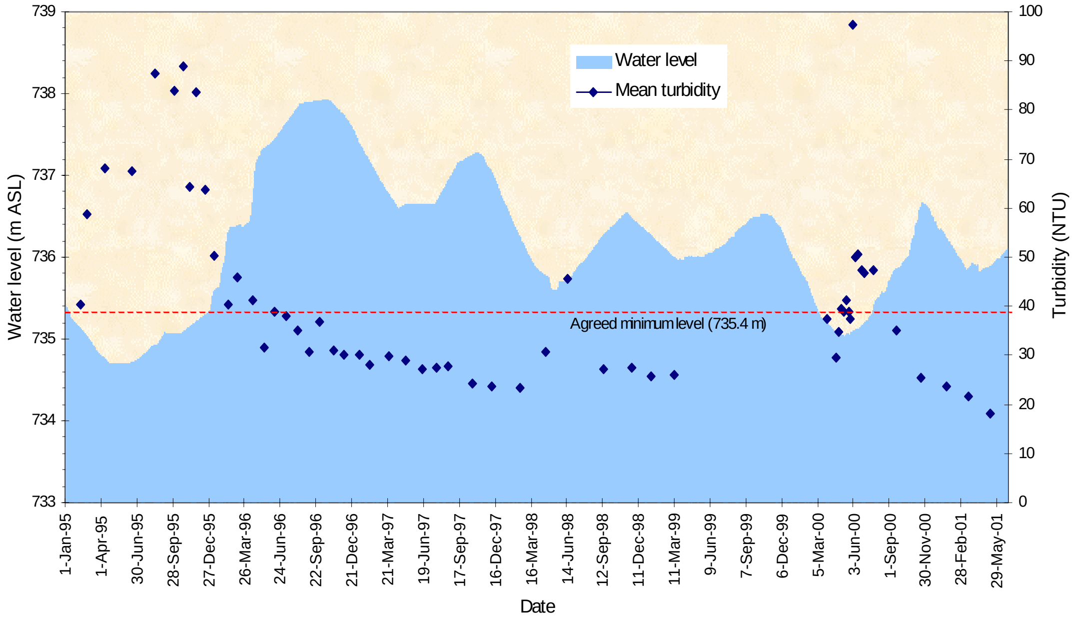


Figure 3: Water level and mean turbidity values recorded in Woods Lake from 1995 to present

The lake also has relatively high background nutrient levels and has also been subject to algal blooms during extended periods of excessive turbidity. Sanger (1993) reported that the algal community was persistently dominated by the filamentous diatom, *Melosira granulata.* Since the informal adoption of the 735.4 m above sea level minimum water level, no lake-wide algal bloom conditions have been recorded, although the nutrient levels continue to remain high relative to other Hydro Tasmania water storages.

Water Temperature

The South Esk – Great Lake Environmental Review (Hydro Tasmania, 1999) also lists the release of cool water from Woods Lake as a potential environmental issue. However, the relative shallowness of the lake combined with the well-mixed nature of the water body would mitigate against this. Thermal stratification has never been recorded in Woods Lake during monitoring as part of Hydro Tasmania's 'Waterway Health Monitoring Program'.

There is the potential that the thermal mass of the lake would keep temperatures lower than in the flowing waters downstream during warm weather, but it is likely that lake water released into the Lake River would soon attain the ambient temperature. The lake level is generally lower during the warmer months; effectively bringing the outflow of the dam closer to the warmer surface waters, again reducing any difference between lake water and ambient temperatures.

Biological Issues

The biological issues identified were related to threatened native fish species and to the recreational trout fishery.

Threatened Species

Woods Lake forms a significant part of the range of two endemic fish species, the saddled galaxias (*Galaxias tanycephalus*) and the Arthurs paragalaxias (*Paragalaxias mesotes*). Both species share a distribution restricted to Woods and Arthurs Lakes. Because of this restricted distribution, and the effects of predation from introduced trout, these species are listed under Tasmanian threatened species legislation. *G. tanycephalus*, which is also listed under Commonwealth threatened species legislation, is relatively common in Woods Lake, but *P. mesotes* has not been recorded there over the past few years during long-term monitoring conducted by the Inland Fisheries Service.

G. tanycephalus is listed as 'Endangered' under both the Tasmanian *Threatened Species Protection Act 1995* and the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*. A recovery plan was prepared by Crook and Sanger (1997) for *G. tanycephalus*, which described the species as being uncommon in Arthurs Lake and abundant in Woods Lake. Recent (March 2001) Inland Fisheries Service surveys indicate that this relative distribution still holds, with 49 individuals caught in Woods Lake and 17 in Arthurs Lake (J. Jackson pers. comm.).

P. mesotes is listed as 'Endangered' under the Tasmanian *Threatened Species Protection Act* 1995. It is likely to be similarly listed under the Commonwealth *Environment Protection and Biodiversity Conservation Act* 1999. *P. mesotes* was not found in Woods Lake during recent Inland Fisheries Service surveys and has not been recorded there over the past few years (J. Jackson pers. comm.). Eighty individuals were caught in Arthurs Lake in the March 2001 Inland Fisheries Service sampling.

Fish Migration & Dispersal

The Woods Dam may act as a barrier to fish species attempting to move upstream, although the only species likely to be affected are eels and lampreys. These animals are adapted to being able to surmount obstacles such as the dam. However, it is likely that downstream factors, such as Trevallyn Dam and the land and water use patterns of the lower South Esk and Macquarie Rivers, have a greater effect on these species' migrations.

The threatened species in Woods Lake are self-sustaining lake-based populations. Their historic natural use of the Lake River between Arthurs and Woods Lake and downstream of Woods Lake for dispersal purposes is unknown but would have been effectively blocked by the dams on both lakes.

Recreational Fish Species

Exotic fish species in Woods Lake comprise the two trout species, brown (*Salmo trutta*) and rainbow (*Oncorhynchus mykiss*). These are major predators of the endemic fish species and are the predominant threatening process associated with the decline in native fish populations.

Geomorphic Issues

No significant geomorphic or hydrologic issues were identified for Woods Lake during the Environmental Review and Community Consultation phases of the WMR.

The lake has a number of inflowing streams each of which has had an effect on its morphology. Predominant in these effects is the development of substantial floodplains, which have been inundated and re-exposed seasonally under the present operating regime for the lake. These floodplains appear to be the source of much of the silt, which now covers the lakebed, and which is resuspended during high wind conditions to produce high turbidity levels in the water column.

Rocky littoral areas of the lake are kept relatively clear of deposited silt by wave action, which may be causing minor erosion in susceptible areas around the margins of the lake. Plate 1 shows erosion along the windward south-eastern rocky shore which is the shore most susceptible to wave erosion.

Plate 1: The effects of wave erosion on the windward south-eastern rocky shore of Woods Lake.

2. FORMULATION OF STUDY OBJECTIVES

Three inter-related issues are predominant in Woods Lake. These are:

- ensuring suitable environmental conditions are maintained for threatened species;
- maintaining low turbidity in lake water; and
- providing sufficient water for irrigation.

Of these issues the threatened species issue required further study before effective strategies could be developed for their management in Woods Lake. The principal objectives of the study fell into two categories:

1. Analysis of lake level management to determine the advantages and disadvantages of;
   - fixing a minimum level (presently maintained through an informal agreement with Inland Fisheries Service);
   - evaluating a range of lake levels to find the most appropriate for both Hydro Tasmania and those maximising public amenity; and
   - entering into a formal agreement on lake level management.
2. Determine the habitat preferences and population statistics of threatened fish species in the lake in order to:
   - guide management of the lake so that Hydro Tasmania's obligations under State and Commonwealth threatened species legislation are complied with; and
   - support recovery actions outlined in Recovery Plans for the fish species.

The main activities that were therefore undertaken for this study included extensive fish surveys of Woods to allow a more accurate interpretation galaxiid population dynamics in the lake, and a thorough investigation regarding the presence or absence of *P. mesotes* in Woods Lake. It also involved an examination of stored historical zooplankton samples for presence of larval galaxiids, a survey of the availability of habitat for these species within the lake, and a broad bathymetric survey so that habitat requirements might be related to the variations in lake levels.

3. DATA COLLECTION AND ANALYSIS

Historical Data Collected by Inland Fisheries Service

Abundance of G. tanycephalus

The Inland Fisheries Service has been regularly monitoring numbers of native fish in Woods Lake at a low level since 1997, as part of the Recovery Plan for *G. tanycephalus* (Crook and Sanger, 1997). The data analysed in this section were collected by the Inland Fisheries Service, with funding from the National Heritage Trust, and have been made available to Hydro Tasmania for the purpose of this study.

The Inland Fisheries Service has carried out 13 sampling events since September 1997. *G. tanycephalus* plankton sampling (for larvae and juveniles) was based on 10 minutes of towing a zooplankton net behind a small boat at each of six sampling locations around the lake. The larvae captured were measured for fork length. Adult fish were sampled by using backpack electrofishing for a total of 15 minutes at each of the six sites. Table 2 gives the number of larvae and adults caught during each sampling event.

Year	Mar-Apr		Jun-Jul		Sep		Dec	
	Plankton	Adults	Plankton	Adults	Plankton	Adults	Plankton	Adults
1997					30	95	3	58
1998	16	26			10	43	46	39
1999	0	97	11	45	5	35	157	44
2000	96	113	435	?	658	45		
2001	53	49						

Table 2: Number of *G. tanycephalus* larvae and juveniles (plankton) and adults caught at six sites in Woods Lake from September 1997 to March 2001

These data indicate that most larvae and juveniles (plankton) were caught in the period from December 1999 to September 2000, with peak numbers occurring in July and September 2000. It is interesting to note that this period coincides with one of relatively low water levels in the lake (see Figure 2), while the peak values were recorded as the lake level increased from the May 2000 minimum.

Adult abundance was more uniform over the sampling period, with the greatest numbers usually being caught in March-April.

Size Distribution of G. tanycephalus

The size of the larval fish caught may be a useful indicator of spawning time (from plankton data) and the development and progress of size cohorts in the population (adult and plankton data). Figure 4 illustrates the larval size data presented as length-frequencies for a sequence of the five most abundant larval sampling events.

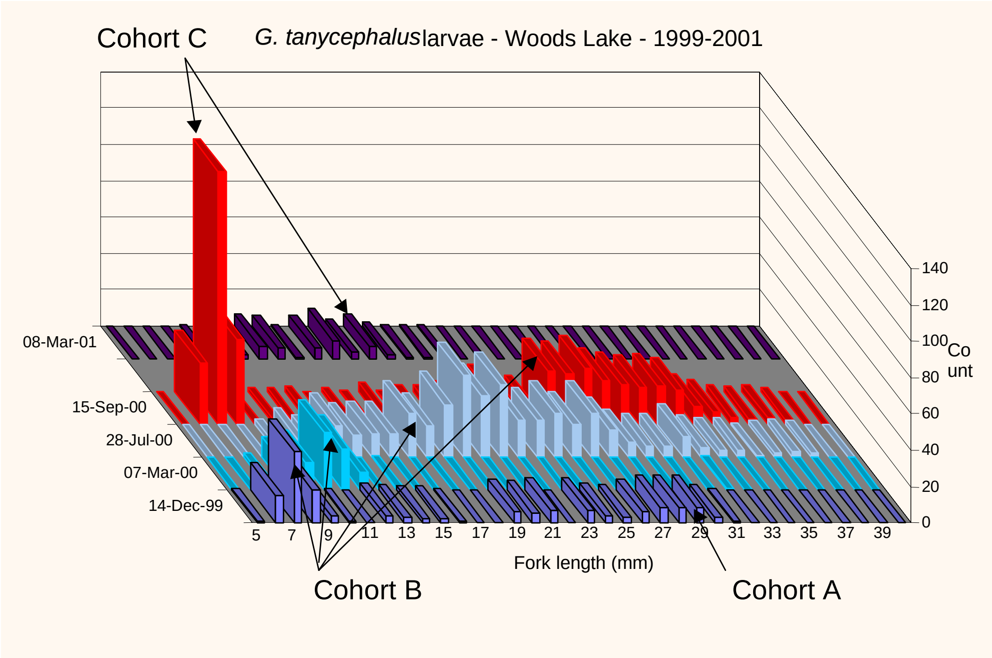


Figure 4: Length frequency data for *G. tanycephalus* larvae caught in Woods Lake from December 1999 to March 2001. Arrows indicate the progress of hypothesised cohorts over time. The gaps between traces represent approximately 3 month intervals.

The size data for December 1999 and September 2000 indicate that spawning had recently occurred, with modal values of 6 – 8 mm recorded. This may indicate that spawning took place in late spring in 1999, and late winter in 2000, and that only one spawning event occurred in each year. However, the missing sampling event in December 2000 leaves open to speculation whether there was a second spawning in early summer, or an extended spawning period during spring-summer.

Figure 4 links the modal values of the various samples, to suggest a hypothetical progression of cohorts through time. For example, cohort B can be followed from recent spawning (December 1999) as it progressed through the larval population to September 2000. By March 2001 this cohort had disappeared from the larval population and had presumably recruited into the adult population. If correct, this hypothesis indicates that *G. tanycephalus* take up to 12 months to reach adult size and move from the pelagic larval life stage into the benthic-feeding, in-shore adult life stage.

This, and similar cohort progressions are shown more completely in Figure 5, which shows the size-frequency data for both larval and adult fish caught during the sampling events. Note that different capture methods were used for larval and adult sampling (plankton netting and electrofishing, respectively), so a comparison of absolute numbers is not appropriate. However, the patterns indicating size-cohorts are representative for each life stage.

Figure 5 shows the sizes and number of *G. tanycephalus* caught during the thirteen sampling events in Woods Lake from September 1997 to March 2001.

These data indicate that larvae recruited into the plankton in about December of each year, with the exception of 2000, when recruitment was recorded in September and no December data are available. The larval size range from the March 2001 sample suggests that either a December spawning event also occurred, or there was relatively continuous spawning throughout the 2000 - 01 summer.

These data tend to not support the statements in Fulton (1990) and Crook and Sanger (1997) that there are small-sized (e.g. <10 mm) larvae in the lake year round or that there is an autumn spawning period.

These data also show a pattern of progression in size over time, with several 'size cohorts' progressing through the population. From this pattern, it appears that *G. tanycephalus* spends 9 - 12 months in the planktonic larval-juvenile stage, appearing in the plankton in December and recruiting into the adult population during the following spring-summer. They then spend 12 - 18 months as adults, with large-sized individuals usually disappearing from the population during the winter months. Fulton (1990) considered that most *G. tanycephalus* were less than 2 years old.

If the above interpretation of the data is correct, it indicates that the adult fish usually have one or, at best, two spawning seasons available. From a management perspective, this indicates that one bad year would have a major effect on the population and two consecutive bad years would threaten the viability of the entire population.

The data also indicate that both environmental and spawning conditions have been suitable since 1997, including the period of low water level in 2000.

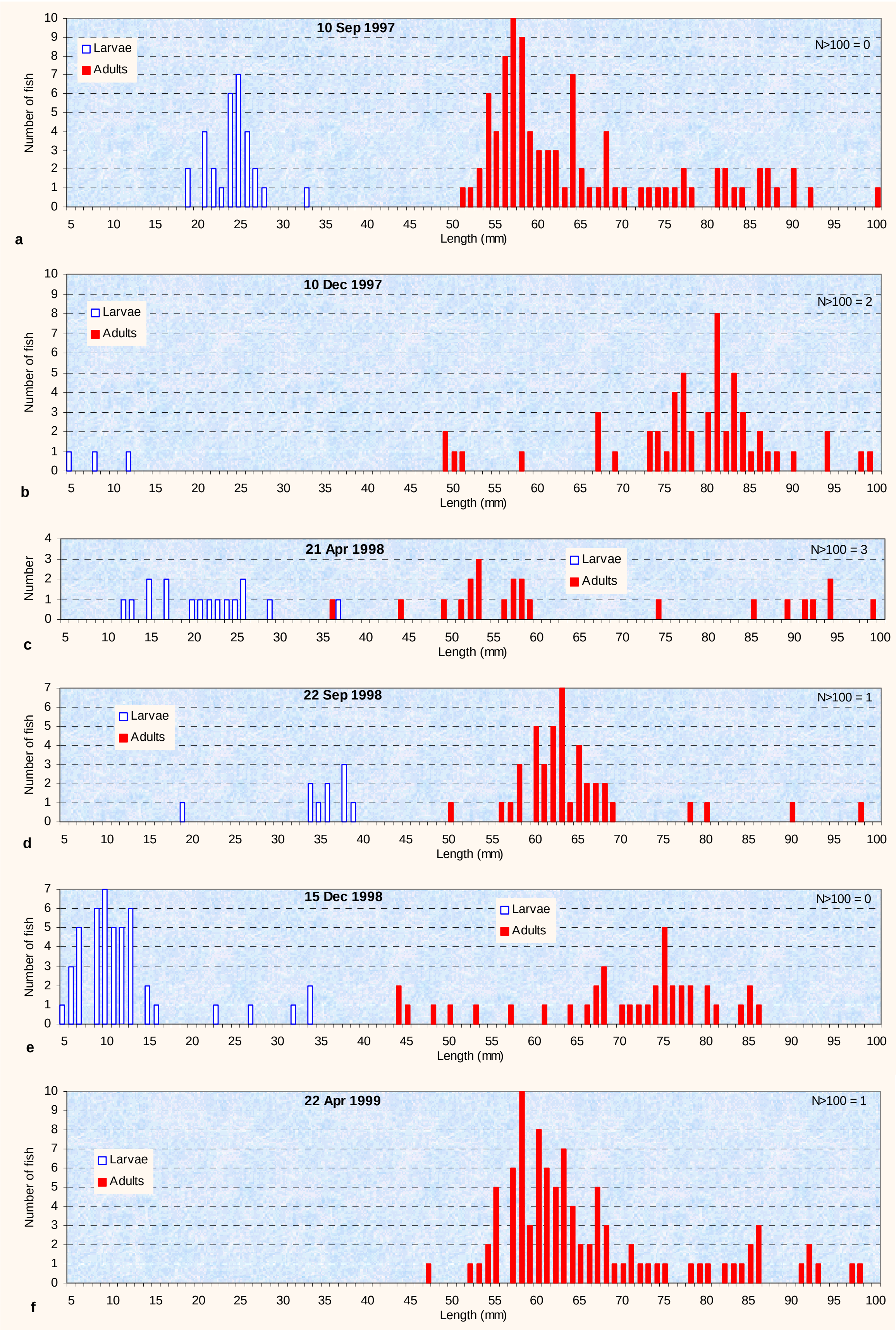


Figure 5 (a-f). Length – frequency data for adult and larval *G. tanycephalus* captured in Woods Lake from September 1997 to April 1999. Note that the absence of larvae data for figure 3.2f (22 April 1999) represents a zero catch.

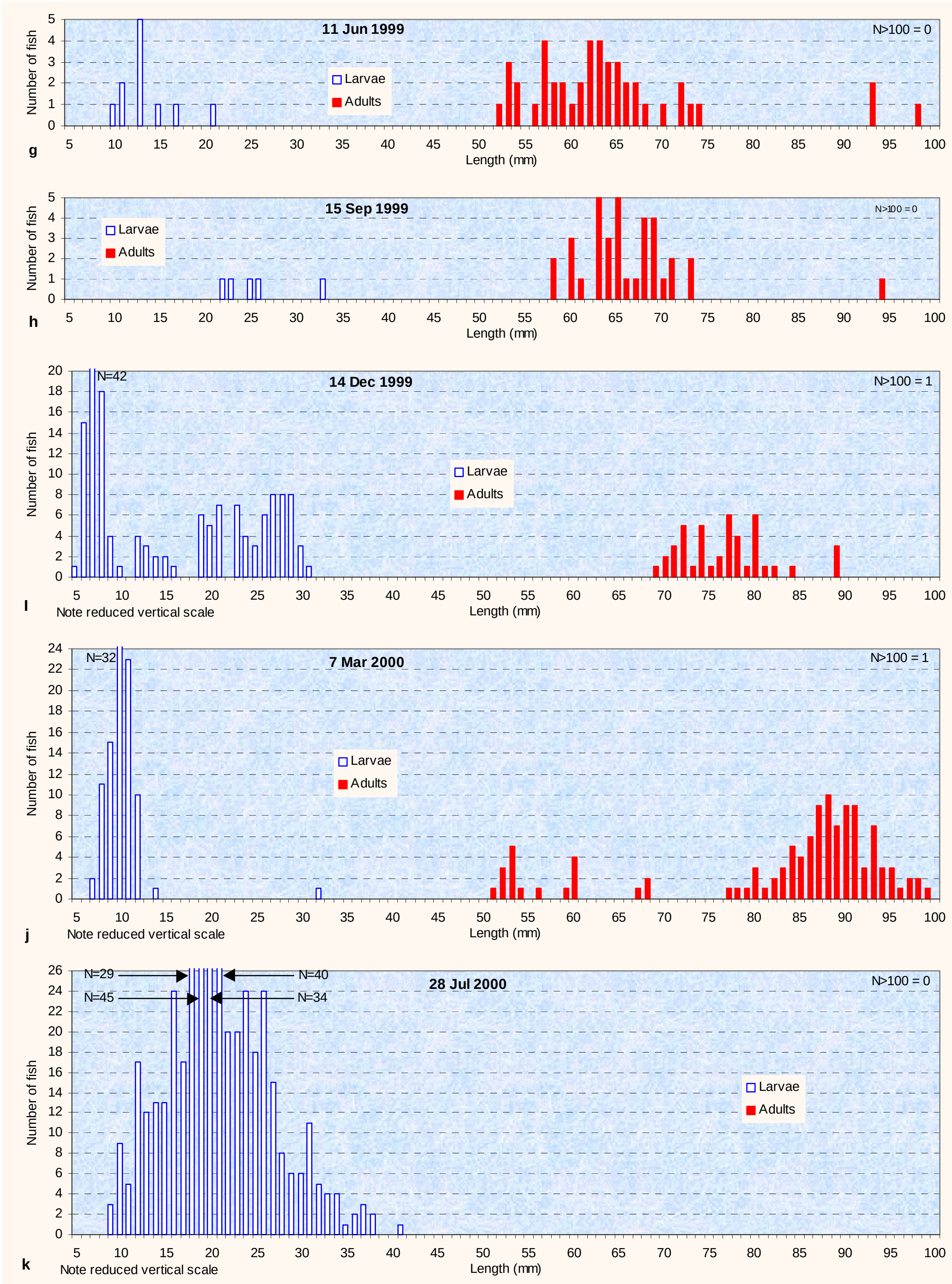


Figure 5 (g-k). Length – frequency data for adult and larval *G. tanycephalus* captured in Woods Lake from June 1999 to July 2000. Note that the absence of adult data for figure 3.2k (28 July 2000) represents unavailable data.

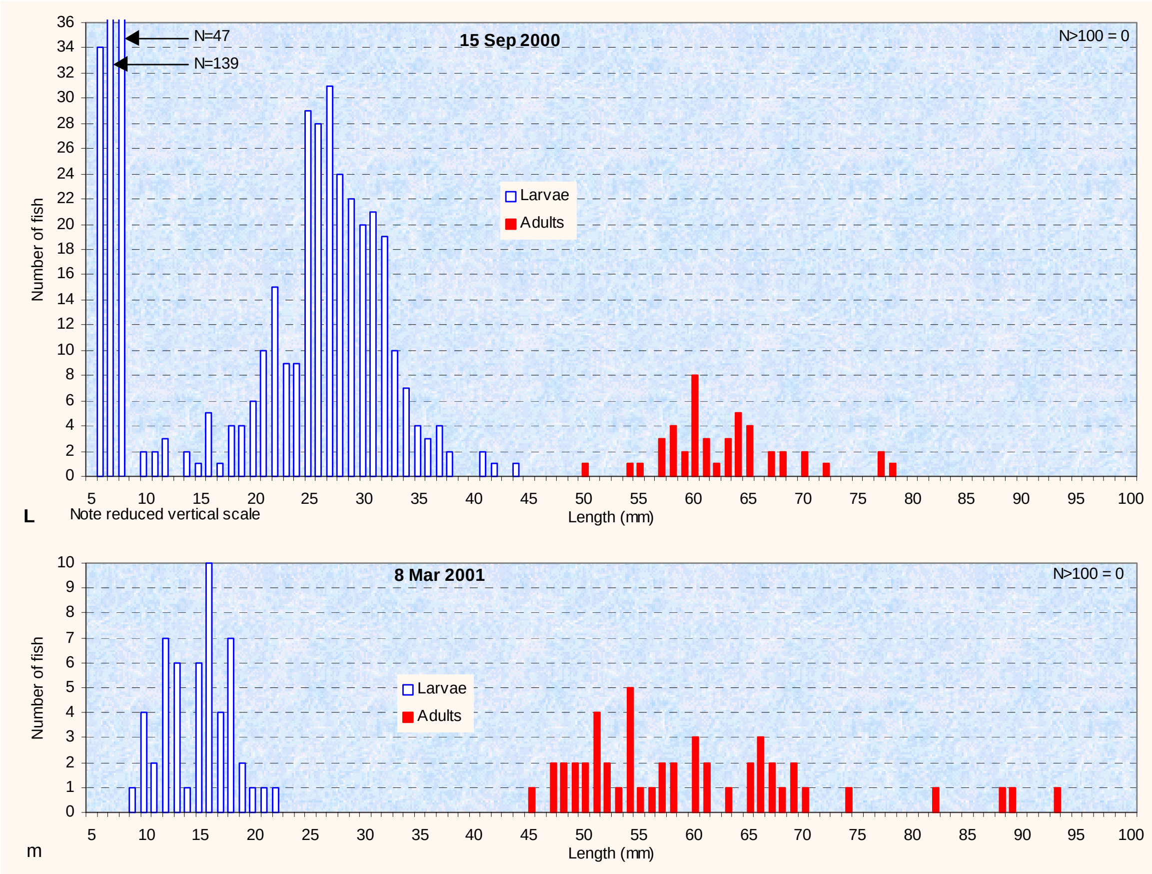


Figure 5 (L-m). Length – frequency data for adult and larval *G. tanycephalus* captured in Woods Lake from September 2000 to March 2001

Paragalaxias mesotes

There are presently no data available for *P. mesotes* in Woods Lake. The species has not been caught in the lake during the Inland Fisheries Service monitoring program, which commenced in September 1997. This program sampled six sites around the lake in habitats, which should have included *P. mesotes* in the catch.

Fulton (1990) describes their habitat as rocky margins of lakes, and McDowall (1996) indicates that the species 'has never been found commonly', being discovered only in the mid-1970s. The species is also reported to occur among aquatic plants and marginal vegetation around lake shores (Inland Fisheries Service, 2001a).

Current Data on Saddled Galaxias (*G. tanycephalus*)

Methods of Data Collection

Fish surveys were conducted by both Hydro Tasmania via Inland Fisheries Service Biological Consultancy and by the Native Fish Conservation Section of the Inland Fisheries Service. The Hydro Tasmania surveys aimed to complement the long-term data collected during Inland Fisheries Service Recovery Plan monitoring for *G. tanycephalus* (Crook and Sanger, 1997), with surveys targeting a wider variety of habitat types with increased fishing effort. Fyke surveys were conducted using fine mesh, single 5 m wing fyke nets fitted with trout/platypus exclusion screens.

Hydro Tasmania sampling consisted of the deployment of four fyke nets placed in sets at seven sites around Woods Lake as shown in Figure 6. With the exception of HT08, the study sites were located around the periphery of the lake. Five of the sample sites were located in less that 1.5 m of water, while a deep was set off the mid western shore of Woods Lake in approximately 3 m of water. Sites HT02-04 were situated in areas of cobble or boulder substrate, while sites HT07 and HT08 were situated on silty or muddy substrates. Site HT05 was characterised by a moderate cover of aquatic plants while site HT01 had a mixture of substrate types.

Nets were set for overnight soak. Upon collection the fish were identified to species and their fork length measured to the nearest millimetre. Initially the technical study aimed to sample on a quarterly basis, however an additional sample was included at the start of the year and the final sample was delayed due to inclement weather. Sampling was conducted on the following 5 occasions: August, September, December 2001, March and July 2002. Quarterfoil larval light traps were also purchased for use in the survey in order to sample a wider range of depth and habitats than have previously been sampled by the Inland Fisheries Service using towed plankton nets.

The locations of the Inland Fisheries Service Recovery Plan sample sites are also shown in Figure 1. Sites were generally located in areas of rocky substrate in water depths less than 1.5 m. Surveys were conducted in July, September, and December 2001, and April 2002. Fish were sampled by using backpack electrofishing for a total of 15 minutes at each of the six sites supplemented by fyke nets deployed for overnight soak. While the 2001-2002 the Inland Fisheries Service surveys initially used both fykes and electrofishing methods, fyke sites were reduced and subsequently omitted in later surveys, as presumably the Inland Fisheries Service considered electrofishing adequate for comparison with historical Recovery Plan monitoring data. The Inland Fisheries Service has been regularly monitoring numbers of native fish in Woods Lake since 1997, as part of the Recovery Plan for *G. tanycephalus* (Crook and Sanger 1997).

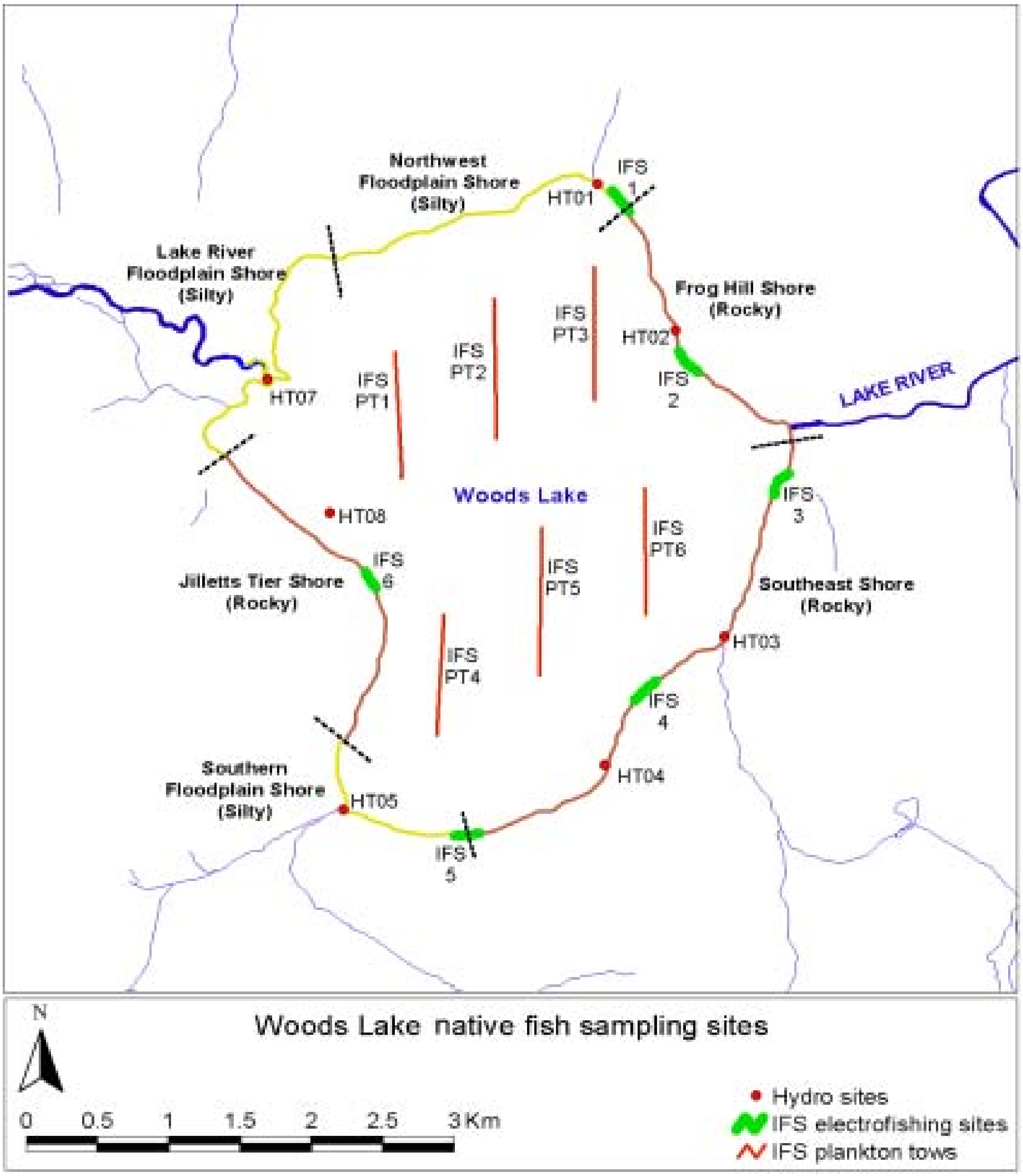


Figure 6: The location of sites used in the technical study, and sampled during IFBC Recovery Plan monitoring and Hydro Tasmania technical studies. Site Wfy 08 was a deep set site while the remainder were shore set in less than 1.5 m of water.

Catch Rates for G. tanycephalus

Numbers of *G. tanycephalus* collected from the seven study sites during surveys conducted between August 2001 and July 2002 are shown in Table 3. A total of 2,981 *G. tanycephalus* were captured during the survey, the majority of which were captured from sites HT03 and HT05 and HT07. These sites were located in areas characterised by boulder, macrophyte and silt substrate respectively. Highest catches of fish were recorded from the March and July 2002 surveys (n = 548 and n = 2001 respectively) which mirrors the timing of peak catch rates reported in the Arthurs Lake technical study, indicating a reasonable degree of peak catch rate synchronisation in these closely situated lakes.

Summarised adult galaxiid catch results from the Inland Fisheries Service recovery plan monitoring for 2001/2002 are shown in Table 4. A total of 461 adult fish were caught in the Inland Fisheries Services surveys, most of which were captured at sites EF1 and EF2, both of which are rocky in nature. Highest electrofishing catches were recorded in April 2002; however fyke-netting effort varied substantially over the survey and so seasonal comparison of net catches is not possible. The Inland Fisheries Service surveys also captured significant numbers of larvae from the six tow sites shown in Figure 5. Numbers of larvae caught during surveys ranged from 17 in July 2001 up to a peak of 372 larvae in December 2001.

The results from both Hydro Tasmania and Inland Fisheries Service surveys show a high degree of spatial and temporal variability, which was also reported in the results from the Arthurs Lake Technical Study. However, saddled galaxias catch results from the Woods Study eclipsed those reported from Arthurs Lake. Fulton (1990) stated that *G. tanycephalus* is nowhere abundant, but the results of this study show that healthy numbers are currently present in Woods Lake.

Sampling Period						
Site	Aug 01	Sep 01	Dec 01	Mar 02	Jul 02	Site totals
HT01	24	15	22	67	226	354
HT02	12	17	2	39	56	126
HT03	16	14	10	152	550	742
HT04	9	10	5	60	25	109
HT05	39	7	6	37	790	879
HT07	90	59	20	143	322	634
HT08	14	31	10	50	32	137
TOTAL	204	153	75	548	2001	2981

Table 3: Number of *G. tanycephalus* caught with fyke nets at seven Hydro Tasmania technical study sites in Woods Lake during surveys conducted between August 2001 and July 2002. Nets were set for overnight soak.

Sampling period									
	July 01		September 01		December 01		April 02		Site totals
site	Fyke	Shock	Fyke	Shock	Fyke	Shock	Fyke	Shock	
IFS 1	14	6	8	21	4	5	-	37	95
IFS 2	136	0	6	21	3	3	-	18	187
IFS 3	62	2	1	4	2	1	-	1	73
IFS 4	0	0	20	0	10	2	-	1	33
IFS 5	27	1	-	0	-	1	-	4	33
IFS 6	0	15	-	0	-	1	-	4	20
TOTAL	239	44	35	46	19	13	-	65	461

Table 4 Number of *G. tanycephalus* caught at the IFS Recovery Plan sites in Woods Lake during four surveys, from July 2001 to February 2002. Fyke nets were deployed overnight, and electrofishing runs were standardised at 15 minutes shock time. Sites that were not sampled are indicated by (–) in the appropriate cell.

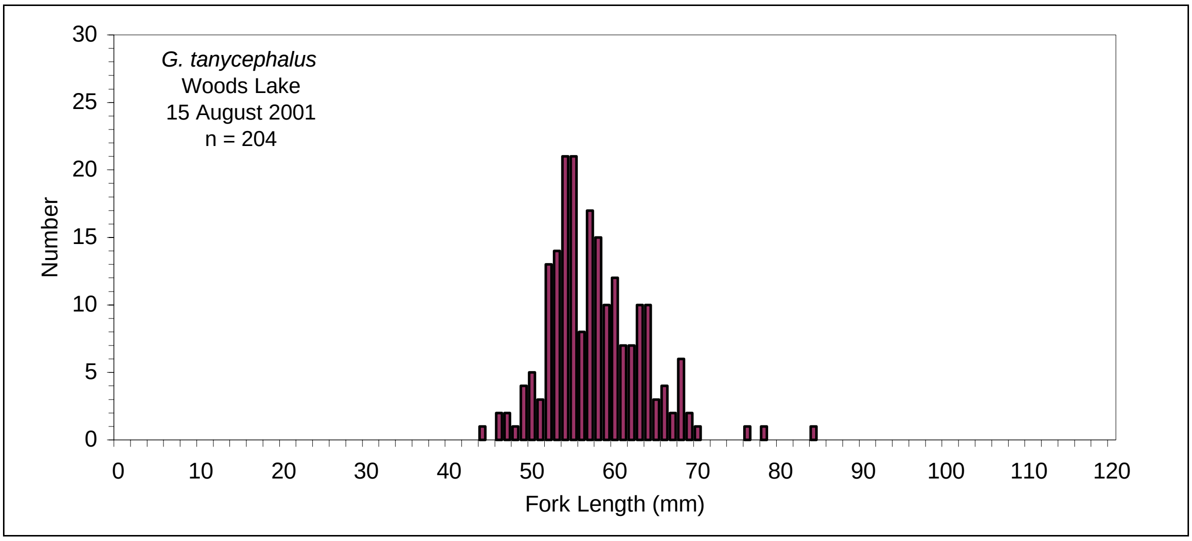
Population Structure

Figure 7 contains *G. tanycephalus* length frequency histograms of fish captured in fyke nets during each of the five sampling events undertaken as part of the technical study. Figure 8 shows length frequencies of saddled galaxias collected during Inland Fisheries Service Recovery Plan monitoring in Woods Lake. Each graph contains segregated plots representing fish collected by electrofishing, fyke netting and larval tows.

Analysis of sample population size structure is a useful indicator of spawning time and the development and progress of size cohorts in the population. When collected with an appropriate time step for the target species (eg quarterly for saddled galaxias), length frequency data can provide an indication of recruitment success or failure, and is a simple but effective threatened galaxiid management tool. Collection of larval recruitment data is particularly useful as it allows forecasting of potential recruitment success into the adult population.

Examination of the histograms in Figure 7 and Figure 8 shows changes in length frequency of *G. tanycephalus* population samples over the year. Analysis of cohort progression using both Hydro Tasmania and Inland Fisheries Service data shows that larval *G. tanycephalus* generally recruit to the adult population at a length of around 45 mm, and both electrofishing and fine mesh fyke sampling methods do not effectively collect galaxiids smaller than this size. It is interesting to note that fyke samples collected by the Inland Fisheries Service in December 2001 were the exception to the rule, capturing several galaxiids between 37 and 41 mm in length, in addition to a single galaxiid larva of 11 mm in length. Examination of the data also shows that very few captured larval galaxiids measured between 20 mm and 40 mm in length, and no galaxiids between 32 mm and 37 mm were collected during the study. Additionally, adult galaxiids greater than 100 mm were collected infrequently in small numbers, and the reasons for this are not clear. Figure 8 shows that electrofishing and fyke nets sampled a similar size range of galaxiids, and should have overcome any gear selectivity issues that may have excluded larger fish from being sampled. While it is widely acknowledged that these methods are ineffective at sampling galaxiid larvae, they have been used extensively to a wide variety of fish species well in excess of 100 mm, and therefore it appears that galaxiids >100 mm are not well represented in the Woods Lake population. Fulton (1990) observed that few large specimens are found, and most would appear to be less than two years old, and the results from this study support these observations.

Strong recruitment of saddled galaxias larvae occurred in September 2001, December 2001 and to a lesser extent April 2002, while evidence of much weaker, but more advanced larval recruitment was indicted in the July 2001 tows. Multiple spawning of saddled galaxias is not unusual, and Fulton (1990) reported that the species has an extended spawning season and small larvae collected year round from Woods Lake. In summary, the Inland Fisheries Service data show that *G. tanycephalus* spawned at least four occasions during the study, with particularly strong larval recruitment in September and December 2001.


G. tanycephalus
Woods Lake
15 August 2001
n = 204
Number
Fork Length (mm)
0
5
10
15
20
25
30
0
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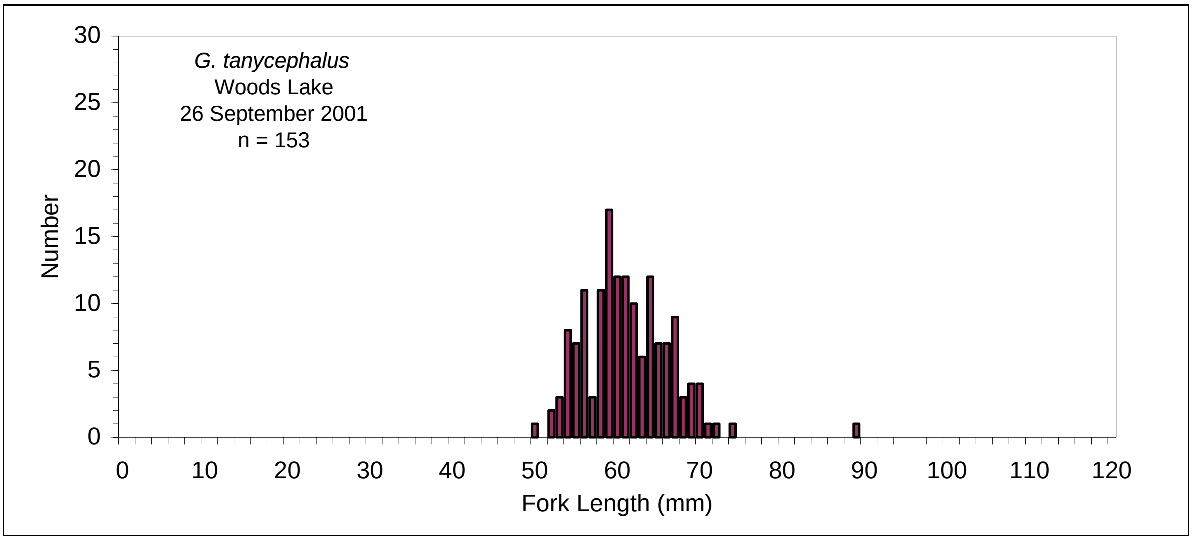
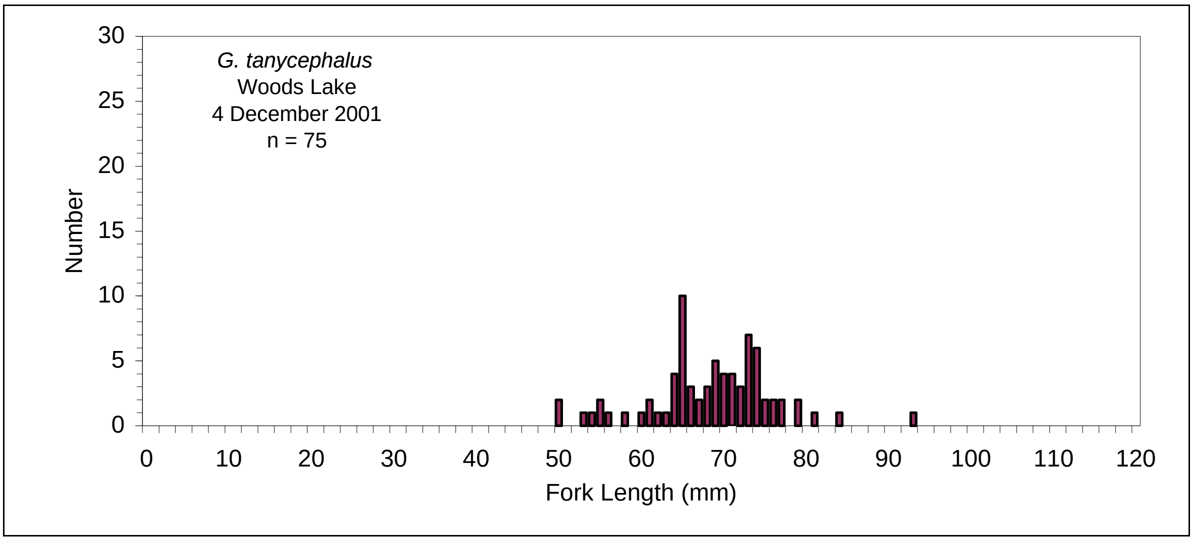
90
100
110
120


G. tanycephalus
Woods Lake
26 September 2001
n = 153
Number
Fork Length (mm)
0
5
10
15
20
25
30
0
10
20
30
40
50
60
70
80
90
100
110
120


G. tanycephalus
Woods Lake
4 December 2001
n = 75
Number
Fork Length (mm)
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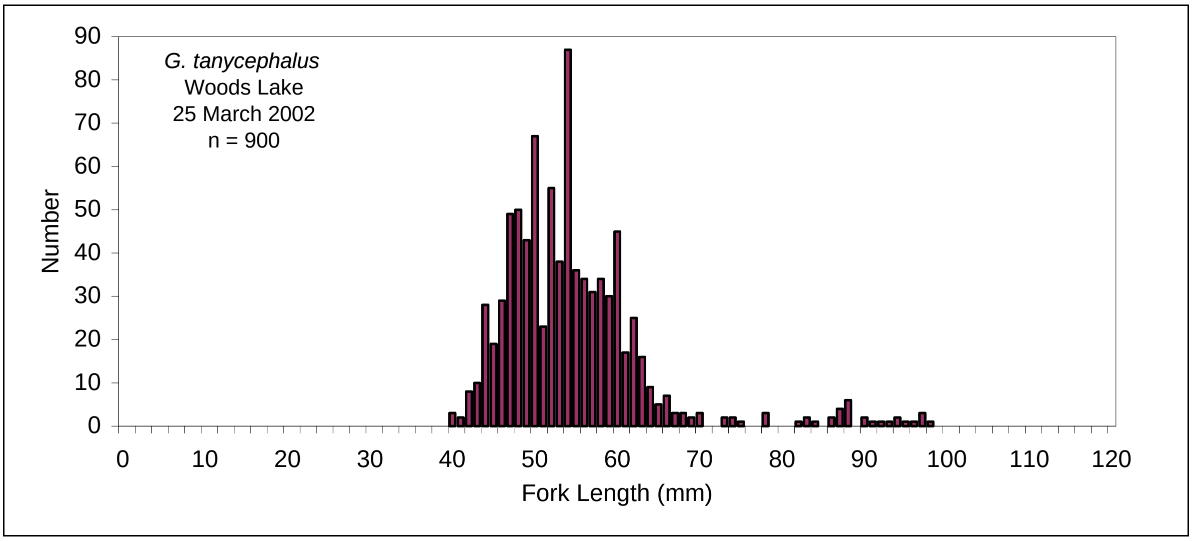
5
10
15
20
25
30
0
10
20
30
40
50
60
70
80
90
100
110
120



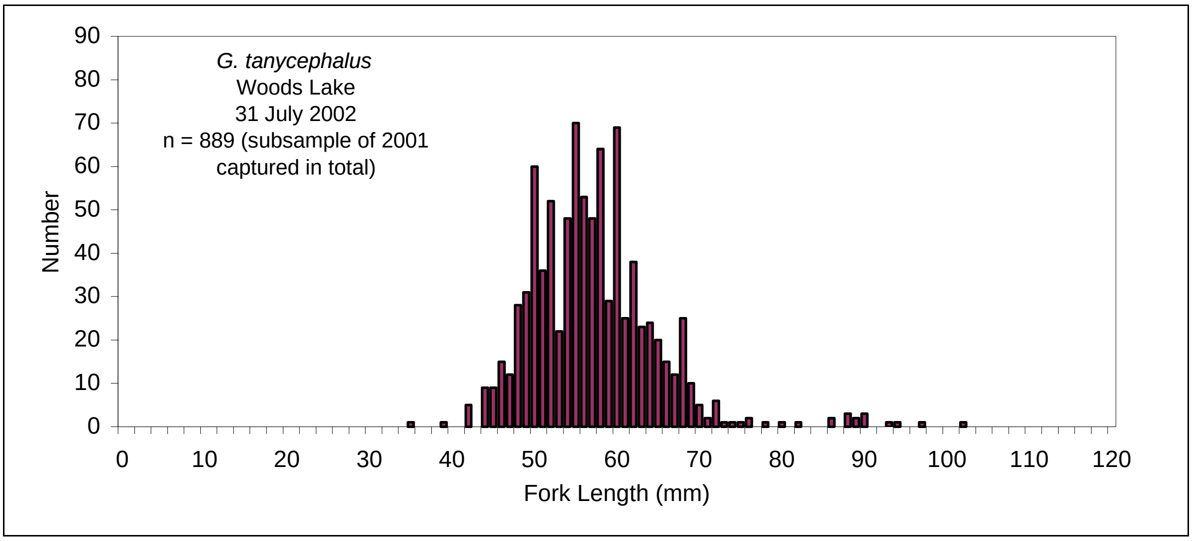
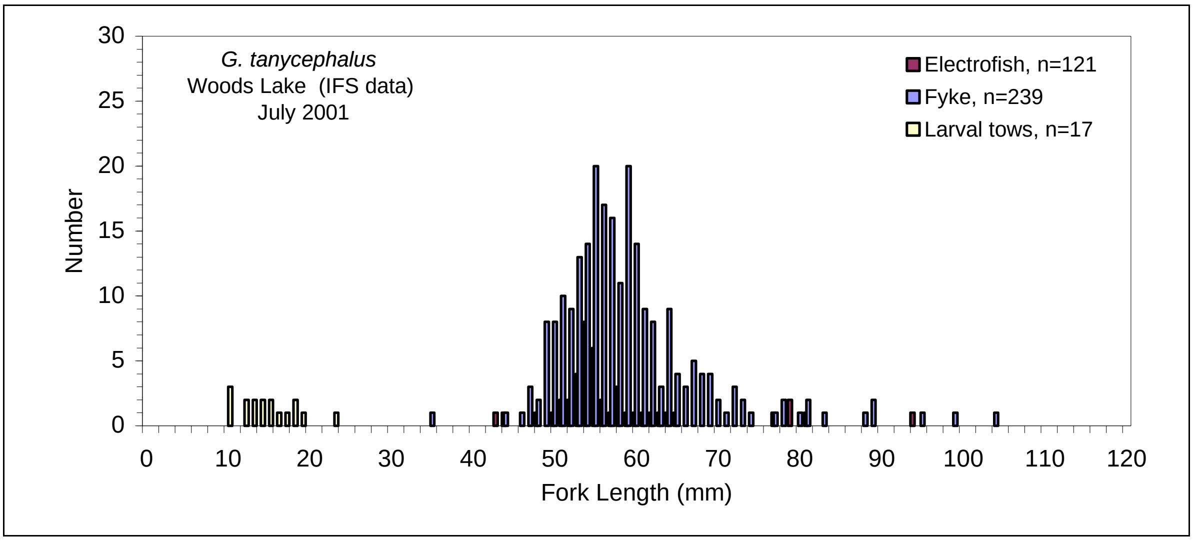
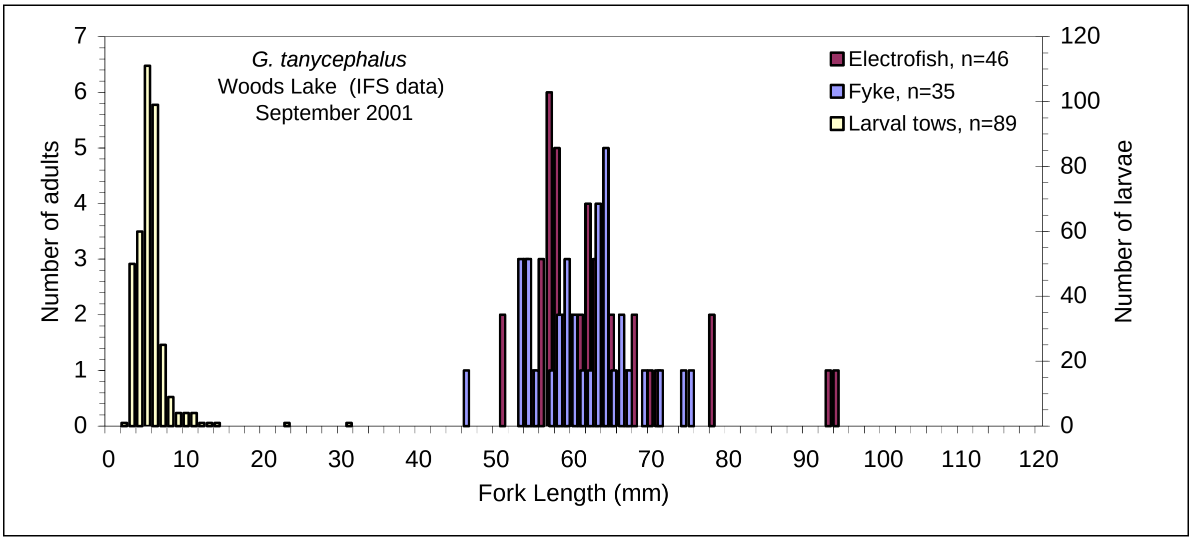
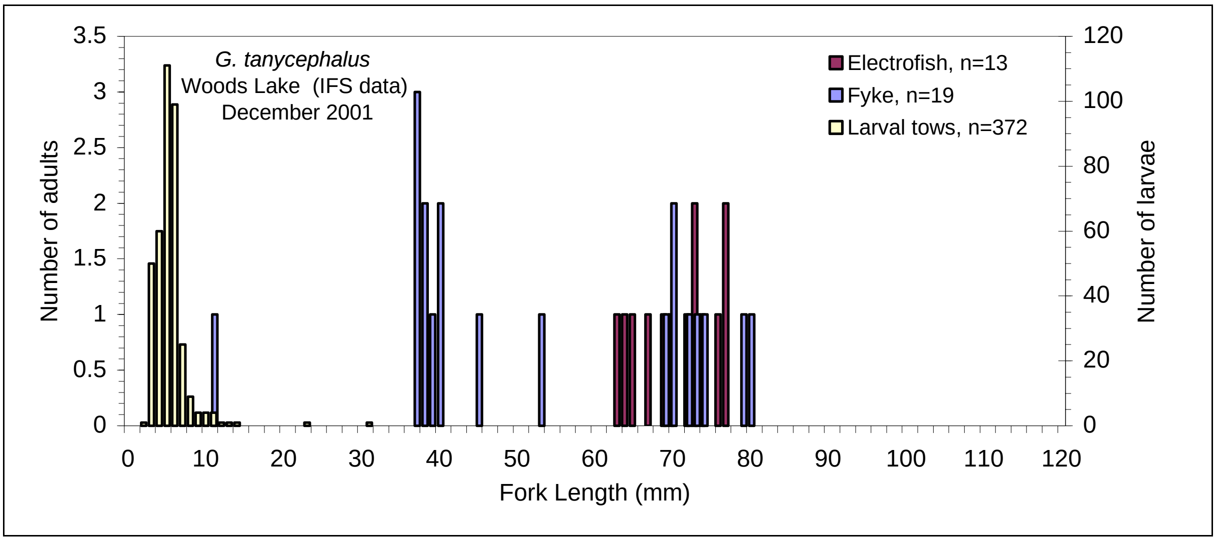


Figure 7: Length frequency data for *G. tanycephalus* caught by the Inland Fisheries Service Biological Consultancy from August 2001 to June 2002 for the Woods Lake Technical Study


G. tanycephalus
Woods Lake (IFS data)
July 2001
Electrofish, n=121
Fyke, n=239
Larval tows, n=17
Number
Fork Length (mm)


G. tanycephalus
Woods Lake (IFS data)
September 2001
Electrofish, n=46
Fyke, n=35
Larval tows, n=89
Number of adults
Number of larvae
Fork Length (mm)


G. tanycephalus
Woods Lake (IFS data)
December 2001
Electrofish, n=13
Fyke, n=19
Larval tows, n=372
Number of adults
Number of larvae
Fork Length (mm)

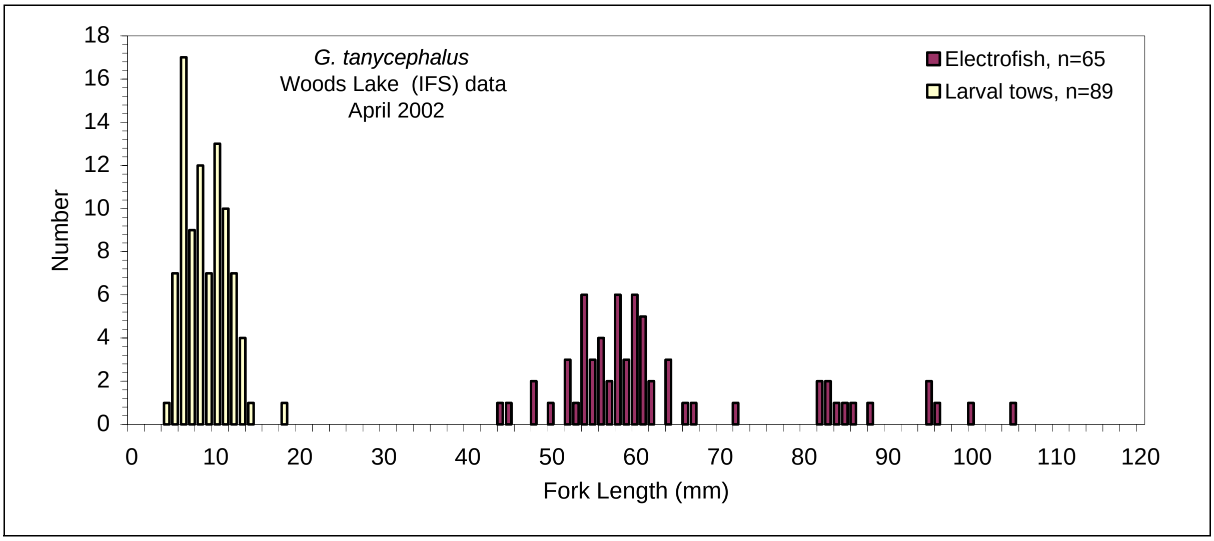


Figure 8: Length frequency data for *G. tanycephalus* caught by the Inland Fisheries Service in Woods Lake from July 2001 to April 2002

The data also shows that individuals in 45 mm to 75 mm size range dominated saddled galaxias population's structure during the study, with closely spaced larval cohorts appearing to recruit into a single large adult cohort in March 2002.

In summary, under the current management regime saddled galaxias appear to be healthy and recruiting regularly in Woods Lake via multiple spawning events during the year.

Arthurs Paragalaxias (*Paragalaxias mesotes*)

Arthurs paragalaxias were not observed or captured during the Woods Lake technical study, and the Inland Fisheries Service Recovery Plan Monitoring failed to collect a single adult or larval specimen during the corresponding period. During the planning phase of the technical study it was envisaged that the combined, increased effort of the Technical Study and Recovery Plan monitoring would confirm whether remnant populations of Arthurs paragalaxias remain in Woods Lake. While the absence of this species from netting and electrofishing catches cannot confirm that it is locally extinct in Woods, it does at least indicate that the Arthurs paragalaxias is in very low numbers if it is still present in the lake.

Bathymetric Survey

A bathymetric survey of the lake was carried out in early March 2001, when the lake level was 736.78 m. Depth and substrate data were collected at approximately 500 m grid intervals across the lake, giving a total of 49 sampling points. Figure 9 shows the depth recorded at each site, adjusted to elevation above sea level.

The depth data indicate a relatively shallow, bowl shaped lake, with the bottom shelving gently from two major floodplains (Lake River in the north-west and unnamed creek in the south-west) to the deepest sites near the Lake River outflow. Of the area sampled:

- ~ 10% was less than 1 m deep (about 735.8 m);
- ~ 25% was between 1 and 2 m deep (734.8-735.8 m)
- ~ 10% was between 2 and 3 m deep (733.8-734.8 m); and

- ~ 55% was between 3 and 3.6 m deep (733.2-733.8 m).

The substrate data indicated a lake with a predominantly muddy bottom, with rocky substrate being recorded mainly in relatively shallow water around parts of the shoreline. No attempt was made to characterise the particle distribution of sediments in the lake.

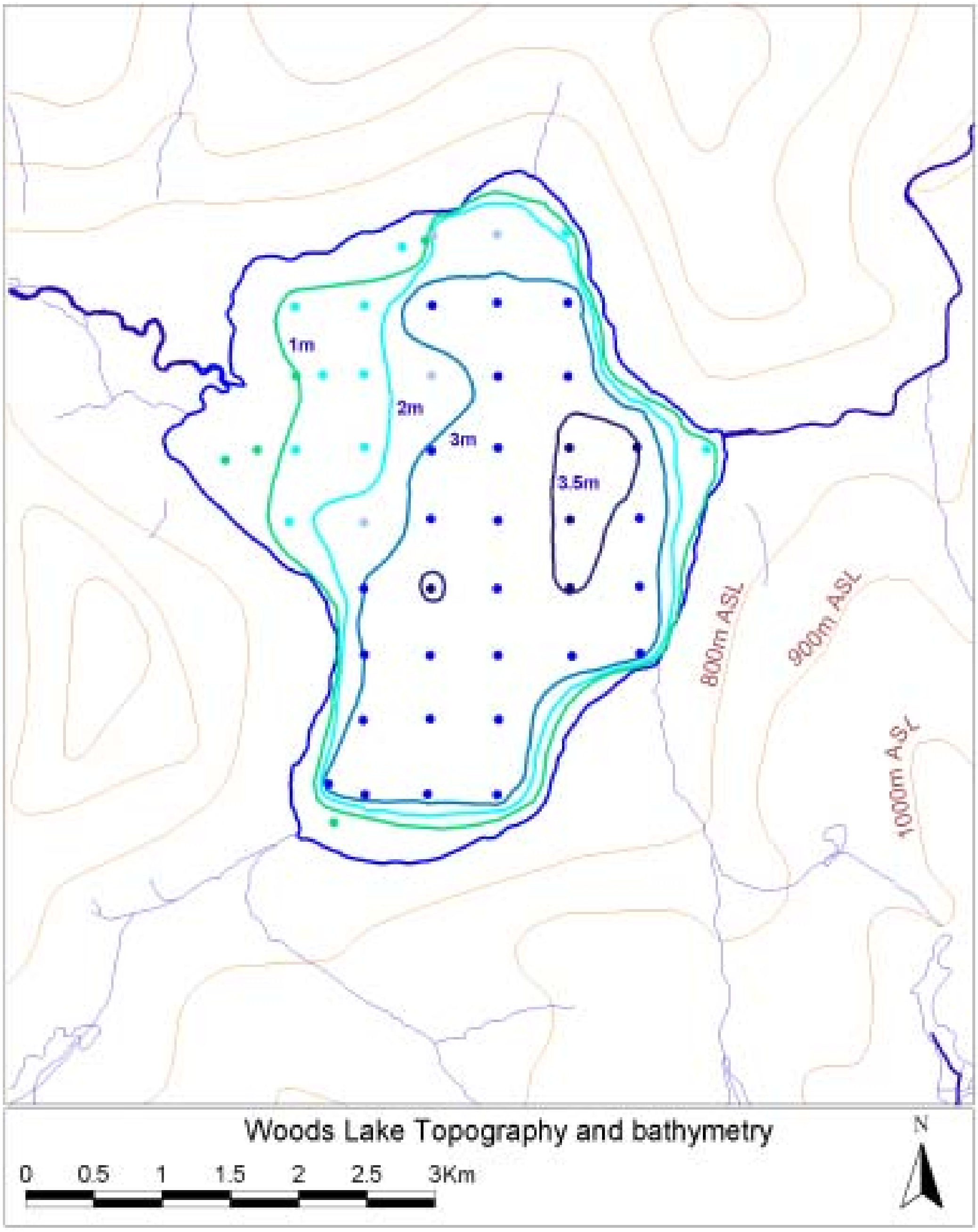


Figure 9: Bathymetric map of Woods Lake showing approximate depth contours at 1, 2, 3, and 3.5 m, equivalent to elevations of 735.8, 734.8, 733.8 and 733.3 m above sea level, respectively)

Shoreline, Littoral and Macrophyte Habitat Survey

Morphology

The morphology of the lake is governed by the location of inflowing rivers and the effects of the dominant winds. The northern, western and southern shorelines (all generally lee shores, with inflowing streams) have gradual slopes with mud substrates associated with floodplain development of the streams. The eastern shore (windward) has steep rocky shores, with little floodplain development. Smaller streams on this windward shore tend to enter the lake by infiltration through a coarse gravel dune system built up by the predominant westerly to north-westerly winds. Figure 10 shows a map of the lake and major inflowing streams.

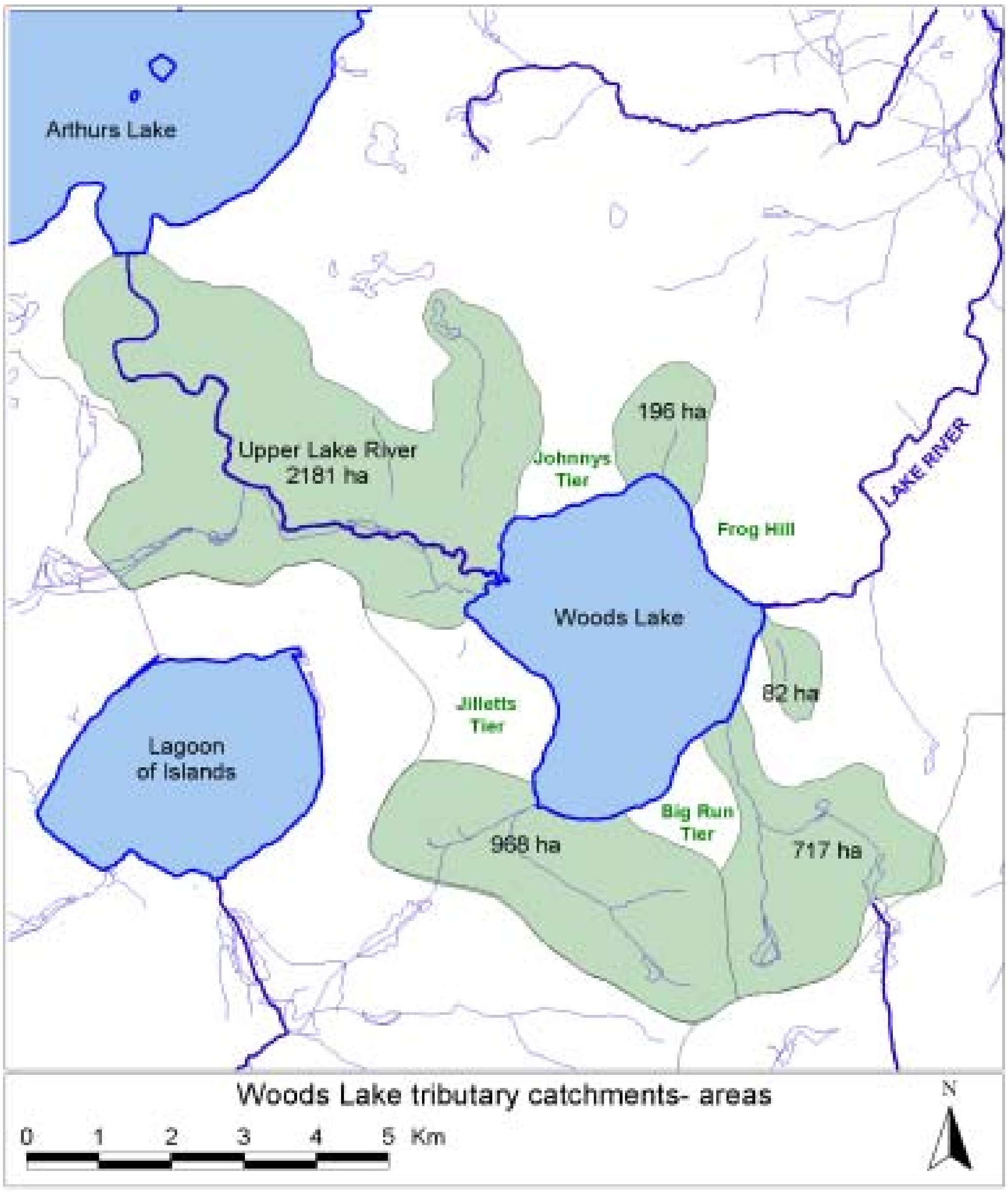


Figure 10: Map of Woods Lake and surrounds, indicating major inflowing streams and their catchment areas

The shoreline alternated from shallow-sloped floodplain, which is usually grass or pasture and bare of trees, to steeply sloping, forested sections. Plate 2 and Plate 3 illustrate these different shoreline types. The steep shores tended to be associated with rocky littoral areas, while muddy littoral substrates were a feature of the floodplains. Drowned trees were associated with the old levee banks of the two largest inflowing streams (Lake River and an unnamed creek in the southwest of the lake).

The mouths of the floodplain streams were drowned during the impoundment of Woods Lake, earlier last century. These flooded soils form significant areas of muddy substrate suitable for macrophyte growth, as well as providing the material, which has been distributed across the floor of the lake through the action of wind and waves. However, because of the strength and duration of the winds, the shallowness of the lake and the long wind fetches, wave action appears to have prevented widespread macrophyte expansion. Areas of macrophytes were found associated with these floodplains, but mostly only where shelter, in the form of logs or other macrophyte beds was available. There was little to no macrophyte development in the more open waters of the lake, despite apparently suitable substrate.

Plate 2: The shallow-sloped Upper Lake River floodplain to the south of where the river enters Woods Lake

Plate 3: Rocky shore, with steep forested bank, near Jilletts Tier, Woods Lake

Shoreline and Littoral Habitats

The shoreline and macrophyte bed survey investigated 23 sites around the circumference of the lake.

A total of six shoreline and littoral habitat areas were defined around the lake. These habitats are shown in Figure 11 (moving anti-clockwise around the lake, from the Lake River inflow) and categorised as the following:

1. the Lake River floodplain in the west and north-west of the lake;
2. the western rocky shore of Jilletts Tier;
3. the southern floodplain of the unnamed creek flowing between Jilletts and Big Run Tiers;
4. the south-eastern rocky shore draining the unnamed ridge to the east of the lake and south of the outflowing Lake River;
5. the north-eastern rocky shore of Frog Hill;
6. the north-western floodplain area associated with an unnamed creek and Johnnys Tier.

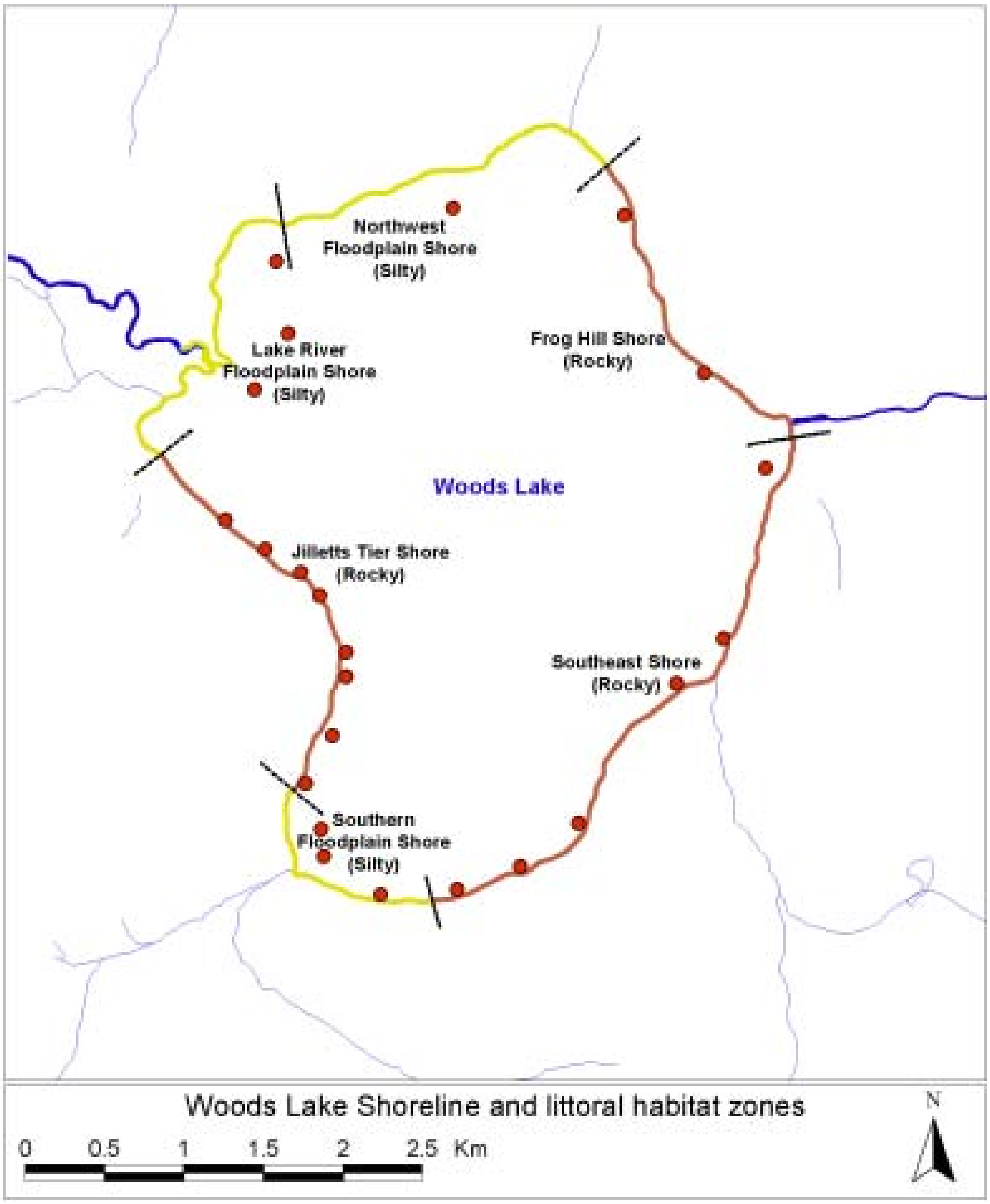


Figure 11: Shoreline and macrophyte bed survey sites in Woods Lake.

While the detailed results of this survey are not included here, the shoreline survey identified a number of distinct habitat areas, each of which are likely to be contributing to the biotic processes within the lake. Some areas may be suited to increased macrophyte abundance, while others may be important for fish species recruitment. In terms of management of Woods Lake, some consideration should be given to:

- knowing the habitat requirements of threatened fish species, so that management does not adversely affect such habitat;
- periodically re-survey the shoreline to evaluate changes over time; and
- take the information about these areas, and their underlying formative processes, into account when considering management options for the water body, such as managing water levels.

Conclusions

Crook and Sanger (1997) and Fulton (1990) described Saddled galaxias and Arthurs paragalaxias as occupying rocky lake margins, however the results from both the Arthurs Lake Study and the Woods Lake Study show that both species are also found associated with macrophyte cover areas, and so these areas should not be discounted as important habitat for both species. Dedicated studies are required before the habitat preferences for both species can be refined.

Data from the surveys indicates that saddled galaxias showed strong larval recruitment to the adult population during 2001/2002, with multiple successful spawning events during the year. While the species currently appears stable in Woods Lake, it is relatively short lived with few large individuals >100 mm collected during the study. The ramifications of this are clear in that the species is vulnerable to habitat disturbance, particularly if it affects mortality or recruitment over several concurrent years. Saddled galaxias do, however, appear more able to cope with population declines than do Arthurs paragalaxias by virtue of their ability to spawn on multiple occasions throughout the year.

Historical Inland Fisheries Service catch records and anecdotal evidence show that Arthurs paragalaxias has not been collected in Woods Lake since the mid 1990s. Inland Fisheries Service Recovery Plan and Hydro Tasmania technical studies conducted in 2001 - 2002 also failed to detect its presence in the lake, and so it is highly likely that it is either locally extinct or very low in numbers. The reasons for this apparent localised extinction are not clear, but the Inland Fisheries Service speculate that it may be related to lake level management, specifically low lake levels and a corresponding negative affect on water quality and/or habitat availability for the species. Consequently, the Inland Fisheries Service has recently nominated *P. mesotes* for listing as 'endangered' under the *Environment Protection and Biodiversity Conservation Act 1999*, and has recently tabled a proposition to translocate *Paragalaxias mesotes* from Arthurs Lake in an attempt to re-establish a significant population in Woods Lake.

The results from the Quarterfoil larval light were generally poor, and were excluded from this report as there was insufficient time to refine the deployment techniques for the study, and the limited trials that were done indicated that they were susceptible to damage if deployed incorrectly in shallow areas.

Although a variety of habitats were surveyed during the technical study and Recovery Plan monitoring programs, habitat preference information derived from the study is limited. Data from the deep set fykes indicates that saddled galaxias occur at depths of up to 5 m, however numbers of fish collected from these sites were low in comparison to the shallow sites.

4. MANAGEMENT OPTIONS FOR WOODS LAKE

Galaxias tanycephalus populations currently appear to be stable in Woods Lake, with multiple spawning events occurring during the year resulting in strong recruitment into the adult galaxiid population. *Paragalaxias mesotes* were not collected from the lake during the study despite the significant joint fishing effort focussed on collection of this species from the lake. While current lake level management regimes appear beneficial to saddled galaxias populations, the principal factors responsible for the decline in *P. mesotes* numbers have not been identified. Significant knowledge gaps in the life history the species remain, and seriously limit the development of appropriate habitat management protocols for Arthurs paragalaxias, and to a lesser extent Saddled galaxias in Woods Lake. Reasonable knowledge of spawning habitat and egg incubation times, habitat preferences and key dietary components for different life history stages is required before appropriate galaxiid habitat management can be implemented.

The work carried out to investigate the issues has produced greater insights into environmental conditions within the lake. However, these do not necessarily give clear guidance for its management. Few of the interactions are simple and apparently appropriate management actions may produce counter-intuitive results. For example, enhancing the spawning success of galaxiid populations, combined with clearer water (both desirable outcomes) may lead to greater trout predation, with consequent crashes in galaxiid and, potentially, trout populations as a result.

Three inter-related management issues are predominant in Woods Lake. These are:

- ensuring suitable environmental conditions are maintained for threatened species;
- maintaining low turbidity in lake water; and
- providing sufficient water for irrigation.

Management objectives to address these issues might therefore include:

1. For threatened species:
    - annually demonstrating, through regular sampling, the presence of healthy planktonic and adult *G. tanycephalus* populations, with appropriate ranges of sizes and numbers;
    - to locate, or reinstate, a population of *P. mesotes* in the lake (this may take more than one year); and
    - provide suitable habitat, water quality and hydrological conditions to ensure the establishment and/or maintenance of sustainable populations of the threatened native species.
2. For low turbidity:
    - mean monthly turbidity values should be below 20 NTU; and
    - the downward trend in turbidity values should be maintained until an asymptotic value is reached. This could be demonstrated by 12 months of stable, low, mean monthly turbidity values.

3. For providing sufficient irrigation water:
    - regularly demonstrating that the stored volume of water is sufficient to meet all projected downstream requirements (irrigation, riparian, environmental) without the need to draw the level below the agreed minimum.

Options for Management

As indicated above, the three predominant issues are closely interlinked, and the primary linkage is through lake level. Therefore options to address the identified issues and to help achieve the management objectives need to include lake level management. Lake level management would help achieve objectives 2 and 3 above.

Macrophytes could play a significant role in reducing turbidity, providing alternative nutrient cycling pathways and nutrient stores. They may also provide additional habitat for the threatened fish species both directly, and indirectly through the structure needed to shelter them from high winds. Options for enhancing macrophyte abundance are considered, as they would help achieve objectives 1 and 2 listed above.

Finally, options for threatened species management, which would help achieve all management objectives above, are discussed.

1. Lake Level Management

Practically speaking, Hydro Tasmania has direct control over inflows to, and outflows from, Woods Lake. This facilitates control of the lake level, with its concomitant influence on water quality. A number of operational and other constraints limit the ability of Hydro Tasmania to manage water levels absolutely. These include:

- Inflows to Woods Lake from Arthurs Lake are generally avoided as the water has a much higher hydro-generation value when diverted to Great Lake, for use in the Poatina power scheme, than it does passing through Woods Lake. That is, there is a significant economic cost involved in releasing water from Arthurs Lake for use in Woods Lake.
- The outflows from Woods Lake are largely controlled by irrigation demand from downstream users. Hydro Tasmania is presently unable, except by mutual agreement, to limit the quantity and timing of such outflows.
- The lake is managed by Hydro Tasmania to provide sufficient storage during the wet seasons to meet irrigation demand during the dry. At times, higher-than-anticipated irrigation demand has caused the lake to be drawn to low levels.
- From an environmental context, the water level of Woods Lake is managed to prevent the occurrence of high turbidity in the water column and the entrainment of high nutrient sediments from the bottom of the lake.

The present operational regime has greatly reduced the incidence of persistent high turbidity and lake-wide algal blooms, however turbidity peaks were recorded in 1995, 1998 and 2000 (see Figure 3), and there is evidence of extensive filamentous algal growth along parts of the eastern shore. The population of *G. tanycephalus* appears to be healthy, although their short life span (12 – 18 months as adults) makes the population susceptible to threats posed by extended periods of poor environmental quality. No information is presently available for the second threatened species, *P. mesotes*, and it may have become locally extinct.

The existing infrastructure and operating regime, which relies on local pick up to the lake and to the upper Lake River, appear to be able to deliver sufficient irrigation water for four years out of five, before the need to draw the lake below the agreed minimum water level.

The options for improving water level management could range from infrastructure changes to maintaining the present management and operational regime. Irrespective of the option chosen, continued water quality monitoring will be required as part of the management strategy for Woods Lake.

1a) Increase the Size of Woods Dam

Increasing the size of the dam would increase storage capacity and the increased water depth could decrease the potential for wind-induced sediment resuspension. However, this would not increase the catchment yield to the lake, and as the present structure rarely approaches full supply level, this option is unlikely to be feasible.

1b) Top Up Water from Arthurs Lake

Another option would be to increase the effective catchment of the lake, by providing inflow from Arthurs Lake. This is the present fallback operation should water levels drop below the minimum agreed. Such a fall back operation generally means the release of a relatively large volume of water for an unpredictable length of time. It has been observed that brown trout have been able to take advantage of such a release, but its utility for native fish species is unknown. Given that trout predation has a great, but unquantified effect on threatened species populations, it is not considered appropriate to further enhance trout production in Woods Lake.

1c) Raise the Minimum Lake Level

A third option is to raise the minimum operating level of the lake to further decrease the incidence of high turbidity. The water level and turbidity data for 1998 indicate that, even though the lowest recorded water level was 735.6 m, a large, coincident increase in turbidity was recorded in this year. This suggests that a higher minimum water level may be needed to prevent spikes in turbidity.

This option would see the minimum water level raised to 735.6 m above sea level (an increase of 0.2 m), with an alert level of 736.0 m above sea level to give an early warning of impending low water levels. The objective of this option would be to further reduce the likelihood of turbidity spikes so that the ambient turbidity decreased to a minimum asymptote, i.e. when all sediments except fine colloids had had a chance to settle out.

Crook (1995) indicates that a water level kept above 735.9 m above sea level would almost eliminate the incidence of turbidity extremes. The suggested revised minimum water level (735.6 m above sea level) represents an incremental step, which could be trialled to determine the actual benefits in relation to turbidity and costs in relation to operation and management of the lake.

However, there are significant issues associated with this option, most particularly in relation to where the water to maintain this higher level would come from. At present, water is intermittently released from Arthurs Lake to ensure that the existing minimum water level in Woods Lake is maintained. This already has a significant cost to Hydro Tasmania. Further reducing the active storage volume of Woods Lake is likely to dramatically increase the need for these releases

1d) Maintain Existing Operations

A fourth option is to leave the present operational procedures and infrastructure as they are. This would maintain the status quo, in terms of ability to:

- meet irrigation demand (provided that demand did not increase significantly);
- manage turbidity, and
- provide suitable environmental conditions for *G. tanycephalus*.

As the data presented earlier shows, when this minimum level is maintained, there are already significant improvements in water quality, and there is some evidence that long-term, baseline turbidity will improve even further if this in adhered to.

2. Macrophyte Enhancement

Macrophytes have the potential to assist with a number of the management issues so far identified.

- Macrophytes provide a primary production pathway for nutrient cycling, which provides an alternative to that of algae. The establishment of a significant macrophyte biomass may reduce the incidence of algal blooms and improve water quality by removing and storing nutrients from the water column.
- The physical effect of healthy macrophyte beds would be to reduce wave action and thereby assist in the mitigation of wind-induced sediment resuspension.
- Macrophytes provide habitat and shelter for organisms subject to predation by predators such as trout. Greater macrophyte abundance may contribute to a reduction of trout predation on threatened fish species. Both *G. tanycephalus* and *P. mesotes* are reported to occur among aquatic plants and marginal lakeshore vegetation.

The bathymetric survey of Woods Lake showed that a muddy substrate was available throughout virtually the entire lake. More than half the area of the lake had water depths greater than 3 m. The survey of macrophytes indicated that macrophyte individuals and beds were found mainly in relatively shallow water (depths less than 1.5 m), which was protected from wave action by some structure (large woody debris or other macrophyte beds).

Options for improving macrophyte abundance in the lake include:

- installing structure (logs, rocks) to both protect macrophyte beds and reduce wind fetch;
- limiting lake level variation, coupled with reduced turbidity;
- actively planting macrophytes at strategic locations, either in association with installed structure or not; and
- maintaining existing conditions.

Any option which effectively altered macrophyte abundance would require ongoing monitoring and management as well as evaluation for effectiveness at reducing sediment resuspension.

2a) Installing Artificial Structures

Both depth and wave action appear responsible for the limited distribution of macrophytes in the lake. A possible option to overcome these factors may be to install structures, in the form of logs or rocks, which would provide the sheltered environment needed to promote macrophyte growth. An added benefit, especially if the installed structures were rocks, would be the provision of additional habitat preferred by the native fish species.

To be effective at reducing wind-induced sediment resuspension, an installed structure would need to be both extensive and resistant to wave action. It would need to be sited in the deeper waters of the lake in order to reduce wind fetch. For navigation and safety purposes it would also need to be highly visible over the entire operating range of the lake.

There are a number of practical limitations to implementing this option, the greatest being the remote nature of the location and the rudimentary access track to the lake. Transport of materials and machinery to the lake to undertake such works would be extremely costly and would necessitate a costly upgrade to the track. Placement of such structures in the lake would also pose some significant technical challenges and is likely to be costly.

2b) Limiting Lake Level Variation

The macrophytes in Woods Lake exist in a water level regime, which fluctuates by up to 1.6 m annually, with a mean annual variation of 1.2 m. If this range were reduced, it might enhance the growth of macrophytes by providing more stable environmental conditions. This effect would be enhanced if turbidity levels were also improved under the altered operating regime.

However, like option 1c, this would result in a reduction in active storage volume and is likely to necessitate more frequent release of highly valued water from Arthurs Lake.

2c) Planting Macrophytes

This option would immediately increase the macrophyte abundance rather than waiting for natural processes to operate. To effectively reduce sediment resuspension, the planting would need to be extensive and include areas of deep (>3 m) water. Such planting would be prone to failure should the water be too turbid, too deep to promote growth or the wave action too strong to allow maintenance of contact with the substrate.

The macrophyte species currently found in the lake tend to favour shallower water (generally less than 1.5 m deep). The reasons for this could be species specific; a consequence of the relatively turbid water reducing the euphotic zone; or inappropriate substrate.

If this option were to be considered further, research would be needed to determine the limitations to existing macrophyte distribution and to investigate other local macrophyte species which may be less limited by prevailing conditions.

Strict adherence to a policy of only using locally available macrophytes would be required and this may limit the range of species available.

As with all environmental interventions, the promotion in abundance, distribution and possibly the introduction of new macrophyte species is not without risk. The options may fail in their objectives or they may produce unexpected results, such as a switch in nutrient cycling processes, for example by making the lake more attractive to swans and other water birds. Additional macrophytes may not enhance habitat availability for the threatened fish species and may introduce other factors, such as increased shading, which may be detrimental to the benthic biota on which the adult native fish feed.

2d) Maintain Existing Conditions

Allowing the existing processes affecting macrophyte distribution and abundance to continue would not incur the risks identified above.

3. Threatened Species Management

Although conditions in Woods Lake appear to be suitable for *G. tanycephalus*, the species, because of its short life span, remains vulnerable to poor environmental quality should it persist for a year or more. More urgently, *P. mesotes* has not been recorded in the lake in recent years, implying a greatly reduced or locally extinct population.

A priority for any management option should be to ensure that nothing is done which has a detrimental effect on the environmental conditions of the lake, in terms of pelagic and in-shore rocky habitats. Options for these species' management include:

- managing water levels and water quality to provide 'more-natural' environmental conditions, especially during the spawning season;
- reducing trout predation by decreasing trout numbers in the lake;
- re-stocking Woods Lake with fish from Arthurs Lake; and
- maintaining existing conditions.

Irrespective of the option chosen, monitoring of threatened species populations should continue in Woods Lake.

References

Bobbi, C., Gamble, S., and Peterson, J. 2000, *Waterway Health Monitoring Program Annual Report 1999-2000*, Hydro Tasmania Internal Report, Hobart.

Crook, D.A. 1995, *Causes of turbidity at Woods Lake*, Inland Fisheries Commission, Hobart.

Crook, D.A. & Sanger, A.C 1997, *Recovery Plan for the Pedder, Swan, Clarence, swamp and saddled galaxias*, Inland Fisheries Commission, Hobart and Environment Australia Biodiversity Group, Canberra.

Fulton, W. 1990, "Tasmanian freshwater fishes", *Fauna of Tasmania Handbook 7*. 80pp.

Hydro Tasmania 1999, *Environmental Review: South Esk – Great Lake Hydro Catchment, November 1999*, Hydro Electric Corporation, Hobart.

Hydro Tasmania 2000, *Community Consultation Report: South Esk – Great Lake Hydro Catchment. August 2000*, Hydro Electric Corporation, Hobart.

Inland Fisheries Service, 2000, *South Esk Catchment Angler Statistics (1996-99)*, Inland Fisheries Service, Hobart.

Inland Fisheries Service, 2001a, *Freshwater Fish acts Number 8: Arthurs paragalaxias (Paragalaxias mesotes).* Inland Fisheries Service, Hobart http://www.ifc.tas.gov.au/fact_sheets/Arthurs_paragalaxias.html

Inland Fisheries Service, 2001b, *Freshwater Fish acts Number 6: Saddled galaxias (Galaxias tanycephalus).* Inland Fisheries Service, Hobart. http://www.ifc.tas.gov.au/fact_sheets/Saddled_galaxias.html

McDowall, R.M. (ed). 1996, *Freshwater fishes of South-eastern Australia (revised edition)*, Reed Books, Chatswood.

Sanger, A.C. 1993, *Inland Fisheries Commission Biological Consultancy: Annual Report for 1992*. Inland Fisheries Commission, Hobart.

Sanger, A.C. & Fulton, W. 1991, "Conservation of endangered species of Tasmanian freshwater fish", *Tasmanian Inland Fisheries Commission Occasional Report* 91-01: 1-29.

Personal Communications

J. Jackson, Inland Fisheries Service, 2001.