Fish communities and migration in the Shoalhaven River – Before construction of a fishway

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NON-TECHNICAL SUMMARY

Fish communities and migration in the Shoalhaven River – Before construction of a fishway.

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OBJECTIVES:

(1) to provide a detailed baseline of the composition of fish communities in the Shoalhaven system; and

(2) to describe the migratory patterns of fish downstream of Tallowa Dam before a fishway is constructed.

Additional information collected whilst working toward these objectives broadened the scope of the study to include a further objective:

(3) to describe the fine-scale distribution of fish at the base of the dam to guide development of a design for the fishway.

NON TECHNICAL SUMMARY:

Since completion of Tallowa Dam in October 1976, the migration of fish within the Shoalhaven catchment has been obstructed. As migratory fishes represent 96% of the native freshwater fishes potentially occurring in the catchment, Tallowa Dam prevents a large proportion of species from using up to 75% of available habitat within the river channel. Twenty-three years after construction of the dam, no fish species that migrate between freshwater and the sea exist naturally upstream of Tallowa Dam, except for those species capable of climbing the dam wall, or Australian bass which have been stocked into the storage.

This project is a joint initiative between the Sydney Catchment Authority (formerly part of Sydney Water), NSW Fisheries and the Cooperative Research Centre for Freshwater Ecology. The overarching objective of the project is to provide fish passage at Tallowa Dam to restore damaged fish communities and the loss of biodiversity upstream of the dam.The project is being conducted as a staged process in which each completed stage provides information required to progress to successive stages.

This report documents the third stage of an investigation into fish passage in the Shoalhaven River and the need for a fishway on Tallowa Dam. The first stage demonstrated that fish attempting to migrate upstream in the Shoalhaven River accumulated at the base of Tallowa Dam when they could not progress any further upstream (Marsden and Harris 1996). This report also provided a preliminary assessment of possible fishway designs, including a winch-operated lift mechanism, a fish lock design, and a new concept of fish pump. The second stage report provided a comprehensive assessment of fish upstream and downstream of the dam, focussing on their biology and distributions, with further consideration of fishway designs (Marsden *et al*. 1997).

This third report provides a baseline on existing fish communities within the Shoalhaven River system against which the effectiveness of a fishway may later be assessed. This survey provided essential information on seasonal and annual variation in fish distributions and abundance, which will be critical to detect changes in fish communities that have resulted from construction of the fishway, as distinct from natural variation. A small sample of fish were also tracked using radio tags to obtain a better understanding of fish migratory behaviour and habitat selection near the dam to guide the design of the fishway.

Condition of fish communities within the Shoalhaven River system.

Effects of Tallowa Dam on fish of the Shoalhaven River system were studied by comparing species abundances, population size-structures and the structure of fish communities above and below the dam. Fish were sampled twice yearly for two years, at twelve sites throughout the catchment, using electrofishing boats and a backpack electrofisher. A helicopter was used to gain access to otherwise inaccessible sampling sites in the Shoalhaven gorge.

The most striking result was an accumulation of fish directly below the dam, including carp, Coxs gudgeon, striped gudgeon, common galaxias, long-finned eels, short-finned eels, Australian bass, striped mullet, freshwater mullet and freshwater herring. More species were encountered below the dam than at other sites in the system. Juvenile and small fish (<100 mm) made up a large proportion (79%) of the fish below the dam. Natural populations of ten migratory species (Australian bass, Australian grayling, striped mullet, freshwater mullet, freshwater herring, striped gudgeon, empire gudgeon, short-headed lamprey, common galaxias and bullrouts) are presumed to be extinct above the dam as a result of obstructed fish passage. A small population of Australian bass exists above the dam only because hatchery-reared fish have been stocked upstream of the dam since the natural population died out. Four migratory species: long-finned eel; short-finned eel; Coxs gudgeon and climbing galaxias are capable of climbing the dam, but even these species have reduced abundances upstream.

Fish communities upstream and downstream of the dam differed significantly, confirming that the dam is the largest discontinuity in fish habitats within the system. In contrast, before the dam was built the fish communities from the tidal limit to approximately 500m elevation were relatively continuous.

This study has demonstrated that Tallowa Dam is a major barrier to fish migration and has caused a significant loss of biodiversity in the system. The fish communities in Lake Yarrunga are distinctive from the riverine communities because of the habitat alteration caused by creating the lake. The dam had very little impact on fish communities at higher altitudes (above 500m). The river system supports populations of two threatened species in need of conservation, Australian grayling and Macquarie perch, and contains unique isolated populations of freshwater catfish and western carp gudgeon.

This study has quantified discontinuities in the distributions of fish in the Shoalhaven River system which have developed since the construction of Tallowa Dam. Comparing this information with the results of a repeat survey after construction of a fishway (Stage 7 of this project) will enable evaluation of the effectiveness of the fishway in rehabilitating fish communities of the river system.

Migratory behaviour of Australian bass and striped mullet

Movements of Australian bass and striped mullet in the Shoalhaven River system were studied using radio telemetry to obtain detailed information on the migratory behaviour of these species in relation to the dam. A uniquely coded radio-transmitter was surgically implanted into the abdominal cavity of each fish. Tagged Australian bass remained near the base of the dam wall and exhibited limited small-scale spatial movements, with a mean monthly distance traveled of 1571 ± 75 m from September 1999 through to March 2000. Similarly, striped mullet did not make any regular large-scale movements either upstream or downstream from their place of capture, although with a mean monthly distance traveled of (2892 ± 71 m), they traveled further than Australian bass. Neither species was observed to undertake movements attributable to seasonality within the period sampled. However, one striped mullet that disappeared from the river was subsequently captured by a commercial fisher in Fingal Bay, over 300 km from the point of release.

Within the complex pool and rapid environment at the base of Tallowa Dam, Australian bass congregated within the flow discharged from the base of the dam in preference to flow from over the spillway. Flow appears to be the major factor attracting Australian bass to the base of the dam, despite the lower temperature of water released from the outlet valve. No tagged striped mullet were recorded near the base of the dam. Juveniles of both species, too small to be tagged, were recorded in large numbers below the dam.

This study corroborates the findings of earlier reports, that provision of fish passage is required at the dam to restore longitudinal connectivity between habitats within the riverine corridor. An efficient high-level fishway has been determined as the most appropriate and viable option for providing fish passage at Tallowa Dam. Restoring fish passage between downstream and upstream habitats will assist rehabilitation of fish communities in the upper 75% of the Shoalhaven River system by allowing locally extinct species to re-establish. A fishway would directly assist the conservation of threatened species and provide a boost to recreational and commercial fisheries in the river system.

Fine-scale distributions of fish below Tallowa Dam and considerations for fishway design.

For a fishway to be effective at Tallowa Dam, where the spillway is 32 m high, the design will need to take into account the following issues:

(i) The fishway will need to be useable by the full range of species requiring passage at the dam. Fish species within the Shoalhaven catchment range in size from an average of 31 mm to 391 mm, with 59% of individuals being less than 50 mm long.

(ii) To use the fishway, fish must be able to find the fishway entrance. Accordingly, the entrance needs to be located where fish congregate and to provide attraction to entice the fish to enter. The preferred location for the fishway entrance is near the outlet at the base of the dam next to the northern abutment. However, the complex flow pattern below the dam will need to be simplified to reduce the influence of distracting flows that attract some fish to the opposite bank of the river.

(iii) Water released from the outlet valve is up to 10ºC cooler than water from the spillway. To prevent fish avoiding cold water at the fishway entrance, the temperature of water released through the fishway will need to be close to ambient temperature in the surface waters of the impoundment.

(iv) It is impractical to design fishways to operate over all flow conditions likely to be experienced at a site. Rather, it is more economical to design fishways to operate over 95%

of flows, with the capacity to withstand extreme flood events. A flow of 3500 Ml day^{-1} represents the maximum flow under which the fishway should be able to operate, corresponding to the 5th percentile of daily flows at Tallowa Dam.

(v) Because of the height of the dam, provision for downstream migration of fish is also an issue for consideration in designing the fishway.

This project can now proceed to a full study of the feasibility of constructing an effective fishway on Tallowa Dam to rehabilitate fish communities in the Shoalhaven River system.

Recommendations

(i) This study has added significantly to the weight of evidence provided in the two preceding reports, that Tallowa Dam has caused a significant impact on fish migrations and fish communities in the Shoalhaven River. It is therefore recommended that a fishway be constructed at Tallowa Dam to restore upstream fish migrations.

(ii) Large numbers of fish consistently occur immediately downstream of the dam, indicating that fish populations within the river system still migrate upstream as far as Tallowa Dam, where they accumulate in habitats at the base of the dam wall. Consequently, there are large numbers of fish attempting to migrate which would use an effective fishway if one was constructed. It is recommended that the fishway be designed to provide passage for all species needing to migrate past the dam.

(iii) Most fish requiring passage at the dam are small, with 59% of individuals being less than 50 mm long. The fishway design will need to specifically address the swimming ability, behaviour and physical requirements of small fish whilst also providing for larger individuals of species such as Australian bass.

(iv) The complex flow and water temperature patterns immediately downstream of the dam may distract migrating fish away from the preferred location of the fishway entrance on the northern abutment to the dam. Options to reduce these effects will need to be included in the design of the fishway.

(v) It is more practical to design fishways to operate over 95% of flows, rather than to design an operating capacity for all flow conditions likely to be experienced. Accordingly, it is recommended that the fishway be designed to operate in flow conditions up to 3500 Ml day^{-1}, which corresponds to the 5th percentile of daily flows at Tallowa Dam.

(vi) Fishway design is a specialist field requiring a unique blend of expertise in hydraulics, engineering and fish biology. It is recommended that the issues identified in this report be expanded in detail in consultation with relevant specialists during a feasibility study for a high-level fishway for Tallowa Dam.

(vii) Because of the height of the dam, provision for downstream migration of fish is also an issue for consideration in designing the fishway.

This study has provided a detailed assessment of fish communities in the Shoalhaven River before construction of a fishway. It is therefore strongly recommended that a similar, comparative assessment be conducted after a fishway has been constructed to evaluate its effectiveness at rehabilitating fish communities in the river system. This study should also include behaviour of fish in the lake once they have passed through the fishway, and their ability to locate riverine habitats upstream. The outcome of this assessment will indicate the potential value of similar fishways on other high dams.

1. INTRODUCTION

Since completion of Tallowa Dam in October 1976, the migration of fish within the Shoalhaven catchment has been obstructed. As migratory fishes represent 96% of the native freshwater fishes potentially occurring in the catchment, Tallowa Dam prevents a large proportion of species from utilising up to 75% of available habitat within the river channel. Twenty-three years after construction of the dam, no diadromous species, that is, fish that migrate between freshwater and the sea, exist naturally within Lake Yarrunga and the upper reaches of the Shoalhaven and Kangaroo Rivers except for those species capable of climbing the dam wall.

This project is a joint initiative between the Sydney Catchment Authority (formerly part of Sydney Water), NSW Fisheries and the Cooperative Research Centre for Freshwater Ecology. The overarching objective of the project is to provide fish passage at Tallowa Dam to restore damaged fish communities and the loss of biodiversity upstream of the dam. The project is being conducted as a staged process in which each completed stage provides information required to progress to successive stages.

The project is composed of seven staged components:

Stage 1 Preliminary investigation of the need for fish passage at Tallowa Dam.

Stage 2 Investigation of the condition of fish communities, options for rehabilitation, and assessment of fishways.

Stage 3 (i) Engineering feasibility study of recommended fishway options for Tallowa Dam.
(ii) Pre-construction ecological assessment to establish reference condition before fishway construction.

Stage 4 Construction and testing of a reduced-scale model fishway (only if required following Stage 3(i).

Stage 5 Design and construction of preferred high fishway at Tallowa Dam.

Stage 6 Assessment of fishway effectiveness, and optimisation of operation for fish migrations.

Stage 7 Post-construction ecological assessment after fishway construction to assess the effectiveness of the fishway.

The restoration of fish passage within the Shoalhaven River System is expected to have several outcomes. It is expected that fish communities below the dam will be enhanced through improved habitat continuity provided by an effective fishway. Fish densities immediately below the dam are expected to decrease because migration will no longer be impeded. It is also expected that riverine fish communities upstream of the dam will become more similar to those present downstream of the dam following construction of a fishway, and that similar changes will occur in fish communities in both the Shoalhaven and Kangaroo Rivers. However, fish communities further upstream from the dam will take longer to respond to improved fish passage than those closer to the dam.

This report provides the results of Stage 3(ii) of the project. The objectives of Stage 3 (ii) were:

(i) to provide a detailed baseline of the composition of fish communities in the Shoalhaven system; and

(ii) to describe the migratory patterns of fish downstream of Tallowa Dam before a fishway is constructed.

Additional information collected whilst working toward these objectives broadened the scope of the study to include a further objective:

(iii) to describe the fine-scale distribution of fish at the base of the dam to guide development of a design for the fishway.

This third report provides a baseline on existing fish communities within the Shoalhaven River system, against which the effectiveness of a fishway in achieving the outcomes listed above may later be assessed. This survey provides essential information on seasonal and annual variation in fish distributions and abundance, which will be critical to detect changes in fish communities that have resulted from construction of the fishway, as distinct from natural variation. A small sample of fish were also tracked using radio tags to obtain a better understanding of fish migratory behaviour and habitat selection near the dam to guide the design of the fishway.

1.1. Fishways and fish passage in New South Wales

Issues associated with fish passage requirements and the status of fishways in New South Wales have been reviewed recently by Thorncraft and Harris (2000). The following text summarises that report and adds additional information where appropriate.

1.1.1. Definition and ecological significance

Fish passage is the process by which fish move around within their environment, and relates particularly to movement past barriers in a stream. All fish require the ability to move freely between habitat areas within their environment, and many forms of fish movements fall into the definition of migrations. Migration is defined as movements resulting in an alternation between two or more separate habitats occurring with regular periodicity and involving a large proportion of the population (Northcote 1978). These movements can be for a variety of reasons, including the search for food and shelter, dispersal into available habitats and most importantly for reproduction. In the long term, fish passage is necessary for the flow of genetic material within populations, essential for the maintenance of fitness and adaptability to change.

1.1.2. Fish migration

Fifty-three species of native freshwater fishes occur in New South Wales, with a further 15 estuarine species known to enter freshwater occasionally (Harris and Gehrke, 1997). Twenty-nine (55%) of these freshwater species (including *Hypseleotris compressa*, defined in this report as catadromous) are presently recognised as having a large-scale migratory stage in their life cycle, while a further 14 species are known to undertake local-scale migrations. The migratory status of the remaining nine species is unknown. Migratory status can be grouped into a number of categories:

Potamodromous	fish that migrate wholly within fresh water
Diadromous	fish that migrate between fresh water and the sea
Diadromous fish can be further subdivided into three categories:	
Anadromous	diadromous fish that spend most of their life in the sea and migrate to freshwater to breed
Catadromous	diadromous fish that spend most of their life in freshwater and migrate to the sea to breed
Amphidromous	diadromous fish that migrate between the sea and freshwater but not for the purpose of breeding

1.1.3. Types of barriers

Physical barriers such as dam walls and weirs, excessive water turbulence or water velocities can obstruct fish passage. Common physical barriers in New South Wales include dams, weirs, regulators, farm dams, floodgates, causeways, culverts, pipes, channelised streams, bridge footings, erosion control works and other kinds of instream works. Behavioural barriers may be created by modifying fish habitats, for example, by creating still-water storages in flowing rivers, straightening stream channels, or by siltation and destruction of aquatic vegetation. Fish may not migrate through such habitats. Additionally, altered streamflow regimes in regulated rivers disrupt the environmental cues responsible for triggering fish migration (Ward and Stanford, 1989; Mallen-Cooper, 1996), while thermally stratified dams may release cold, hypoxic water which fish avoid (Clay, 1995; Astles *et al*., in press).

Complete barriers to upstream fish passage, such as large dams, have the most obvious effect on fish populations (Faragher and Harris, 1984; Marsden *et al.*, 1997; Harris *et al.*, 1998; Pethebridge *et al.*, 1998). Fish that undergo spawning migrations over large distances can become locally extinct above complete barriers and may suffer greatly reduced population sizes downstream. Partial barriers such as low weirs have a less noticeable impact on fish populations, by allowing fish passage infrequently during events such as floods. These events allow fish passage only when they correspond to the natural timing of fish migration and even then may not permit passage for sufficient numbers of fish to maintain an upstream population.

Because Australian fish are predominantly catadromous or potamodromous, it is important to maintain fish passage for both adult and juvenile fish. Even relatively small barriers such as low weirs may be total barriers to the weaker-swimming juveniles, resulting in recruitment failure to upstream habitats in the catchment. Therefore barriers in the lower reaches of rivers usually cause the greatest damage to fish populations.

Over 4300 barriers to fish passage have currently been identified in New South Wales (Thorncraft and Harris, 2000). These include weirs and dams, regulators, floodgates, tidal barriers, and other small structures. Currently only 27 of these structures have fishways specifically designed for native freshwater fish.

1.1.4. Fishways

The need to provide fish passage was recognised early in Australia, with 44 fishways being built in New South Wales between 1913 and 1985. Most of these were poorly designed and maintained, resulting in limited, if any, fish passage. Fishway designs were adapted from the Northern Hemisphere, where upstream migrations are dominated by the large, powerful adult salmon and trout. These designs are unsuited to the predominantly small juvenile potamodromous and catadromous fish that migrate upstream in Australia (Harris, 1984b; Harris and Mallen-Cooper, 1994; Mallen-Cooper, 1993; 1994).

Effective fishways are defined as being able to pass at least 95% of all fish species and individuals attempting to negotiate the barrier, and operate in at least 95% of the prevailing flow conditions (Mallen-Cooper, 1992). Since 1985, 27 fishways designed for native fish species have been built in New South Wales.

There are many types of fishways, with six broad categories presently in use (Clay, 1995; Mallen-Cooper, 1996). These are the pool-type, Denil, lock, trap-and-transport, rock-ramp or bypass and eel-type fishways. Each category has characteristics that make it suitable to particular barriers based on head loss, flow rates and the migratory strategies of the fish communities concerned.

Vertical-slot fishways consist of a channel for water, with several baffles extending almost the full width of the channel to create a vertical slot that extends for the full depth of the channel. Each baffle forms a pool from which water flows through the slot into the pool below. This design allows fish to swim upstream in short bursts against the current without having to jump. The slope of the channel and the interval between slots control the water velocity through each slot, thus the fishway can be designed to suit the swimming ability of ascending fish. The vertical-slot design operates effectively over varying headwater and tailwater levels, allows fish to pass through the fishway at any depth, and is suitable for weirs ranging from 1 to 6 metres in height (Thorncraft and Harris, 2000).

Denil fishways have a series of internal, upstream-sloping ‘U’-shaped baffles without intervening pools. The Denil design allows steeper channels to be used than vertical-slot designs, resulting in shorter and cheaper fishways. This feature allows for prefabrication and installation of Denil patterns into many existing ineffective pool-type fishway channels. However, large resting pools are required for every 1 metre of vertical rise, and the Denil design has a limited operational depth range compared to vertical slot fishways, which limits its usefulness. Denil fishways have been successfully tested at varying slopes at Euston Weir on the Murray River and their use in coastal streams is still being assessed. The requirement for some fish such as young mullet to ascend through the fishway at the surface may be of concern with this design (Thorncraft and Harris, 2000).

Lock fishways operate by attracting fish through an entrance similar to a pool-type fishway, but instead of swimming up a channel, fish accumulate in a holding area at the base of the lock. This holding area is then sealed and filled with water to reach a level equal to the water upstream of the barrier. Fish are then able to swim out of the lock. To encourage fish to move through the lock cycle, a combination of attraction flows and crowding screens can be used. The only lock fishway so far built in New South Wales waters is on the Murray River at Yarrawonga Weir. This fishway transports fish effectively over the 12 metre-high weir, but requires modification to reach its potential Thorncraft and Harris, 1997a). A fish lock is one option being considered for Tallowa Dam.

Trap-and-transport fishways attract fish below a barrier, where they are trapped and then physically transported by road, rail or aerial car over the barrier. No fishway of this type is operating in New South Wales, but this design has potential application at Tallowa Dam.
Pump fishways, where fish are trapped, then pumped through a pipe over the barrier, are an innovative form of fishway that has potential as a low-cost alternative design at both high and low barriers. This is one of the designs being considered for use on Tallowa Dam. This design has been examined for installation at Audley weir, and estimated costs compare very favourably with a vertical-slot fishway (Thorncraft and Harris, 2000).

Rock-ramp fishways are simple and relatively low-cost adjuncts to more-formally engineered fishway designs, and have been used to overcome low barriers up to 1 metre in height. They are built on a slope of 20:1, with large rocks placed to form a series of transverse small pools and falls at about two-metre intervals. Rock-ramp fishways in New South Wales allow small and juvenile fish to ascend during low flows, but larger fish require higher flows (Harris *et al.*, 1998).

1.1.5. Current management

Provision for fish passage is made under Part 7 (8) of the Fisheries Management Act (1994) whereby the Minister may require that fishways be provided on any new or modified structures such as dams, weirs, blockbanks, floodgates, levee banks, bridges, roads, culverts and headworks which cross any tidal or inland river or creek. Penalties may be imposed for obstructing the free passage of fish.

The State Fishways Program was created in 1992. Its objectives are to restore and maintain adequate fish passage throughout the rivers of New South Wales for the preservation of native fish populations; for ecosystem conservation; for human consumption and for economic benefit. This program combines expertise in fish biology from NSW Fisheries with hydraulic engineering expertise within NSW Department of Land and Water Conservation to design and construct effective fishways.

The State Fishways Program has provided rock-ramp fishways at Manilla No. 1 and No. 2 weirs on the Namoi River, Theresa Park and Mt Hunter on the Nepean River, Lane Cove Weir on the Lane Cove River, Bray Park on the Tweed River, and at Landsdowne on the Landsdowne River. The program also provided a Denil fishway on the Edward River offtake.

Other fishways that were not initiated by the State Fishways Program, but which have been assisted by the program include a vertical-slot fishway at Boggabilla on the Macintyre River, and rock-ramp fishways on the Wyong River, Macquarie Rivulet, Bell River, and at Goondiwindi on the Macintyre River.

Because of the large number of barriers, a method has been developed for allocating priority to fish-passage restoration work. The ranking criteria include (1) river size; (2) location of the barrier in the river system; (3) the presence of threatened species; (4) the amount of upstream habitat; (5) the occurrence and severity of downstream obstructions; (6) the proportion of the catchment which lies upstream of the barrier; (7) drownout frequency for the barrier; (8) barrier type; (9) presence or absence of an effective fishway; (10) likely fishway cost; and (11) independent support for a fishway from other government or community groups (Pethebridge *et al.*, 1998).

Rehabilitating native fish populations requires a long-term, well-funded program of fishway development and construction, weir-operation improvements, and removal of barriers wherever possible. Until less-costly designs have been rigorously tested, vertical-slot fishways should be used for any new barriers less than six metres in height and, wherever practical, for restoring passage at existing barriers. Restoration of fish passage and development of better and cheaper fishway designs require continuing Government involvement and support (Thorncraft and Harris, 2000).

1.1.6. Recent NSW Fisheries research

NSW Fisheries has undertaken extensive research into the need for fish passage and fishways since 1985. This work has identified barriers to fish passage, investigated the behaviour of migratory fish, measured the swimming ability of native fish, assessed fishway designs, and examined effectiveness of fishways for rehabilitating fisheries and aquatic ecosystems.

Current projects are examining changes in upstream fish communities following installation of fishways or partial removal of weirs, investigating designs to provide fish passage at high dams such as Tallowa Dam, investigating new, low-cost designs for smaller barriers, road crossings and culverts, and monitoring effectiveness of new fishways.

1.1.7. Future needs

Sufficient expertise is now available to build and operate successful fishways for native fish. Nevertheless, fishways often suffer initial problems in their operation that have to be addressed to provide effective fish passage. New fishways will continue to require expert technical assessment to identify design difficulties, and monitoring to verify their effectiveness and fine-tune operation.

To minimise the cost of providing fish passage, there is a continuing need for innovative and low-cost designs, and for less expensive construction methods such as prefabricated modular fishways. At the same time, a risk-averse approach is necessary to ensure fish passage is not compromised. The best tested, most-effective current fishway design is the vertical-slot fishway. Other designs are also capable of passing fish effectively, but require more extensive testing to optimise the design and operation for native fish.

Cost-effective high-level fishway designs are a high priority to restore fish passage at dams and weirs greater than 6 m in height.

2. METHODS

2.1. Study design

This report describes two separate investigations:

(i) Pre-construction assessment of fish communities to provide a baseline for comparison following construction of a fishway.

(ii) Investigation of fish migration (a) between the dam and the estuary, and (b) at the base of the dam.

2.2. (i) Pre construction assessment of fish communities

Multiple sites were chosen within reaches above and below Tallowa Dam, as well as within the impoundment itself (Fig. 2.1). It was necessary to account for seasonal variation, requiring a minimum of two samples per year, and inter-annual variation, requiring sampling over a minimum of two years. A total of ten sites was sampled during Stage 1 and Stage 2 of this project (Marsden and Harris 1996, Marsden *et al*. 1997): three sites below the impoundment; four sites above the impoundment; and three sites within the impoundment (one each within the Shoalhaven and Kangaroo River arms, and one site at the junction of the two arms). Some of these sites were found to be unsuitable. Site 1 on the Endrick River, a tributary of the Shoalhaven River upstream of the dam, was deleted from the sampling program, because it was immediately above a large waterfall, resulting in no fish being found at this site. Site 3, 500m upstream of the dam, was also deleted because it was close to site 2, Fossickers Flat, and there was no measurable difference between samples collected from these sites. Deleted sites were replaced with site 11 on the Mongarlowe River near Braidwood, and site 12 near Tolwong Mines on the upper Shoalhaven River. Two extra sites were also included within the upper reaches of the impoundment (sites 13 and 14), resulting in a total of 12 sites.

2.2.1. Sampling methods

Sampling was conducted using three forms of electrofishing: two boat mounted electrofishers (*FRV Electricus* and *FRV Polevolt*) and a backpack electrofishing unit. *FRV Electricus* is a five metre, twin-hulled aluminium boat equipped with a boat-mounted 7.5 kW Smith-Root Model GPP 7.5 H/L electrofishing system. Two anodes were suspended in front of the boat and two cathodes were mounted along the sides. One person operated the electrofisher controls and the boat, while two people at the bow dip-netted stunned fish from the water to a live well in the centre of the boat. For safety reasons, both driver and one of the dip netters controlled the duration of fishing with foot switches. During this study the electrofisher was generally operated at between 340 and 1000 V DC, 3 to 15 amps pulsed at 60 Hz and 70 - 90% duty cycle, depending on the conductivity of the water and other environmental conditions.

FRV Polevolt is a 3.6 m aluminium flat bottom boat, designed to sample habitat types too small to be sampled effectively with *FRV Electricus*. *FRV Polevolt* can additionally be slung beneath a helicopter, thus adding more flexibility to its field applications.

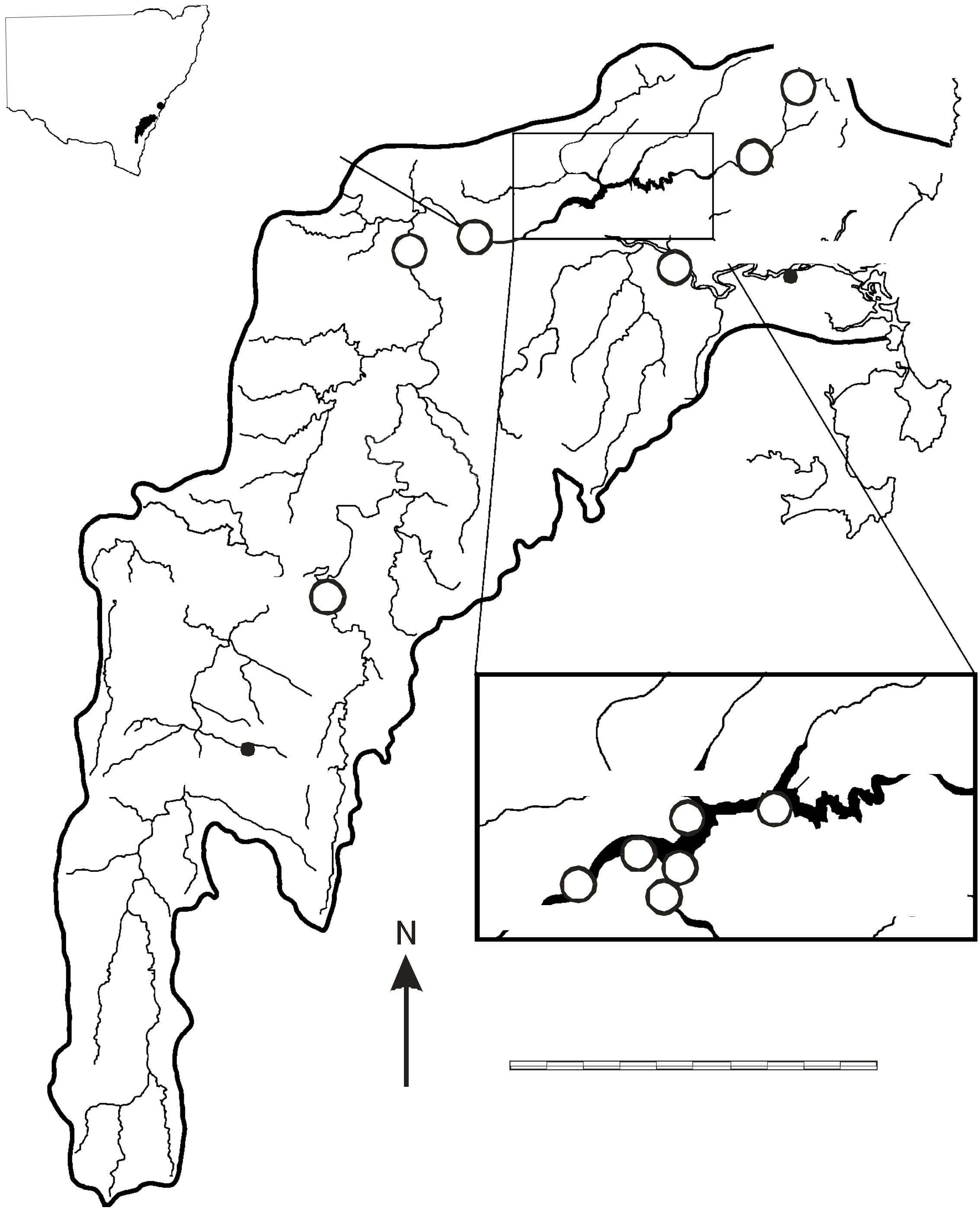


Figure 2.1. Sites sampled above and below Tallowa Dam to investigate the effects of the dam on fish communities in the Shoalhaven River system

FRV Polevolt is equipped with a boat-mounted 2.5 kW Smith-Root Model GPP 2.5 H/L electrofishing system. The setup of *FRV Polevolt* is essentially a scaled-down version of *FRV Electricus*, with two anodes suspended in front of the boat and two cathodes mounted along the sides. One person operated the electrofisher controls and the boat, while one person at the bow dip-netted stunned fish from the water to a live well in the centre of the boat. As with *FRV Electricus*, both driver and dip netter controlled the duration of fishing with foot switches for safety purposes. During this study the electrofisher was generally operated at between 500 and 1000 V DC, 4 to 8 amps pulsed at 120 Hz and 70 - 90% duty cycle, depending on the conductivity of the water and other environmental conditions.

Boat electrofishing was conducted during daylight hours with fifteen two-minute shots at each site. Each shot was conducted by cruising along the bank electrofishing at approximately 5 m intervals for the duration of the specified time period. This method usually covered approximately 50 m of bank per shot.

Back-pack electrofishing uses the same principles as boat electrofishing, but on a smaller scale. This method was used in shallow, wadable riffles and rapids (to a maximum depth of operator hip height). Electricity is provided by two 12 V batteries connected in series to provide a 24 V power supply to a 400 W Smith- Root Model 12 backpack electrofisher. The pulsed DC output used in this study was generally between 400 and 600 V, 0.5 to 1.0 amp at 60 Hz. The current is transferred to the water via an anode ring mounted at the end of a 2 m non-conducting fibreglass pole and a trailing cathode. Fish were immobilised and collected by an assistant with a dip net, and placed in a bucket for recovery and measurement. Back-pack electrofishing was conducted during daylight hours and was standardised by using set bank lengths of 50m of riffle and rapid habitats per shot.

Where possible lentic habitats were sampled using *FRV Electricus*. Where this was not possible because of the small size of the area sampled, or difficult site access, *FRV Polevolt* was used. Sites with riffle or rapid habitat were also sampled using backpack electrofishing to sample all available habitat types and maximise species represented in each catch.

Sites 2 and 12 were sampled using *FRV Polevolt* and backpack electrofishing. Because of inaccessability of these sites equipment and personnel were airlifted by helicopter. Sites 4, 5, 8, and 11 were sampled using *FRV Polevolt* and backpack electrofishing The smaller electrofishing boat was used as these sites proved difficult to gain access to and sample with the larger boat. Sites 6, 7, 9, 10, 13 and 14 were sampled using *FRV Electricus*, because these sites provided deep, steep sided habitat, negating the need for backpack sampling.

After capture, all fish were identified to species (using the standard reference text, McDowall, 1996). A subsample of each species (n=20) was then measured. Length of fish was measured to the nearest millimetre (fork length for fork tailed species, total length for other species). Fish observed to be affected by the electrofisher but which were not caught were also recorded where positive identification was possible. Any abnormalities, diseases and lesions were also recorded. All fish were returned to the water alive. All sampling was conducted with the approval of the Animal Care and Ethics Committee (approval no. ACEC 98/4).

2.3. (ii) Radio telemetry methods

Australian bass and striped mullet were selected for use in the radio telemetry component of the study, because they are abundant within the lower Shoalhaven catchment, exhibit strong migratory behaviour, and grow large enough to have transmitters inserted in their abdominal cavity. A.T.S. Model 10-12 transmitters were selected for use in the current study (Advanced Telemetry Systems, Isanti, Minnisota) and have a nominal battery life of 100 days. Each cylindrical transmitter was 28 mm long and 12 mm in diameter, and weighed approximately 6 grams. The flexible antenna was made of Teflon-coated steel wire, and was 305 mm in length. The transmitters were coated in an inert resin (Scotchcast electrical 5, 3M, Austin, Texas). Field tests indicated that the range of the transmitters varied from 200 - 300 m, depending on noise conditions. Each transmitter was set with a specific frequency (48-50 kHz), to enable individual fish to be identified. Pulse rate and width was constant (55 Hz and 20 msec, respectively). The transmitters were set to a duty cycle of one week on, three weeks off to conserve battery power and to enable the study to be conducted over a long time period. Radio transmitters were surgically inserted into 18 striped mullet and 18 Australian bass collected downstream of Tallowa Dam between 8 and 22 September, 1999. Fish were then tracked during one week of each month for the next 7 months using an A.T.S. R2000 receiver and a 3-element directional Yagi antenna. The directional nature of tracking equipment used enabled exact locations of stationary fish to be determined to within 5 m.

2.3.1. Surgical procedures

Surgical procedures were adapted from previous studies (Lucas 1989, Haeseker *et al.* 1996, Knights and Lasee 1996, Walsh *et al.* 2000). Aseptic conditions were maintained through strict sterilization procedures. Before surgery, all transmitters and surgical instruments were sterilized in a three-stage process: scrubbing in a high concentration salt bath; sterilising in a 70% ethanol solution; then rinsing in a low concentration oxytetracycline solution. Gloves were worn at all times, and scalpel blades and suture material were used once per fish.

Fish were anaesthetised using a 0.5 ppt benzocaine solution. Fish were then placed ventral side up in a harness to stabilise the body of the fish during surgery. A flexible tube was inserted in the fish's mouth supplying a gentle flow of oxygenated benzocane solution (.25 ppt) over the gills. A lateral incision approximately 30 mm long was made in the flank of the fish below the ribs and anterior to the anus, with the centre of the incision in line with the tip of the pelvic fin. Care was taken not to cut the viscera beneath the peritoneal lining. The transmitter was inserted with the antenna protruding from the posterior end of the incision. The incision was then closed with five to six sutures, swabbed, and bonded further with surgical glue (Vetbond). An external spaghetti tag was inserted to the left of the dorsal fin for identification. Signs at access points and newspaper advertisements advised that tagged fish were part of a migration study and should be released if captured. Before release fish were also injected with oxytetracycline (1 ml per kg of fish) into their body cavity, and their weight and lengths recorded. Fish were then placed in a salt bath (15 ppt) to recover. Average duration of surgery from anaesthesia to recovery was 10 minutes.

2.3.2. Telemetry procedures

Radio tracking was conducted on the Shoalhaven River for one week every four weeks from 18 November, 1999. Tracking began immediately below Tallowa Dam, and progressed continuously towards the estuary. Tracking was discontinued upon reaching brackish waters because the transmitters could not be detected in even moderate salinities. The receiver used automatically scanned the pre-programmed frequencies of each of the 38 transmitters for 2 seconds each, taking a total of one minute and sixteen seconds to complete each scan. Once fish were located, their position was recorded using a hand-held global positioning system (Lowrance, Globalnav 212). Searching was then resumed downstream. Tracking was conducted from a canoe in the upper reaches to negotiate rapids, and was continued from a power boat upon reaching the lower reaches. Each pass from Tallowa Dam to the estuary took approximately one day to complete. Tracking was conducted for three consecutive days each month where possible, however difficulties attributable to weather and equipment failure resulted in only two consecutive trips being made on three sampling occasions.

3. CHANGES IN FISH COMMUNITIES OF THE SHOALHAVEN RIVER 20 YEARS AFTER CONSTRUCTION OF TALLOWA DAM, AUSTRALIA.

3.1.1. Summary

Effects of Tallowa Dam on fish of the Shoalhaven River system were studied by comparing species abundances, population size-structures and the structure of fish communities above and below the dam. Fish were sampled twice yearly for two years at twelve sites throughout the catchment. Species richness was greater downstream of the dam, with 21 species, compared to 16 species upstream of the dam. Ten diadromous species are believed to be extinct above the dam because of obstructed fish passage. Another four migratory species capable of climbing the wall have reduced abundances upstream. Accumulations of fish, particularly juveniles, directly below the dam were evident for nine species. Fish communities upstream and downstream of the dam differed significantly, identifying the dam as a significant discontinuity in the available fish habitats within the system. Historical evidence suggests that before the dam was built, fish communities below 500 m elevation and above the tidal limit were largely continuous. This study has demonstrated that Tallowa Dam is a major barrier to fish migration and has had adverse effects on the biodiversity of the system. The creation of Lake Yarrunga by Tallowa Dam has resulted in distinctive fish communities in riverine and lacustrine habitats. The dam had little impact on fish at higher altitudes. The Shoalhaven River system has special conservation significance because it supports populations of two threatened species, Australian grayling (*Prototroctes maraena*) and Macquarie perch (*Macquaria australasica*).

A high-level fishway is now planned for the dam to restore fish passage within the Shoalhaven River system. Data from this study will serve as a baseline against which to assess the effectiveness of the fishway in rehabilitating fish communities of the river system.

3.2. Introduction

Riverine fish migrate for many reasons, usually associated with completing the life cycle, searching for food, or to avoid adverse conditions. Although fish migrations commonly invoke images of the large-scale migrations of salmonids over thousands of kilometres in the Northern Hemisphere, much smaller-scale migrations can be equally important to the survival of species within a river system. The distributions of migratory species are greatly influenced by the existence of natural barriers such as cascades and waterfalls, and the species' abilities to negotiate these barriers. Artificial barriers on rivers, such as dams, weirs and culverts impede fish migrations within the natural distribution of a species, often with detrimental effects on fish populations (Orth and White, 1993; Holmquist *et al*., 1998). For example, Atlantic salmon (*Salmo salar*) disappeared from most eastern rivers in the USA, largely because of the construction of dams without fish passage facilities (Moring, 1993). Migratory fish in Puerto Rico disappeared above high dams and species normally capable of climbing dam walls were excluded when no spillway flow was provided (Holmquist *et al*., 1998). Even small barriers such as flow-gauging weirs can delay fish migration and cause reduced spawning upstream (Lucas and Frear, 1997). In Australia, Australian bass (*Macquaria novemaculeata*) have disappeared upstream of Audley Weir on the Hacking River and from the Warragamba River upstream of Warragamba Dam (Harris, 1983) since construction of barriers in these rivers. Similar disappearances have been recorded following the construction of many barriers throughout Australia (e.g. Bishop and Bell, 1978; Cadwallader, 1978; Pollard *et al*., 1980; Kowarsky and Ross, 1981; Russell, 1991)

Construction of Tallowa Dam, on the Shoalhaven River, approximately 30 km west of Nowra, New South Wales, Australia, began in 1972 and finished in October 1976. The dam is a concrete gravity structure 43 m high, 520 m long and 50 m wide at the base. The spillway is a fixed-crest overshot design 350 m long and 32 m high, with a maximum slope of 55°. During construction, large numbers of fish began accumulating below the dam, with occasional massive mortalities (Bishop and Bell, 1978). Closure of the dam to create Lake Yarrunga effectively blocked access by migratory fish to upstream tributaries draining approximately 5,410 km^2 (75%) of the Shoalhaven catchment, representing significant loss of potential habitat from the system. Three diadromous species, Australian bass, striped mullet (*Mugil cephalus*) and freshwater mullet (*Myxus petardi*) were sampled within the newly formed impoundment after construction (Bishop, 1979). Striped mullet disappeared within a few months but remnants of the other two species were still found in Lake Yarrunga over 2 years after completion. Bishop (1979) suggested that at sexual maturity, these fish descended the spillway during spawning migrations. Numbers of Australian bass above the dam in Lake Yarrunga, and in the Shoalhaven and Kangaroo Rivers declined (Bishop and Walsh, 1984) to the point where the natural population is now extinct above the dam (Marsden *et al*., 1997). Lake Yarrunga and the Kangaroo River were stocked with Australian bass fingerlings in 1990 (25,000), 1994 (140,000) and 1998 (85,775) in an effort to create a recreational fishery.

The Shoalhaven River system has special significance for fish conservation, because it supports populations of Australian grayling (*Prototroctes maraena*) and Macquarie perch (*Macquaria australasica*). These species are classified by the IUCN (International Union for the Conservation of Nature) as vulnerable, and data deficient. The Shoalhaven River was formerly the most northern permanent habitat for Australian grayling. Recent surveys collected only a single specimen from the Shoalhaven system downstream of the dam (R. Faragher, NSW Fisheries unpublished data). Concern over the conservation status of Australian grayling is heightened by the species being the only extant member of the family Prototroctidae. The only other known member of this family, the New Zealand grayling (*Prototroctes oxyrhynchus*) became extinct very rapidly in the 1930's. Populations of Macquarie perch in the Shoalhaven and Hawkesbury River systems possibly constitute a separate species from fish in the Murray-Darling River system (Dufty, 1986; Harris and Rowland, 1996). Australian grayling and Macquarie perch are protected in New South Wales, so that management of the Shoalhaven River system has a vital role in the conservation of both species.

This study investigates fish above and below Tallowa Dam to characterise spatial and temporal variation in contemporary fish communities, and to establish changes that have occurred in species distributions in the 27 years since work on the dam commenced. This report also represents the first component of a Before-After assessment of the effectiveness of a high-level fishway planned for Tallowa Dam.

3.3. Methods

3.3.1. Sites

Fish were sampled at twelve sites within the Shoalhaven catchment: three sites below the dam; four sites within the storage of Lake Yarrunga; and five sites upstream of the storage. Upstream sites included two sites in each of the Shoalhaven and Kangaroo Rivers and one site in the Mongarlowe River in the upper reaches of the catchment (Fig. 3.1). Descriptions of the habitat at each site are given in Table 3.1. Sites were sampled four times, in April - May 1998, November - December 1998, February - March 1999 and October - November 1999.

3.3.2. Sampling methods

Sampling was conducted using three forms of electrofishing: two boat mounted electrofishers (*FRV Electricus* and *FRV Polevolt*) and a backpack electrofishing unit. *FRV Electricus* is a five metre, aluminium electrofishing boat equipped with a 7.5 kW Smith-Root Model GPP 7.5 H/L electrofishing system. *FRV Polevolt* is a 3.6 metre, flat bottom aluminium electrofishing boat equipped with a 2.5 kW Smith-Root Model GPP 2.5 H/L electrofishing system, capable of sampling habitat types too small to be sampled effectively with *FRV Electricus*. Because of its small size, *FRV Polevolt* could be transported by helicopter to sites 2 and 12 where conventional access was unavailable. Boat electrofishing operations consisted of 15 replicated 2 minute shots per site during daylight hours. Electrofishing units were generally operated at between 500 and 1,000 V DC, 4 to 8 amps pulsed at 120 Hz and 70-90% duty cycle, depending on conductivity. In addition to the standard boat electrofishing sample, back-pack electrofishing using a 400 W Smith-Root Model 12 backpack electrofisher was used at sites 2, 4, 5, 8, 9, 11 and 12 where shallow water or riffles were present. Each of these sites was sampled along two 50 m transects in addition to the standard 15 boat electrofishing shots. The catch from all electrofishing shots at each site visit was pooled and treated as a single sample.

After capture, all fish were identified, counted, measured and released alive. Length measurements to the nearest millimetre were taken as fork length for species with forked tails, and total length for other species. Where large catches of a species occurred, a sub-sample of 20 individuals of each species was measured per electrofishing shot. Fish observed during the sampling operations, but not dip netted from the water were recorded as observed.

3.3.3. Reconstruction of pre-dam fish assemblages

Records of fish distributions from previous studies in the Shoalhaven system (Bishop and Bell, 1978; Bishop, 1979; Llewellyn, 1983) and species recorded at similar elevations in neighbouring river systems (Gehrke and Harris, 1996; McDowall, 1996; Harris and Gehrke, 1997; NSW Fisheries unpublished data.) were used to reconstruct fish assemblages recorded or predicted to have occurred at each site before the construction of Tallowa Dam. The resulting binary matrix of species distributions served as a model for comparison with present-day assemblages to detect changes likely to have occurred over time.

3.3.4. Analytical methods

The total number of fish caught at each site on each of the four surveys was analysed using one-way analysis of variance to compare total fish abundances at different sites, with the four different times of sampling as independent replicates. Abundances were log-transformed to stabilise variances. *A priori* comparisons were used to compare total abundance, and the abundance of individual species among sites immediately below and 500 m downstream of the dam with those in the rest of the catchment.

Separate analyses were done to identify spatial and temporal effects of the dam on fish communities. Spatial differences in contemporary fish assemblages were detected by a combination of multivariate analyses of species abundances, assessment of individual species abundances, and comparison of population size-structures for species that occurred in sufficient numbers above and below the dam.

Spatial analyses of fish assemblages were done using PRIMER 4.0 (Plymouth Marine Laboratory) to perform multi-dimensional scaling (MDS) ordinations in two dimensions. Species abundances were transformed to the fourth root, with similarities between fish assemblages at each site calculated using the Bray-Curtis similarity measure (Bray and Curtis, 1957). The fourth-root

Table 3.1 Habitat descriptions at twelve sites within the Shoalhaven River system. See Figure 3.1 for site locations. Sites 1 and 3 were used in an earlier study (Marsden *et al.*, 1997) but were excluded from this study.

Site	Name	Elev. (m)	Habitat description
2	Fossickers Flat	70	Shoalhaven River upstream of Lake Yarrunga. Long pool up to 2 m deep, bounded by rapids and riffles. Substratum sand, gravel and cobble with abundant boulders. No macrophyte beds and sparse riparian vegetation.
4	Upper Kangaroo River	120	Upper reaches of Kangaroo River. Two short pools up to 2.1 m deep separated by a series of low cascades and bounded by riffles and rapids. Substratum bedrock with abundant boulders and large cobbles. Littoral grasses and undercuts common. No macrophyte beds and abundant riparian vegetation.
5	Kangaroo Valley	60	Kangaroo River immediately upstream of Hampden Bridge. Medium-sized pool up to 11 m deep, bounded by downstream riffle and upstream causeway. Substratum sand with frequent boulders. No macrophyte beds. One bank is composed entirely of a sandy beach while the other is dominated by a cliff face with occasional vegetation.
6	Sawyers Spur	50	Kangaroo River arm within Lake Yarrunga. Sampled depth up to 3 m. Substratum mud and silt with occasional bedrock and boulders. Sparse macrophyte beds and rushes, occasional riparian vegetation.
7	Pauls Lookout	50	Shoalhaven River arm within Lake Yarrunga. Sampled depth up to 3 m. Substratum mud and silt with occasional bedrock and boulders. Occasional macrophyte beds and timber structure, with abundant leaf litter. Frequent riparian vegetation.
8	Directly under dam	30	Complex of four small pools and inter-connecting rapids/riffles. Depth up to 2 m. Southern two pools receive water from spillway. Northern pool receives cold water from base of dam. Fourth pool mixes water from other pools. Substratum cobble with occasional bedrock. Sparse macrophyte beds. Occasional dense stands of riparian vegetation.
9	500 m downstream of dam	30	Long pool with maximum depth 3 m. Substratum diverse, including bedrock, boulders, mud and silt. Frequent macrophyte beds are. Occasional riparian vegetation.
10	Burrier pump station	<10	Long pool 22 km downstream of dam, just upstream of the tidal limit. Maximum depth 3.8 m. Substratum sand with occasional cobble and boulders. Macrophyte beds common. Riparian vegetation is abundant on one bank and sparse on the other.
11	Mongarlowe River	550	Extreme upper reach site above the confluence the Mongarlowe River and Shoalhaven River rivers. Long pool 1.5 m deep with riffles upstream and downstream. Substratum sand and cobble. Frequent macrophyte beds and timber cover ,with abundant riparian vegetation.
12	Tolwong Mines	130	Shoalhaven River upstream of Lake Yarrunga. Long pool 3 m deep, bounded by rapids and riffles. Substratum cobble with abundant bedrock. Frequent macrophyte beds and rushes. Abundant riparian vegetation on one bank, sparse on other bank.
13	Monarch Bluff	50	Shoalhaven River arm within Lake Yarrunga. Sampled depth to 5 m. Substratum mud and silt with abundant bedrock and boulders. Drowned trees and undercuts abundant. Frequent macrophyte beds and rushes with abundant riparian vegetation.
14	Beehive Point	50	Kangaroo River arm within Lake Yarrunga. Average depth 5 m. Substratum mud and silt with frequent boulders and bedrock. Drowned trees abundant. Frequent macrophyte beds and rushes with occasional riparian vegetation.

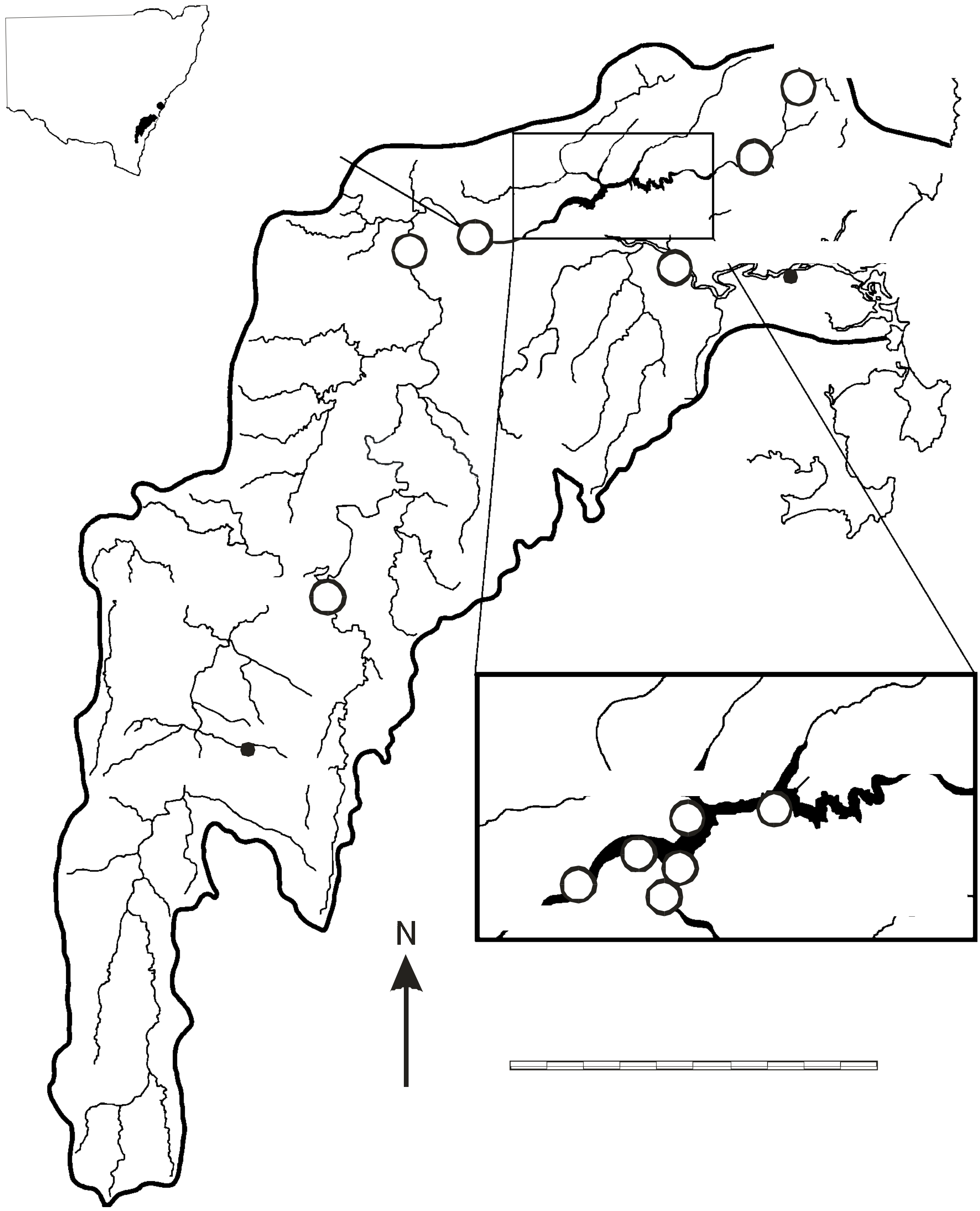


Figure 3.1 Sites sampled in the Shoalhaven River system to investigate the effects of Tallowa Dam on fish communities. Sites 1 and 3 were sampled during previous surveys but were not sampled during this study.

transformation has the advantage that, as it is a power transformation, similarities calculated using the Bray-Curtis measure are invariant to the scale of measurement (Stephenson and Burgess, 1980). Ordination was done on similarities among sites to indicate the affinities of fish assemblages among sites, and the effect of Tallowa Dam on the composition of assemblages. Analyses used two data sets. The first analysis used the complete data set. The second analysis used a subset of the same data from which stocked Australian bass were omitted to better reflect the effect of the dam on natural fish distributions. One-way ANOSIM (ANalysis Of SIMilarities) comparisons (Clarke, 1993) were done to identify differences in fish assemblage composition between sites downstream of Tallowa Dam, within Lake Yarrunga, in the Shoalhaven and Kangaroo Rivers, and in the Mongarlowe River. ANOSIM is a non-parametric multivariate analogue of analysis of variance, based on rank similarities among all samples. Permutation tests to estimate the probability of observed results used 5000 randomisations. SIMilarity PERcentage (SIMPER) analyses were used to identify species contributing to observed dissimilarities among sites. Similarity matrices with stocked populations of Australian bass included and omitted were compared using the Spearman rank correlation coefficient generated in the RELATE module in PRIMER.

Size distributions of species above and below the dam were compared using Kolmogorov-Smirnov tests. These analyses provide a spatial assessment of the effect of the dam on contemporary fish populations. This analysis was done for species with 30 individuals or more recorded both above and below Tallowa Dam. These species were long-finned eel (*Anguilla reinhardtii*), carp (*Cyprinus carpio*), Cox's gudgeon (*Gobiomorphus coxii*), Australian bass, flat-headed gudgeon (*Philypnodon grandiceps*) and Australian smelt (*Retropinna semoni*).

Temporal analyses were done by comparing contemporary fish assemblages with reconstructed natural fish distributions in the Shoalhaven River system before the dam was built. Because the reconstructed species distributions could only be expressed as binary data, fish samples from the present study were pooled over sampling occasions and converted to binary form. Heirarchical agglomerative classification analyses using the group-average linking algorithm were done on reconstructed data and on contemporary data sets with Australian bass included and omitted. Similarity matrices were calculated using the Bray-Curtis similarity measure.

Comparison of reconstructed fish assemblages with actual contemporary assemblages involves a number of assumptions. The first assumption is that the reconstructed assemblage accurately reflects the natural assemblage at each site before construction of the dam. Because all available records from the Shoalhaven system, as well as from the Hawkesbury-Nepean River system to the north (Gehrke and Harris, 1996; Harris and Gehrke, 1997), and the Clyde, Tuross and Bega rivers to the south (McDowall,1996; Harris and Gehrke, 1997) were used in reconstructing pre-dam assemblages, there is no independent way to test this assumption. The presence/absence method used to reconstruct species distributions does not recognise differences in abundance between species, nor the relative sampling efficiency of different investigations, with the result that it over-estimates the contribution of rare species, such as the short-headed lamprey (*Mordacia mordax*) and Australian grayling, which may be widely distributed within the river system, but rarely encountered.

It must be assumed that the sampling methods used in the present study are not biased, and target all species in the original assemblage. This assumption appears to be well-justified on the basis of the efficiency of a similar suite of sampling gear (Faragher and Rodgers, 1997), with electrofishing methods used in this study being more efficient at targeting a wider range of species than sampling methods used in earlier studies of the Shoalhaven system.

Another sampling assumption is that the time of sampling in this study is appropriate for catching all species present at a site. Faragher and Rodgers (1997) and Gehrke and Harris (2000) demonstrated that the greatest number of species were caught by sampling during summer, to the point where this assumption is well-justified. Provided that these assumptions are met, any differences detected between contemporary and reconstructed assemblages may be considered to reflect real changes.

3.4. Results

3.4.1. Reconstructed fish assemblages

Reconstructed fish assemblages at sites equivalent to those sampled in the present study are given in Table 3.2. Twenty-one species were known to occur in the Shoalhaven River system before the dam was built. A further three species – short-headed lamprey, bullrout (*Nothesthes robusta*) and southern blue-eye (*Pseudomugil signifer*) – are considered likely to have been part of the pre-existing fish community because of records from neighbouring catchments (Gehrke and Harris, 1996; Harris and Gehrke, 1997). The species composition of the reconstructed assemblage is therefore well substantiated for 87.5% of species.

Three additional species recorded during the present study were not known to occur in the Shoalhaven system before construction of Tallowa Dam. Carp have only become established since 1986. The second species, western carp gudgeon (*Hypseleotris klunzingeri*), is believed to be native to the Murray-Darling River system and to coastal rivers in north-eastern New South Wales, south to the Hunter River (McDowall, 1996; Harris and Gehrke, 1997). This species was only collected from the Mongarlowe River and from Paul's Lookout in Lake Yarrunga. Freshwater catfish (*Tandanus tandanus*) also appear to have become established since the dam was built (Bishop, 1979).

Two salmonid species, rainbow trout (*Oncorhynchus mykiss*) and brown trout (*Salmo trutta*) were known from the Shoalhaven system, but were not included in the reconstructed assemblage for this study. The distributions of these species were confined to higher altitudes than sites sampled in this study, and the populations were maintained by stocking by local acclimatisation societies (Bishop, 1979).

3.4.2. Present-day fish assemblages

Twenty-six species were sampled during this study. Sixteen species and 11,298 individuals were caught from nine sites within and upstream of Lake Yarrunga (Table 3.3, Fig. 3.2). Downstream of the dam, 21 species and 10,292 fish were sampled from three sites. Species richness was greater at all sites downstream of Tallowa Dam than at any site upstream. The Mongarlowe River supported eight species, which is within the range of the number of species at other sites upstream of the dam. However three species, climbing galaxias (*Galaxias brevipinnis*), mountain galaxias (*Galaxias olidus*) and Macquarie perch were recorded only from the Mongarlowe River. At an elevation of 120 m, the upper Kangaroo River contained only three species despite the lack of any significant fish passage obstructions between the upper Kangaroo River and the site further downstream at Kangaroo Valley.

The mean number of fish collected per site was greater immediately below the dam (1,171 ± 175 fish per sample) and 500 m downstream of the dam (1,025 ± 451 fish per sample) (Fig. 3.3) than at other sites upstream or downstream (minimum 20 ± 5 fish per sample from the Mongarlowe River, maximum 611 ± 184 fish per sample from Kangaroo Valley) ($p < 0.0001$), demonstrating the existence of significant accumulations of fish downstream of the dam. Significant accumulations below the dam were detected for short-finned eels, long-finned eels, carp, common galaxias, striped gudgeon, Cox's gudgeon, Australian bass, striped mullet, freshwater herring and Australian

Table 3.2 Reconstructed historical distributions (presence/absence) of fish species in the Shoalhaven River system before dam construction. Species not recorded until after 1972 are recorded as absent from all sites. Data sources: Bishop and Bell, 1978; Bishop, 1979; Llewellyn, 1983; Gehrke and Harris, 1996; McDowall, 1996; Harris and Gehrke, 1997; NSW Fisheries unpublished data.

Common name		**Site**											
		2	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Recorded species													
Yellow-finned bream[c]	*Acanthopagrus australis*	0	0	0	0	0	0	0	1	0	0	0	0
Short-finned eel	*Anguilla australis*	1	1	1	1	1	1	1	1	1	1	1	1
Long-finned eel	*Anguilla reinhardtii*	1	1	1	1	1	1	1	1	1	1	1	1
Goldfish[a]	*Carassius auratus*	0	0	0	1	1	1	1	1	1	0	1	1
Climbing galaxias	*Galaxias brevipinnis*	1	1	1	0	0	0	0	0	1	1	0	0
Common jollytail	*Galaxias maculatus*	1	0	1	1	1	1	1	1	0	0	1	1
Mountain galaxias	*Galaxias olidus*	0	0	0	0	0	0	0	0	1	0	0	0
Gambusia[a]	*Gambusia holbrooki*	0	0	1	0	0	0	0	0	0	0	0	0
Striped gudgeon	*Gobiomorphus australis*	1	1	1	1	1	1	1	1	0	1	1	1
Cox's gudgeon	*Gobiomorphus coxii*	1	1	1	1	1	1	1	1	0	1	1	1
Empire gudgeon	*Hypseleotris compressa*	1	1	1	1	1	1	1	1	0	1	1	1
Macquarie perch	*Macquaria australasica*	1	1	1	1	1	1	1	0	1	1	1	1
Estuary perch	*Macquaria colonorum*	0	0	0	0	0	0	0	1	0	0	0	0
Australian bass	*Macquaria novemaculeata*	1	1	1	1	1	1	1	1	0	1	1	1
Striped mullet	*Mugil cephalus*	1	1	1	1	1	1	1	1	0	1	1	1
Freshwater mullet	*Myxus petardi*	1	1	1	1	1	1	1	1	0	1	1	1
Flat-headed gudgeon	*Philypnodon grandiceps*	1	1	1	1	1	1	1	1	0	1	1	1
Dwarf flat-headed gudgeon	*Philypnodon* sp.1	1	1	1	1	1	1	1	1	0	1	1	1
Freshwater herring	*Potamalosa richmondia*	1	1	1	1	1	1	1	1	0	1	1	1
Australian grayling [a]	*Prototroctes maraena*	1	1	1	1	1	1	1	1	0	1	1	1
Australian smelt	*Retropinna semoni*	1	1	1	1	1	1	1	1	0	1	1	1
Predicted species not sampled before 1972													
Short-headed lamprey	*Mordacia mordax*	1	1	1	1	1	1	1	1	0	1	1	1
Bullrout	*Notesthes robusta*	1	1	1	1	1	1	1	1	0	1	1	1
Southern blue-eye	*Pseudomugil signifer*	0	0	0	0	0	0	0	1	0	0	0	0
Species recorded at study sites since start of construction													
Western carp gudgeon[b]	*Hypseleotris klunzingeri*	0	0	0	0	0	0	0	0	0	0	0	0
Freshwater catfish[b]	*Tandanus tandanus*	0	0	0	0	0	0	0	0	0	0	0	0
Carp[a]	*Cyprinus carpio*	0	0	0	0	0	0	0	0	0	0	0	0
Rainbow trout[a]	*Oncorhynchus mykiss*	0	0	0	0	0	0	0	0	0	0	0	0
Brown trout[a]	*Salmo trutta*	0	0	0	0	0	0	0	0	0	0	0	0

[a] alien species introduced from other countries.
[b] translocated species, or species from neighbouring drainages.
[c] marine species recorded from freshwater reaches.

Table 3.3 Summary of fish sampled in the Shoalhaven River system. Sites upstream of Lake Yarrunga designated as: MR Mongarlowe River; SR Shoalhaven River; KR Kangaroo River. Catches are pooled results from four sampling occasions.

Species	Sites															
	Upstream of L. Yarrunga						Within L. Yarrunga					Downstream of dam				
	MR	SR		KR												
	11	**12**	**2**	**4**	**5**	**Sub total**	**14**	**6**	**7**	**13**	**Sub total**	**8**	**9**	**10**	**Sub total**	**Grand total**
Mordaciidae																
Mordacia mordax														1	1	1
Anguillidae																
Anguilla australis	1	3	4			8			6		6	32	4	6	42	56
Anguilla reinhardtii	10	57	20	74	48	209	11	27	11	6	55	747	136	88	971	1235
Clupeidae																
Potamalosa richmondia												200	11	63	274	274
Galaxiidae																
Galaxias brevipinnis	20					20										20
Galaxias maculatus												70	1	3	74	74
Galaxias olidus	11					11										11
Salmonidae																
Salmo trutta	2					2						9			9	11
Retropinnidae																
Retropinna semoni		787	708	813	1862	4170	820	1055	758	1210	3843	1661	3068	660	5389	13402
Cyprinidae																
Carassius auratus					1	1						1		2	3	4
Cyprinus carpio		19	12		1	32	9	7	19	15	50	90	33	7	130	212
Plotosidae																
Tandanus tandanus							6	8	11	2	27	5	1	1	7	34
Poeciliidae																
Gambusia holbrooki	19	1				20	15	31	24	15	85					105
Scorpaenidae																
Notesthes robusta												1	1	4	6	6
Percichthyidae																
Macquaria australasica	6					6										6
Macquaria colonorum														1	1	1
Macquaria novemaculeata		3	13		35	51	39	23	25	11	98	703	89	118	910	1059
Sparidae																
Acanthopagrus australis														1	1	1
Mugilidae																
Mugil cephalus												723	157	198	1078	1078
Myxus petardi												59	32	291	382	382
Gobiidae																
Gobiomorphus australis												54	94	27	175	175
Gobiomorphus coxii		43	12	78	2	135	4	3	5	5	17	183	93	3	279	431
Hypseleotris compressa													2	23	25	25
Hypseleotris klunzingeri	10					10			1		1					11
Philypnodon grandiceps		19	5		417	441	786	397	530	202	1915	139	377	12	528	2884
Philypnodon sp.1					10	10	25	17	24	11	77	4		1	5	92
Total number of fish	79	932	774	965	2376	5125	1715	1568	1414	1477	6173	4681	4099	1510	10292	21590
Total species	8	8	7	3	8	15	9	9	11	9	11	17	15	20	21	26

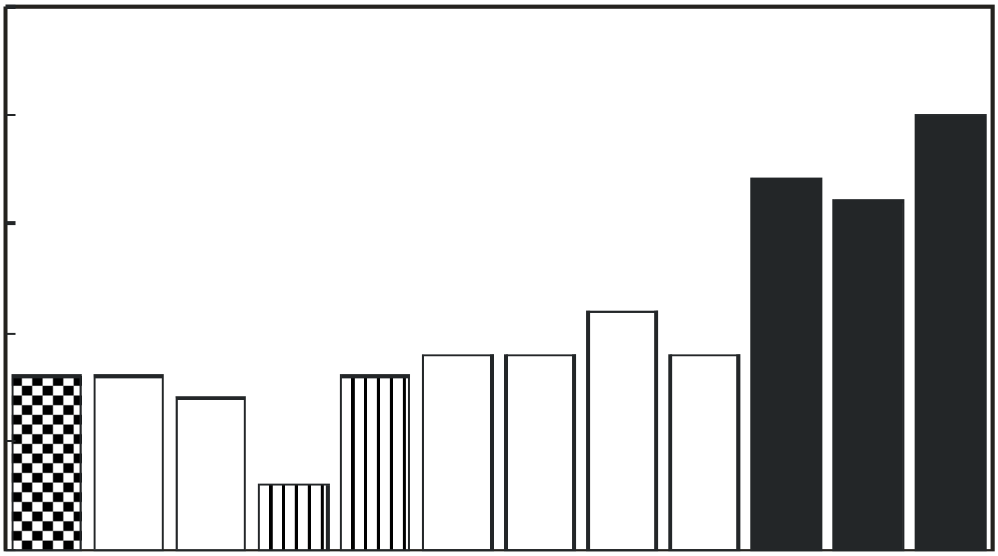


Figure 3.2 Total number of species sampled at each site. Mongarlowe River (chequered); Shoalhaven River upstream (hollow); Kangaroo River (vertical hatching); Lake Yarrunga (oblique hatching); Shoalhaven River downstream of dam (solid).

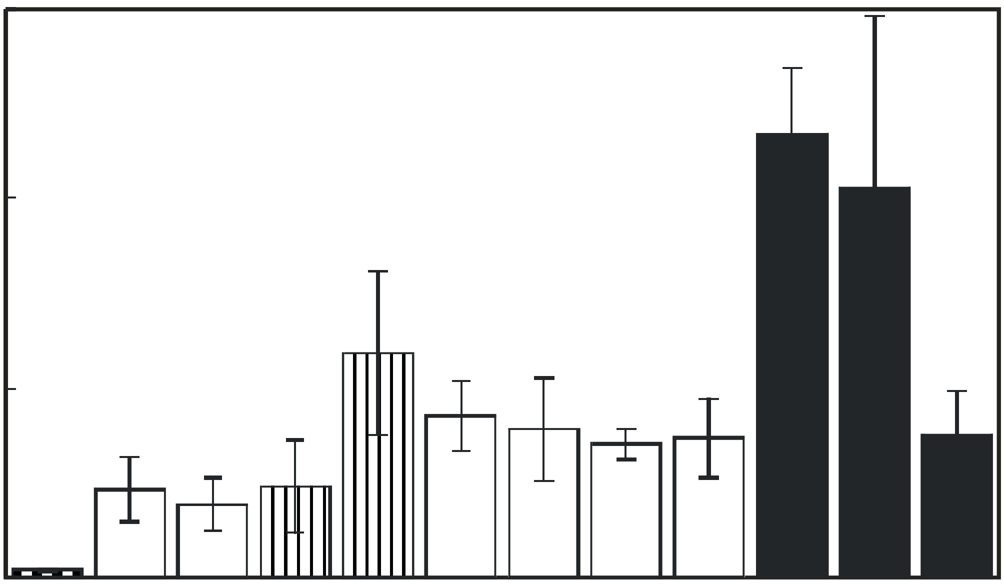


Figure 3.3 Mean number of fish sampled at each site averaged over four sampling occasions. Mongarlowe River (chequered); Shoalhaven River upstream (hollow); Kangaroo River (vertical hatching); Lake Yarrunga (oblique hatching); Shoalhaven River downstream of dam (solid).

smelt ($p < 0.05$, Fig. 3.4). With the exception of short-finned eels (*Anguilla australis*), long-finned eels, climbing galaxias and Australian bass, diadromous species were only found downstream of the dam (Fig. 3.4). Short-finned eels, long-finned eels and climbing galaxias are capable of climbing the spillway wall to maintain populations upstream of Tallowa Dam. Australian bass only occurred upstream of Tallowa Dam because hatchery-reared fish were stocked into the impoundment. Cox's gudgeon are potamodromous and are also capable of climbing the dam. Despite their climbing ability, accumulations of short-finned eels, long-finned eels and Cox's gudgeon were still observed below the dam wall (Fig. 3.4), indicating the barrier effect of the dam even for these species.

3.4.3. Spatial variation among sites

Significant spatial differences were observed between fish communities in the Mongarlowe River, the Shoalhaven River above Lake Yarrunga, the Kangaroo River, within Lake Yarrunga and in the Shoalhaven River downstream of the dam (ANOSIM: $R = 0.788$, $p < 0.001$, Table 3.4). The Mongarlowe River in the upper reaches of the catchment supported the most distinctive fish community (Fig. 3.5), and was significantly different from all other sites ($p < 0.002$). The upper catchment fish community was characterised by the absence of Australian smelt, flat-headed gudgeon, Cox's gudgeon and carp, the unique occurrence of climbing galaxias, comparatively high abundance of western carp gudgeon and gambusia, and low abundance of long-finned eels (Table 3.5).

The next most distinctive community occurred in sites downstream of Tallowa Dam (Fig. 3.5, Table 3.4). This community was characterised by the unique presence of striped mullet, freshwater mullet, Australian bass and striped gudgeon, and higher abundances of long-finned eels, short-finned eels, Cox's gudgeon, Australian smelt and carp than at sites above the dam. Flat-headed gudgeon and dwarf flat-headed gudgeon (*Philypnodon* sp.1) were less abundant below the dam than above (Table 3.5).

Remaining fish communities upstream of the dam were less distinctive than other communities (Table 3.5) but showed significant differences between riverine and lacustrine habitats (Fig. 3.5, Table 3.4). Communities in the Kangaroo and Shoalhaven rivers differed significantly from the community in Lake Yarrunga ($p < 0.001$), and also from each other ($p < 0.005$). All four sites in Lake Yarrunga consistently grouped together. Similarly, sites in the Shoalhaven River also formed a cohesive group. However, assemblages in the Kangaroo River did not group uniformly with either the riverine or lacustrine communities. The fish assemblage at Kangaroo Valley consistently grouped with the Lake Yarrunga community. In contrast, the assemblage in the upper Kangaroo River formed a separate community distinct from both the lacustrine and Shoalhaven River communities. Riverine fish communities were characterised by greater abundances of Cox's gudgeon, Australian smelt and long-finned eels, whilst lacustrine sites had greater abundances of flat-headed gudgeon, dwarf flat-headed gudgeon, carp and freshwater catfish (Table 3.5).

Differences in communities among sites are supported by classification analysis (Fig. 3.6*b* & *c*). The community in the Mongarlowe River in the upper reaches of the system is clearly shown as distinct from other communities at low levels of similarity. The upper Kangaroo River and sites downstream of the dam also contain distinctive communities. Fish within Lake Yarrunga and the Shoalhaven River are recognisable as separate riverine and lacustrine communities at higher levels of similarity.

Neither ordination nor classification analyses were substantially altered by the inclusion or omission of stocked Australian bass from the data set (Figs 3.5 and 3.6). This conclusion was supported by a significant Spearman rank correlation between similarity matrices with Australian bass included and omitted ($R = 0.979$, $p < 0.01$), indicating that stocking Australian bass has had little effect on the upstream fish communities.

Table 3.4 Summary of analysis of similarity of fish communities in designated reaches of the Shoalhaven system.

Comparisons	**R**	***p***
Among reaches	0.788	< 0.001
Pairwise comparisons		
Mongarlowe River *v* Shoalhaven River upstream	0.997	0.002
Mongarlowe River *v* Kangaroo River	0.991	0.002
Mongarlowe River *v* Lake Yarrunga	0.996	< 0.001
Mongarlowe River *v* downstream of Tallowa Dam	1.000	0.001
Shoalhaven River upstream *v* Kangaroo River	0.353	0.004
Shoalhaven River upstream *v* Lake Yarrunga	0.846	< 0.001
Shoalhaven River upstream *v* downstream of Tallowa Dam	0.883	< 0.001
Kangaroo River *v* Lake Yarrunga	0.559	< 0.001
Kangaroo River *v* downstream of Tallowa Dam	0.877	< 0.001
Lake Yarrunga *v* downstream of Tallowa Dam	0.98 3	< 0.001

Table 3.5. Contributions of species to the dissimilarity between fish assemblages in different reaches. Stocked fish were omitted from this analysis. Consistency ratio indicates the consistency with which species distributions discriminate between reaches, with larger values indicating greater consistency. The cumulative percentage column indicates the cumulative contribution of species to the average dissimilarity between reaches. Average dissimilarity (D %) between reaches is expressed as a percentage ranging from 0 (identical) to 100 (totally dissimilar).

Species	**Mean abundance**		**Consistency ratio**	**Cumulative %**	**D %**
Mongarlowe River v rest of the catchment					
	Mongarlowe	Remainder			85.4
Retropinna semoni	0.00	304.60	3.38	22.77	
Philypnodon grandiceps	0.00	65.55	1.56	34.84	
Galaxias brevipinnis	5.00	0.00	1.50	42.13	
Gobiomorphus coxii	0.00	9.79	1.09	48.56	
Gambusia holbrooki	4.75	1.95	1.36	54.83	
Cyprinus carpio	0.00	4.78	1.45	60.87	
Hypseleotris klunzingeri	2.50	0.02	1.48	66.71	
Anguilla reinhardtii	2.50	27.85	1.52	70.74	
Upstream[a] v downstream of Tallowa Dam					
	Upstream[a]	Downstream			56.5
Mugil cephalus	0.00	89.86	4.95	13.42	
Macquaria novemaculeata	0.00	75.85	4.53	25.75	
Gobiomorphus australis	0.00	14.58	4.09	34.57	
Myxus petardi	0.00	31.83	1.51	43.29	
Philypnodon grandiceps	73.62	44.03	1.33	50.53	
Anguilla reinhardtii	7.95	80.94	1.54	56.59	
Gobiomorphus coxii	4.75	23.21	1.39	62.45	
Retropinna semoni	250.41	449.11	1.24	68.15	
Cyprinus carpio	2.52	10.80	1.38	72.70	
Anguilla australis	0.40	3.53	1.12	76.49	
Philypnodon sp.1	2.72	0.42	1.15	80.18	
Riverine[a] v lacustrine habitats upstream of Tallowa Dam					
	Riverine[a]	Lacustrine			39.4
Philypnodon grandiceps	27.59	119.66	1.69	23.34	
*Philypnodon sp.*1	0.63	4.81	1.86	36.46	
Gobiomorphus coxii	8.45	1.06	1.34	48.33	
Retropinna semoni	260.62	240.19	1.28	59.51	
Cyprinus carpio	1.94	3.09	1.23	68.43	
Tandanus tandanus	0.00	1.69	1.21	77.16	
Anguilla reinhardtii	12.46	3.44	1.24	85.83	

[a] Upstream sites for these analyses excluded the Mongarlowe River because this site had already been established as distinct.

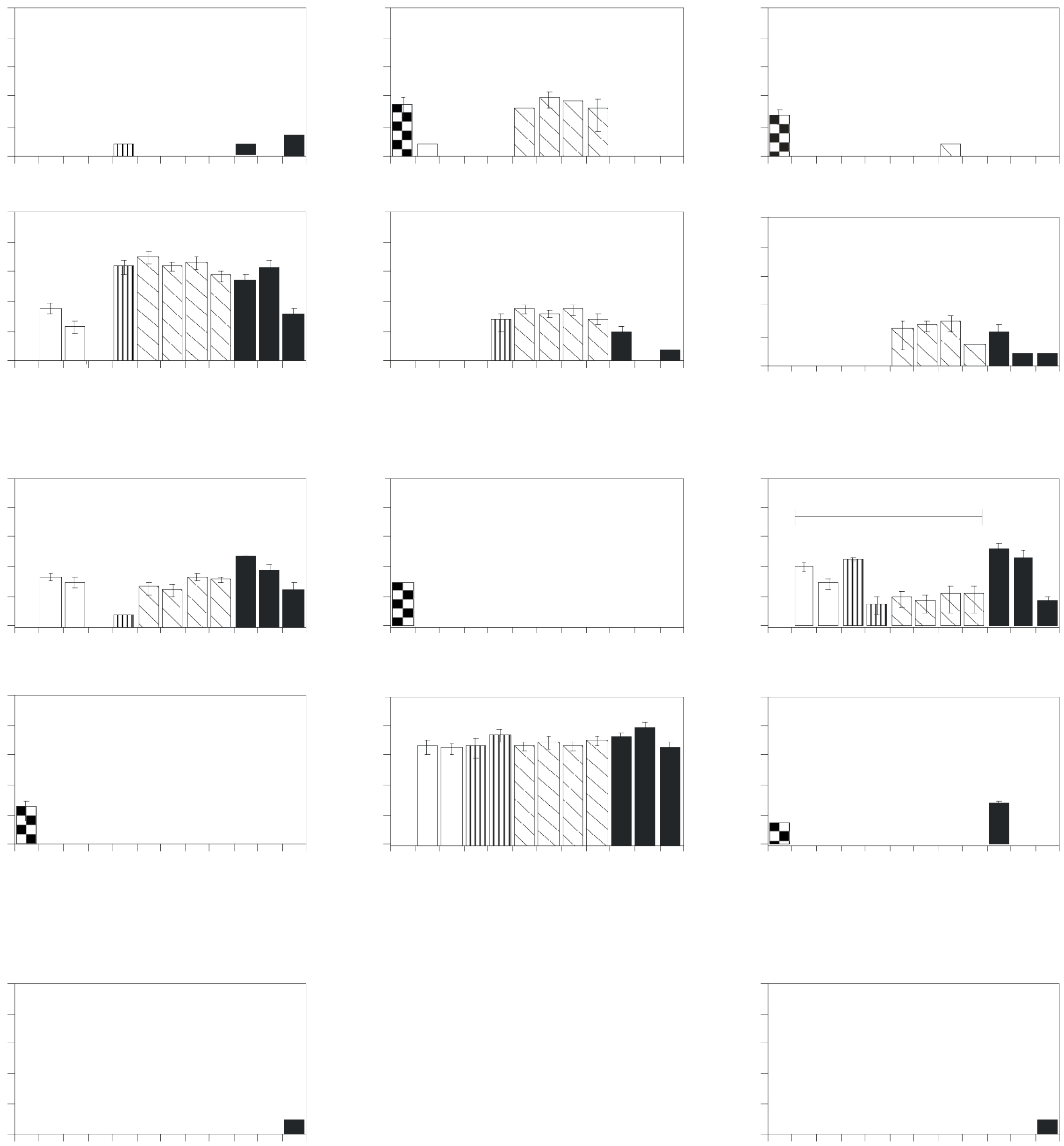
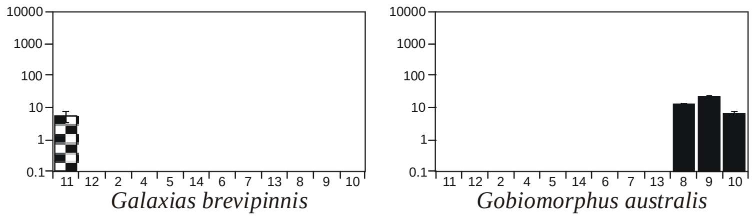


Figure 3.4 Mean catches (± SE) of individual species at sites upstream and downstream of Tallowa Dam. C represents species capable of climbing the dam wall. S represents fish that have been stocked. Mongarlowe River (chequered); Shoalhaven River upstream (hollow); Kangaroo River (vertical hatching); Lake Yarrunga (oblique hatching); Shoalhaven River downstream of dam (solid).

Amphidromous



Catadromous

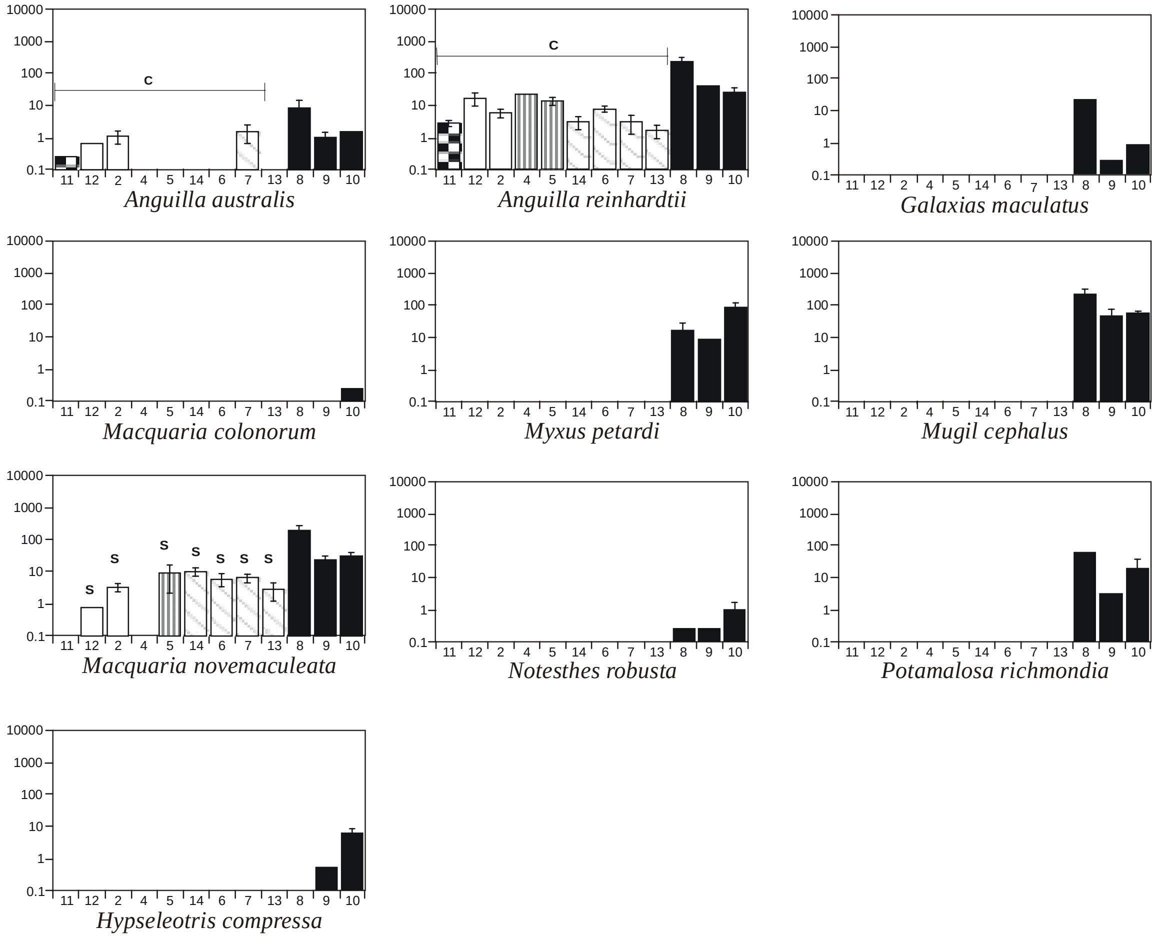
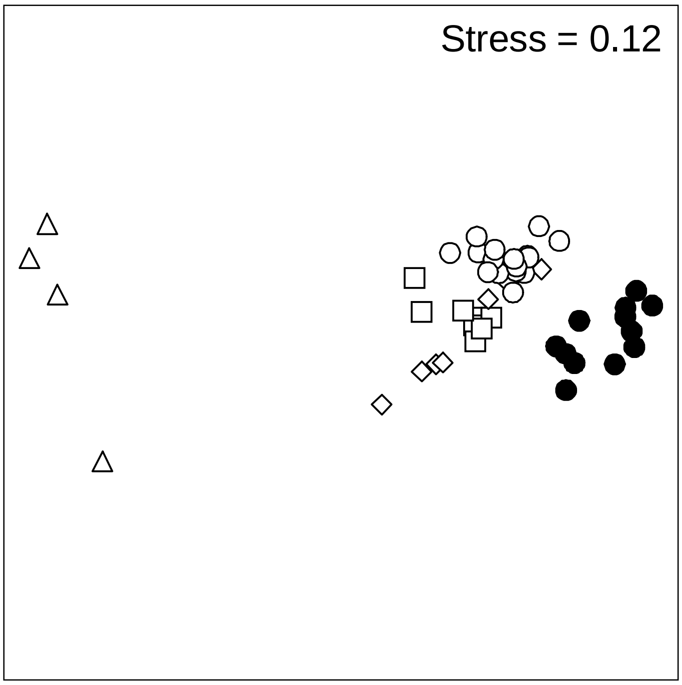
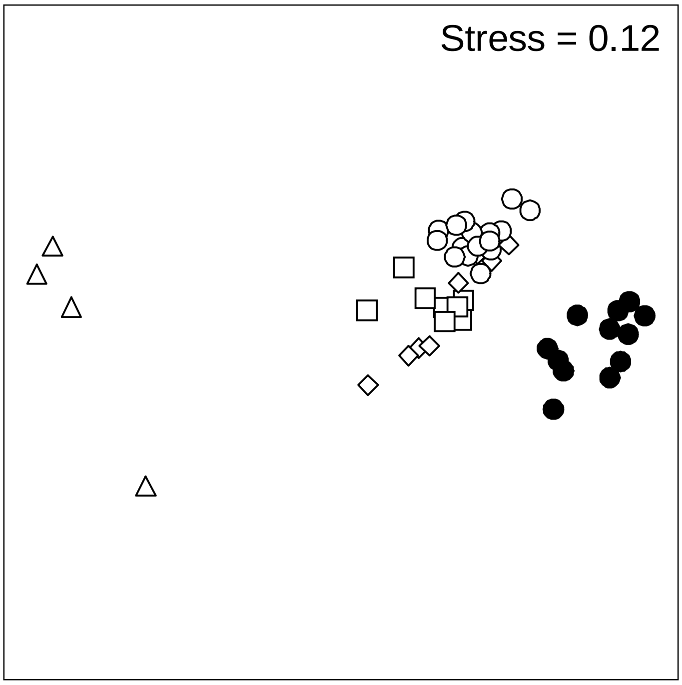


Figure 3.4 (cont.) Mean catches (± SE) of individual species at sites upstream and downstream of Tallowa Dam. C represents species capable of climbing the dam wall. S represents fish that have been stocked. Mongarlowe River (chequered); Shoalhaven River upstream (hollow); Kangaroo River (vertical hatching); Lake Yarrunga (oblique hatching); Shoalhaven River downstream of dam (solid).



(*a*)



(*b*)

Figure 3.5 MDS ordinations of species abundances from sites in Shoalhaven River system, based on similarities among fish communities. (a) Fish communities sampled in this study, (b) as for (a) but with Australian bass omitted from data for upstream sites to negate the effects of stocking. Mongarlowe River (+); Shoalhaven River upstream ('); Kangaroo River ((); Lake Yarrunga (∗); Shoalhaven River downstream of dam (#).

Of the species that were abundant both upstream and downstream of the dam, carp was the only species that showed no difference in size distributions of individuals upstream and downstream (Kolmogorov-Smirnov test $p = 0.977$) (Fig. 3.7). Differences in population size-structure were highly significant ($p<0.0001$) for long-finned eels and Cox's gudgeon, with a large proportion of small individuals downstream of the dam (Fig. 3.7). The modal population size of flat-headed gudgeon and Australian smelt were significantly lower downstream of Tallowa Dam (Fig. 3.7). The size-structures of Australian bass populations were also significantly different, with a stronger modal pattern upstream reflecting growth of stocked cohorts.

3.4.4. Temporal differences between historical and contemporary assemblages

Temporal comparisons between reconstructed historical and contemporary fish communities, based on binary data matrices, revealed substantial changes associated with the construction of the dam. In contrast to the discontinuous distribution of contemporary fish communities, the fish community before the dam was built demonstrated greater than 80% similarity among most sites within the river system (Fig. 3.6*a*), with only the Mongarlowe River site having lower similarity. The Mongarlowe River fish community showed less than 40% similarity with other sites because of its distinct high-elevation species assemblage. This assemblage has been maintained since the construction of Tallowa Dam (Fig. 3.6). The only significant difference among fish communities before the construction of Tallowa Dam occurred between the Mongarlowe River site and the remaining sites (ANOSIM: $R = 0.562$, $p = 0.005$). Other sites showed no evidence of a discontinuity in species distributions before the dam was built (Fig. 3.6*a*). Comparing classification analyses of fish distributions before and after dam construction confirms that the dam represents a critical discontinuity in contemporary fish communities.

3.5. Discussion

This study has identified a number of characteristics of the fish communities of the Shoalhaven River system which indicate damaging effects of Tallowa Dam. These include: (i) a reduced species richness upstream of the dam because of localised extinction of non-climbing diadromous fish (Figs 3.2 and 3.4); (ii) accumulations of fish directly below the dam wall (Figs 3.3, 3.4 and 3.7); (iii) divergence of population size-structures of species that live upstream and downstream of the dam (Fig. 3.7); (iv) creation of an artificial discontinuity between fish communities upstream and downstream of the dam (Fig. 3.6); and (v) creation of a divergence between fish communities in lacustrine habitats of Lake Yarrunga and in riverine habitats upstream of the dam.

The biodiversity of the river system in the upper 75% of the Shoalhaven catchment has been reduced by the extinction of ten migratory species upstream of Tallowa Dam. Natural populations of striped mullet, freshwater mullet, common galaxias, striped gudgeon (*Gobiomorphus australis*), empire gudgeon (*Hypseleotris compressa*), Australian bass, bullrout, short-headed lamprey, Australian grayling and freshwater herring (*Potamolosa richmondia*) are believed to be extinct above Tallowa Dam. Cox's gudgeon, short-finned eels and long-finned eels accumulate in large numbers below the dam, despite their ability to climb barriers (Beumer, 1996; Larson and Hoese, 1996), and are significantly less abundant upstream of the dam.

Empire gudgeons were previously thought to be as potamodromous, with migrations confined to freshwater reaches of rivers (Marsden *et al*., 1997). However, compelling evidence shows that the species should be re-classified as catadromous because: (i) it becomes extinct above barriers to fish passage; (ii) adults spawn in freshwater (Auty, 1978; Leggett and Merrick, 1987); (iii) larvae do not survive in freshwater aquaria for more than 11 days (Auty, 1978; Leggett and Merrick, 1987); (iv) small juveniles have been observed in estuaries and migrate upstream from estuaries in large numbers (Herbert *et al*., 1995); (v) Genetic analyses indicate little population substructuring between river systems (McGlashan and Hughes 2000), suggesting an estuarine or marine migration phase or frequent mixing of populations between rivers.

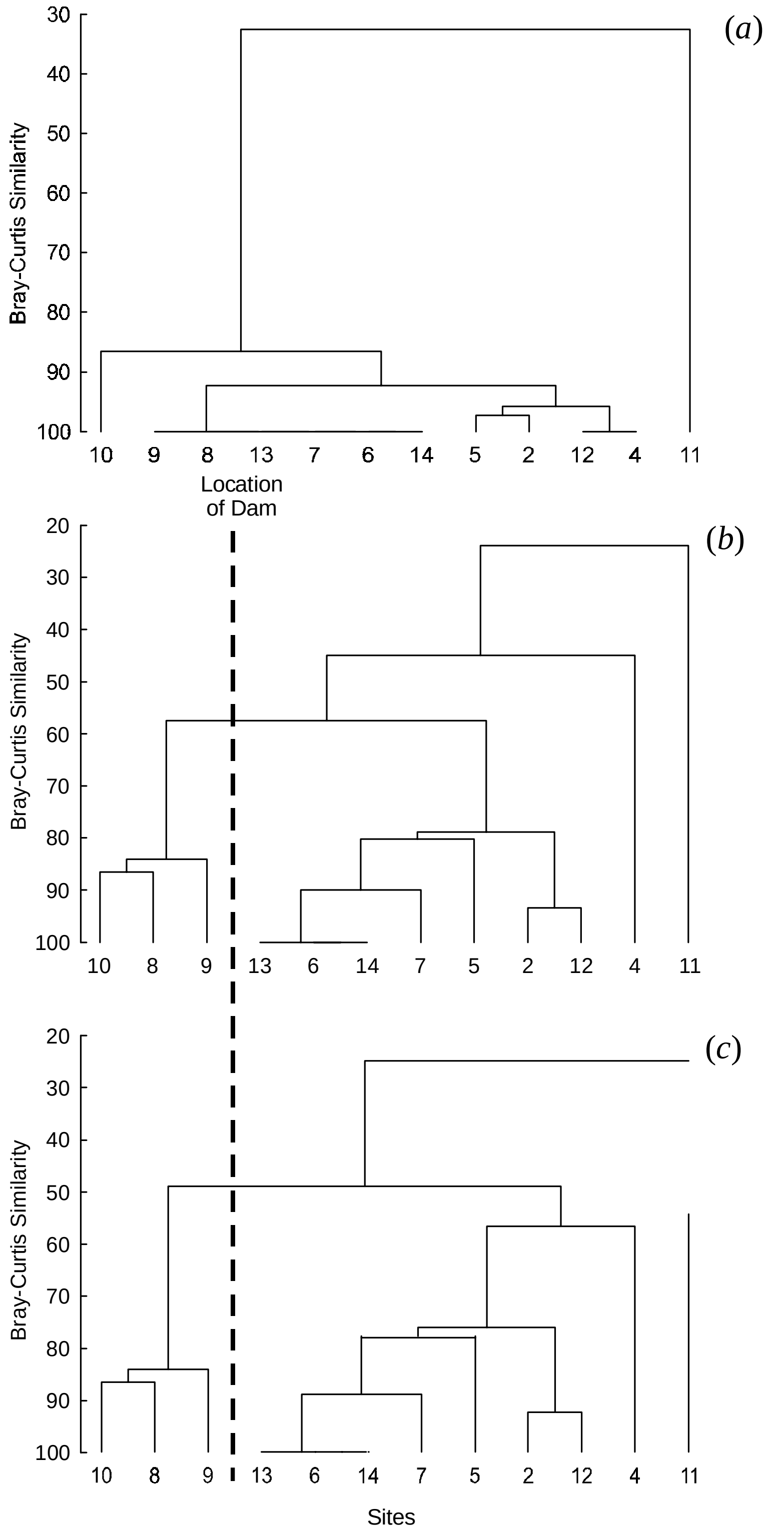


Figure 3.6 Classification analysis of sites in the Shoalhaven River system based on similarities among binary fish community data: (a) reconstructed fish community based on species distributions in the absence of Tallowa Dam; (b) fish communities sampled in this study; and (c) as for (b) but with stocked populations of Australian bass omitted from the data set.

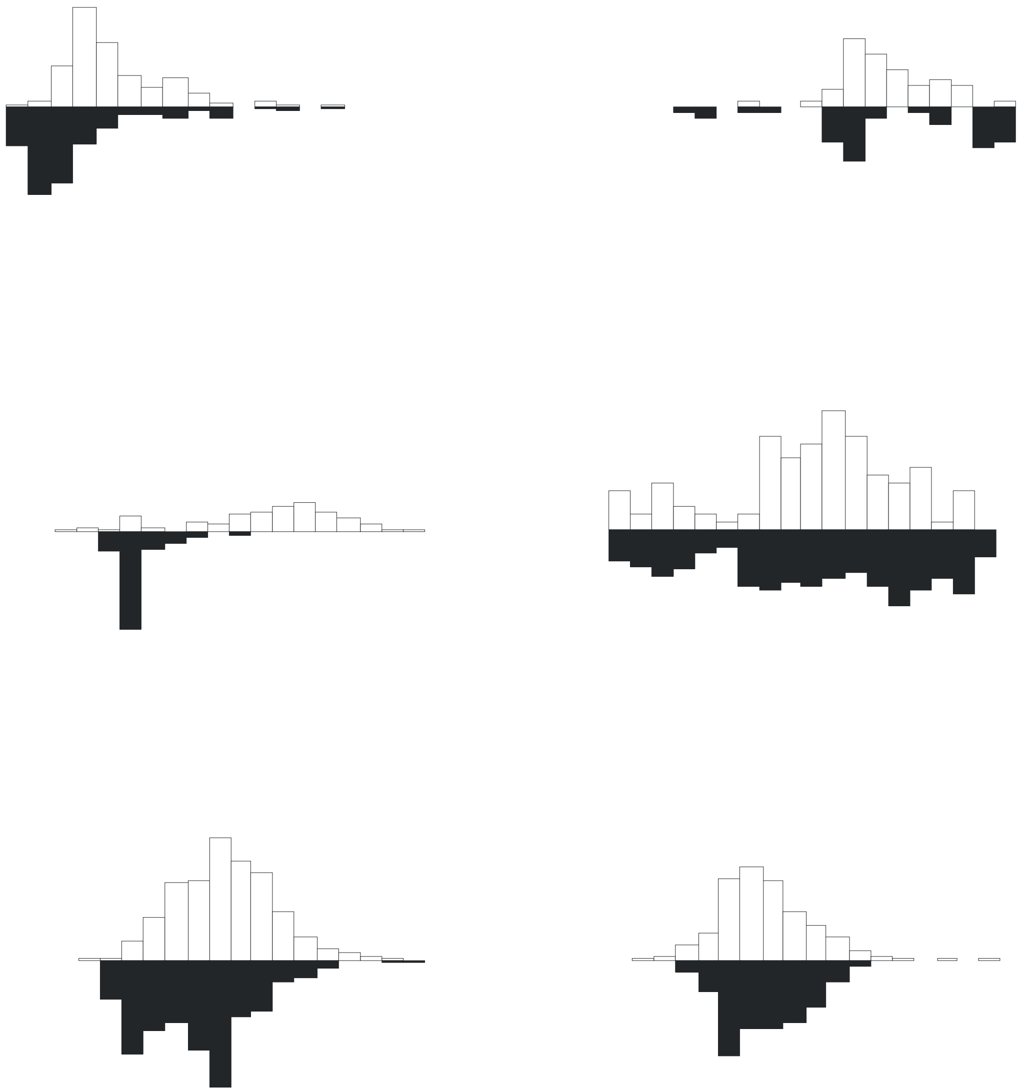


Figure 3.7 Length frequency distributions of six species from sites upstream and downstream of Tallowa dam. All species except carp (*Cyprinus carpio*) show significantly different size distributions between upstream (hollow) and downstream (solid) populations. * $p < 0.05$, *** $p < 0.0001$.

Declines in fish communities upstream of high dams are common worldwide, but few cases have been well-documented. In a study of dams in Puerto Rican rivers (Holmquist *et al.* 1998), all native species apart from a climbing goby (*Sicydium plumieri*) were unable to migrate past dams and became extinct upstream. Furthermore, the goby was significantly less abundant upstream of dams. Similarly in the Nidd/Ouse River system in Yorkshire, populations of Eurasian dace (*Leuciscus leuciscus*) and gudgeon (*Gobio gobio*) declined dramatically upstream after construction of a dam prevented return from their over-wintering habitats (Axford, 1991). Allibone (1999) reported that even New Zealand long-finned eels (*Anguilla dieffenbachii*) have disappeared from the upper Waipori River since the river was dammed to create a hydroelectric storage in Lake Mahinerangi. Downstream losses of biodiversity have also been widely reported. In Australia, the diversity of fish species in highly regulated rivers in New South Wales was significantly lower than in rivers with a more natural flow regime (Gehrke *et al.*, 1995; Gehrke and Harris, 2001). In the River Hoz Seca in Spain, populations of brown trout (*Salmo trutta*) became fragmented and were reduced by 43-50% as a result of altered habitats and changed flow regimes after the construction of a small hydroelectric power station (Almodóvar and Nicola, 1999). Fish in the Sinnamary River in French Guiana also showed a reduction in species diversity and changes in relative abundance after the closure of a dam in 1994 (De Mérona and Albert, 1999).

In addition to the effects of Tallowa Dam on fish communities upstream of the dam, populations of migratory fish downstream experience density dependent effects. After completion of the dam, the accumulation of fish downstream led to increased fishing pressure from anglers targeting Australian bass (Harris, 1984). To reduce fishing mortality, the waters 300 m below the dam were closed to angling. In addition to human threats, piscivorous birds (Elson, 1962; Barlow and Bock, 1984; Kennedy and Greer, 1988; Feltham and Maclean, 1996) and disease epidemics (Welcomme, 1985; Moring, 1993) can also threaten accumulations of migrating fish below barriers to fish passage.

The fish community in the Mongarlowe River was composed of a small number of characteristically montane species. The abundance of all species at this site was also characteristically low. Two of these species, brown trout and short-finned eels were identified as characteristic montane species at elevations greater than 700 m in the South Coast region of New South Wales (Gehrke and Harris, 2000). Long-finned eels, climbing galaxias and mountian galaxias recorded in the Mongarlowe River are also commonly encountered in montane fish communities. At an elevation of 550 m, the Mongarlowe River site is considerably lower than other rivers characterised by montane fish communities. A steep gradient and large number of natural cascades and rapids within the Shoalhaven gorge may be responsible for the predominance of montane species at lower elevations.

In addition to localised extinction of migratory species upstream of dams (Ribeiro *et al*., 1995; Holmquist *et al*., 1998; Peter, 1998), fragmented populations upstream and downstream of dams often develop independent population structures (Almodóvar and Nicola, 1999). In the Shoalhaven River, differences in population size-structure were observed for five of the six species that occur in large numbers both upstream and downstream of Tallowa Dam, including migratory species such as Cox's gudgeon and long-finned eels which can climb the dam wall. Juveniles of non-climbing species, such as flat-headed gudgeon and Australian smelt also accumulate downstream of the dam and make no contribution to upstream populations.

The size-structure of the stocked population of Australian bass in Lake Yarrunga also differed from the natural population below Tallowa Dam (Fig. 3.7). The upstream population only exists because of stockings in 1990, 1994 and 1998. The stocked population has a more pronounced modal size-structure than the downstream population, representing stocked cohorts.

Stocking is commonly undertaken as a method for re-establishing fish populations (Hickley, 1994; Welcomme, 1998). However, in the Shoalhaven River, costs and logistics prohibit the stocking of ten locally extinct species and other species with depressed abundances to rehabilitate the degraded fish community upstream of the dam (Marsden *et al.*, 1997). This study suggests that from a conservation perspective, stocked Australian bass have little effect on the structure of existing fish communities, despite providing a recreational fishery for this species upstream of the dam. Because stocking fails to address the cause of declines in fish communities, stocking upstream of Tallowa Dam does not provide a long-term solution to the obstructed passage of migratory fish species in the Shoalhaven River.

Lacustrine habitats within Lake Yarrunga supported different species assemblages to riverine habitats in the Shoalhaven and Kangaroo Rivers. Lake Yarrunga provides a relatively stable habitat that did not exist before Tallowa Dam was built. It is common for impounded lakes to develop divergent biological communities from those that originally occurred in the river (Welcomme, 1985; Walker *et al.*, 1992; Sheldon and Walker, 1997).

The fish community in the upper Kangaroo River consisted of only long-finned eels, Cox's gudgeon and Australian smelt. The low species richness at this site is surprising. There are no apparent obstructions to fish passage between this site and Kangaroo Valley downstream, and the elevation (120 m) is similar to that of Tolwong Mines (130 m) where eight species were collected. It is possible that frequent flash flooding in the upper Kangaroo River displaces less resilient species. In the neighbouring Hawkesbury-Nepean River system, the three species encountered at this site are known to be tolerant of sporadic flow conditions (Gehrke *et al.,* 1999).

Reconstructed historical fish distributions suggest that before 1974, the fish community was relatively continuous from the tidal limit to at least 130 m elevation. Tallowa Dam now presents a major barrier to fish migration and has fragmented the fish community that existed previously. Similar fragmentation has been noted almost without exception following construction of dams elsewhere, both in Australia and overseas. In the rivers of south-eastern Australia, from the Mary River in Queensland to the Gippsland Lakes system in Victoria, 32% of the total smoothed valley length (range 2% - 95%, mean 35%) is upstream of physical barriers to fish migration (Harris, 1984). Depending on the size of the barriers, the number of diadromous species upstream was greatly reduced, or restricted to only those species able to climb dam walls (Harris and Mallen-Cooper, 1994) . Mallen-Cooper *et al.,* (1995) discussed the degree of fragmentation of riverine habitats in the Murray-Darling River system, and the effects on populations of silver perch. In the Araguaia-Tocantins River basin in Brazil, closure of the Tucurui Dam resulted in the virtual disappearance of curimata (*Curimata cyprinoides* and *C. amazonica*) and large catfish species (*Brachyplatystoma* spp., *Phractocephalus hemiliopterus* and *Pinirampus pirinampu*) upstream, with an initial 70% decline in fish production downstream of the dam (Ribeiro *et al.*, 1995). In this case, however, the large number of species (217) in the river system has enabled other species to increase in number above the dam.

It has been argued that increases in fish production in impounded waters more than compensate for the losses of migratory species and species that are poorly adapted to lentic habitats (e.g. Ribeiro *et al.*, 1995). Welcomme (1985), however, emphasised the tendency for dams to lower the net fisheries productivity of river ecosystems, and the initial increase in fisheries production following dam closure is unlikely to be sustainable (Ribeiro *et al.*, 1995). The argument in favour of compensation for lost species neglects the need to sustain biodiversity and to conserve threatened species and habitats. Locally extinct species cannot simply be replaced by other species to maintain the ecological integrity of a river system. In the Shoalhaven River, a combination of low species diversity (relative to diversity in other continents) and a high proportion of migratory species provides no opportunity for naturally occurring species to compensate for the local extinction of species upstream of Tallowa Dam. Consequently, the dam has not only altered habitats downstream of and within the storage, it has also contributed to a fundamental change in the ecology of the rivers upstream by reducing the biomass of predators, such as Australian bass, at or near the top of the food web.

A high-level fishway is currently being planned to restore fish passage at Tallowa Dam. The results of the presents study will enable the effectiveness of the fishway in rehabilitating fish communities of the river system to be evaluated in the future.

4. MOVEMENTS OF AUSTRALIAN BASS (*Macquaria novemaculeata*) AND STRIPED MULLET (*Mugil cephalus*) IN THE SHOALHAVEN RIVER, ASSESSED USING RADIO TELEMETRY.

4.1.1. Summary

Movements of Australian bass and striped mullet in the Shoalhaven River system were studied using radio telemetry to obtain detailed information on the migratory behaviour of these species downstream of a dam. A uniquely coded radio-transmitter was surgically implanted into the abdominal cavity of each fish. Tagged Australian bass remained near the base of the dam wall and exhibited limited small-scale spatial movements, with a mean monthly distance travelled of 1,571 ± 75 m from September 1999 through to March 2000. Similarly, striped mullet did not make any regular large-scale movements either upstream or downstream from their place of capture, although with a mean monthly distance travelled of 2,892 ± 71 m, they travelled further than Australian bass. Neither species was observed to undertake population scale movements attributable to seasonality within the period sampled. One striped mullet that disappeared from the river was subsequently captured by a commercial fisher in Fingal Bay, over 300 km from the point of release.

Within the complex pool and rapid environment at the base of Tallowa Dam, Australian bass congregated within the flow discharged from the base of the dam in preference to flow from over the spillway. Flow appears to be the major factor attracting Australian bass to the base of the dam, despite the lower temperature of water released from the outlet valve. No tagged striped mullet were recorded near the base of the dam. Juveniles of both species, too small to be tagged, were recorded in large numbers below the dam.

4.2. Introduction

A large number of the freshwater fish species native to southeastern Australia are diadromous, requiring the ability to migrate between freshwater and salt water to complete their life-cycles (McDowall 1996). Dams, weirs and culverts prevent migration of many diadromous species, although species such as long-finned eel (*Anguilla reinhardtii*) short-finned eel (*Anguilla australis*), Cox's gudgeon (*Gobiomorphus coxii*) and climbing galaxias (*Galaxias brevepinnis*) that are capable of climbing barriers are less affected (Harris 1984, Mallen-Cooper 1992). Both natural and artificial barriers can impede fish passage, resulting in fragmentation of fish populations, interruption of gene flow, or localised extinctions (Marsden and Gehrke 1996). Obstruction of fish passage is widespread in eastern New South Wales, with approximately fifty percent of riverine aquatic habitat being described as inaccessible to diadromous fish because of man-made structures (Harris 1984). Since 1985, fish passage technology has been developed and applied to many rivers in New South Wales to rehabilitate fish communities (Mallen-Cooper 1992, Harris and Mallen-Cooper 1994).

Tallowa Dam was constructed in 1976 at the confluence of the Shoalhaven and Kangaroo rivers on the southeast coast of New South Wales, Australia (34^{o} 47' S: 150^{o} 19' E) (Fig. 4.1). The dam is a concrete gravity structure 43 m high, 520 m long and 50 m wide at the base. The spillway is a fixed-crest overshot design 350 m long and 32 m high, with a maximum slope of 55 ^{o}. The

Figure 4.1. Location map of Lake Yarrunga and the reaches downstream of Tallowa Dam.

dam created a barrier to upstream migration for many diadromous fish species within the system. Marsden *et al.* (1997) recommended construction of a high-level fishway to restore fish passage at the dam. An understanding of the migratory behaviour of fish species with respect to the dam is required to maximise the efficiency of the proposed fishway. Although knowledge of fish migrations in New South Wales has improved dramatically in recent years (Reynolds 1983, Harris 1984, Harris 1988), small-scale movements of most species within rivers have not been studied in detail. Significant advances in understanding of migrations have been made recently for Murray cod and trout cod using radio telemetry (Koehn 1995). This study investigates daily and monthly movement patterns of striped mullet and Australian bass using radio telemetry to assist with the location, design and operation of a fishway on Tallowa Dam.

4.3. Methods

4.3.1. Species selection

Previous studies have recommended that radio transmitters weigh no more than 2% of the fish's body weight (Knights and Laysee 1996). Australian bass and striped mullet were used in this study because they are important migratory species. Both species are present in sufficient numbers to be easily caught downstream of the dam at sizes large enough to carry radio transmitters. These species were also present in upper reaches of the river before the dam was built and have since become locally extinct above the dam. The annual excursion of adults to saline waters to breed, and subsequent migration of both adults and juveniles into upper reaches mean they are also likely to use the proposed fishway.

4.3.2. Telemetry system

Radio tagged fish were tracked using a R2000 receiver and a loop antenna (Advanced Telemetry Systems, Isanti, Minnisota). The directional nature of tracking equipment enabled exact locations of stationary fish to be determined to within 5 m. Model 10-12 transmitters (Advanced Telemetry Systems, Isanti, Minnisota) have a rated battery life of 100 days. To extend battery life and enable the study to be conducted over a longer time period, transmitters were programmed on a duty cycle of 7 days on, 21 days off. Each cylindrical transmitter was 28 mm long and 12 mm in diameter, and weighed approximately 6 g. Field tests indicated that the range varied from 200-300 m, depending on background noise. Each transmitter was set with a specific frequency in the range of 48-50 kHz, allowing identification of individual fish.

4.3.3. Surgical procedures

Surgical procedures were adapted from those of previous studies (Lucas 1989, Haeseker *et al.* 1996, Knights and Lasee 1996, Walsh *et al.* 2000). Fish were anaesthetised using a 0.5 ppt benzocaine solution, then placed ventral side up in a cradle to stabilise the body during surgery. A tube was inserted in the mouth supplying a gentle flow of aerated benzocaine solution (0.25 p.p.t.) over the gills. A ~30 mm long incision was made on the lower right flank with the centre of the incision in line with the tip of the pelvic fin. The transmitter was inserted with the antenna protruding from the posterior end of the incision. The incision was then closed with five to six sutures, swabbed with Betadine, and sealed with surgical glue (Vetbond). An external spaghetti tag was inserted to the left of the dorsal fin, to assist identification of tagged fish upon capture. Fish were weighed, measured and given an intra-peritoneal injection of oxytetracycline (50 mg kg^{-1}: Roscocycline-5), before being placed in a 15 ppt salt solution to recover. Average duration of surgery was 10 minutes. Antiseptic conditions were maintained through strict sterilisation procedures. Before surgery, all transmitters and surgical instruments were scrubbed in a high concentration salt bath, sterilised in a 70% ethanol solution, then rinsed in a low concentration oxytetracycline solution. Gloves were worn at all times, and scalpel blades and suture material were replaced for each fish.

Surgical procedures adopted were refined during a pilot study designed to examine survival and transmitter retention rates. Twenty-eight fish were collected for the study, consisting of sixteen striped mullet and twelve Australian bass. Five mullet and four bass were implanted with dummy transmitters of similar dimensions, mass and coating to live transmitters. A further five mullet and four bass were operated on, but with no tag inserted (sham-operated). Three mullet and two bass were not operated on, but were anaesthetised and put in the operating harness for 10 minutes (average duration of operating time) before being revived (control-unoperated). A further three mullet and two bass were not operated on or anaesthetised, but were weighed and measured (control-untouched). Fish were then held in 4,500L tanks and observed for one month.

Results of the pilot study are shown in Table 4.1. Survival of Australian bass was 100% in all groups. Survival of striped mullet was lower, ranging from 0% in sham-operated mullet, to a maximum of 60% in fish with dummy transmitters inserted. It was noted that all control and sham-operated fish developed fungal infections. Fish with dummy transmitters were not observed to suffer fungus infection, possibly attributed to oxytetracycline injections administered to fish within this group. Mortalities within unoperated controls and untouched controls indicate water quality or disease to be the main factors contributing to mortalities. On the basis of these findings survival of tagged Australian bass can be expected to be approximately 100%, whilst survival of tagged striped mullet may exceed 60%. Transmitter retention was 100% in both species, indicating a low risk of tag expulsion by fish released into the river.

4.3.4. Telemetry procedures

Radio transmitters were implanted in 18 Australian bass and 18 striped mullet between 21 and 23 September, 1999. Australian bass were caught and tagged immediately below the dam wall, whereas striped mullet were captured near Grady's Riverside Retreat, 27 km downstream of the dam. Tagged fish were released at the point of capture. Radio tracking was conducted for three days every 4 weeks from the 21 September 1999 to 8 March, 2000 beginning at the base of Tallowa Dam and progressing continuously downstream towards the estuary. Tracking was conducted from a canoe in the upper reaches to negotiate rapids, and from an outboard-powered punt downstream from Coolendel to the salt water limit approximately midway between Grady’s and Nowra. The actual location of the salt water limit varied with flow conditions and tide. Radio frequencies emitted by the transmitters used could not be detected in even moderate salinities. The receiver automatically scanned the pre-programmed frequencies of each of the 36 transmitters for 2 seconds each, taking a total of one minute and sixteen seconds to complete each scan. Once fish were located, the date, location description and latitude/longitude (± 100 m) were recorded using a hand-held global positioning system (Lowrance, Globalnav 212). The complex river environment below the dam included (Fig. 4.2), a cold water pool fed by cold water from the outlet at the bottom of the wall, two warm water pools below the southern end of the wall, a mixing pool at the confluence of the warm and cold water pools, and a spillway trench immediately below the dam wall. Each tracking pass from Tallowa Dam to the estuary took approximately one day to complete. Tracking was conducted for three consecutive days each month where possible to record daily movements as well as monthly patterns. On three occasions weather and flow conditions allowed only two full scans of the river to be completed.

4.3.5. Analytical methods

Positions of located fish were plotted within a GIS (Mapinfo Professional 5.5) in separate layers for each species and transposed against the drainage and catchment data. Distances from the dam wall for all detected individuals were determined by scaling along an approximate river centre line from the cold water discharge point directly below the dam wall. This allowed upstream or

Table 4.1. Survival of striped mullet and Australian bass used in the pilot study.

		n	Week 1	Week 2	Week 3	Week 4	Week 5	Survival %
M. cephalus	Dummy	5	5	4	3	3	3	60
	Sham	5	2	1	0	0	0	0
	Unoperated	3	2	1	1	1	1	33
	Untouched	3	1	1	1	1	1	33
M. novemaculeata	Dummy	4	4	4	4	4	4	100
	Sham	4	4	4	4	4	4	100
	Unoperated	2	2	2	2	2	2	100
	Untouched	2	2	2	2	2	2	100

downstream movement to be determined by calculating the distance traveled from the last detected position for each individual. Mean distances travelled over each month and the daily mean distances travelled were determined for individual fish.

Detection frequencies of individual Australian bass were calculated within each of the five regions below the dam wall. Pool preference was assessed using a log likelihood G-test (Sokal and Rohlf 1995) comparing frequencies of occurrence within four of the five areas directly below the dam wall. The first warm water pool was not included in the analysis because Australian bass were not located within this pool.

4.4. Results

Two striped mullet (49.104 kHz and 49.144 kHz) either died or expelled the transmitter during the first month of the study. The signals from these individuals were found in exactly the same location (Fig. 4.3) on all occasions. These fish were subsequently used as in situ controls to check operation of tracking equipment, inter-operator reliability and transmitter battery life. The ability to locate these transmitters consistently confirmed that tracking methods were appropriate to detect all individuals in the main channel. If a fish was not detected, it was assumed that it had entered the estuary, or one of the two main tributaries of the lower Shoalhaven (Yalwal or Bugong Creeks), or that it had been removed from the system by anglers or predators. On 8 and 9 February 2000, low numbers of both species were detected along the standard transect so a single transect along the full length of Yalwal Creek was completed on 10 February to determine if any tagged fish had entered this tributary. No individuals of either species were located within this creek.

Three of the eighteen Australian bass (49.404, 49.444, 48.794 kHz) and seven of the eighteen striped mullet (49.344, 49.065, 49.063, 49.681, 49.184, 49.242, 49.621, 49.721 kHz) were only detected in the first month of sampling (September 1999) and were undetected thereafter (Figs 4.3 and 4.4). A further five Australian bass (48.734, 48.774, 48.834, 48.854, 49.044 kHz) and three striped mullet (49.164, 49.184, 49.641 kHz) were only detected in the first 2-3 months (Figs 4.3 and 4.4) before they disappeared.

Both Australian bass and striped mullet generally remained within the areas where they were captured and tagged (Fig. 4.5). Fourteen Australian bass were located immediately below the dam wall (Figs 4.5 and 4.6*a*) where they were captured and tagged. Only two striped mullet were detected near the dam on three monthly occasions (Fig. 4.6*b*). At other times, striped mullet were mainly detected within the vicinity of their capture and tagging site at Grady's (Fig. 4.5).

Australian bass moved over shorter distances than striped mullet (Fig. 4.7*a* and *b*). Mean distances travelled by Australian bass were 414 m $\pm$ 75 m day^{-1} and 1571 m $\pm$ 75 m month^{-1}. In comparison, striped mullet travelled 1204 $\pm$ 43 m day^{-1} and 2892 m $\pm$ 71 m month^{-1}).

These findings indicate daily movements of both species were within a home range, with infrequent excursions within the river beyond the home range undertaken by a small number of individuals (Fig. 4.7*a* and *b*). There were no trends in movements attributable to seasonality for either species, with fish undertaking excursions sporadically throughout September 1999-March 2000 (Fig. 4.7*a* and *b*). Further, no large-scale population movements were detected for either species (Fig. 4.7*a* and *b*).

Four of the eighteen Australian bass (48.734, 49.024, 48. 713, 48.854 kHz) made large-scale downstream movements (6,032 m, 28,309 m, 4,237 m, 34,491 m respectively) from their release point (Fig. 4.4). Equally considerable upstream movements (5,931 m, 28,167 m, 2,767 m respectively) were observed for three of these individuals (48.734, 49.024, 48.713 kHz) in the following month. The fourth (48.854 kHz) was not detected over the remaining sampling period (Fig. 4.4).

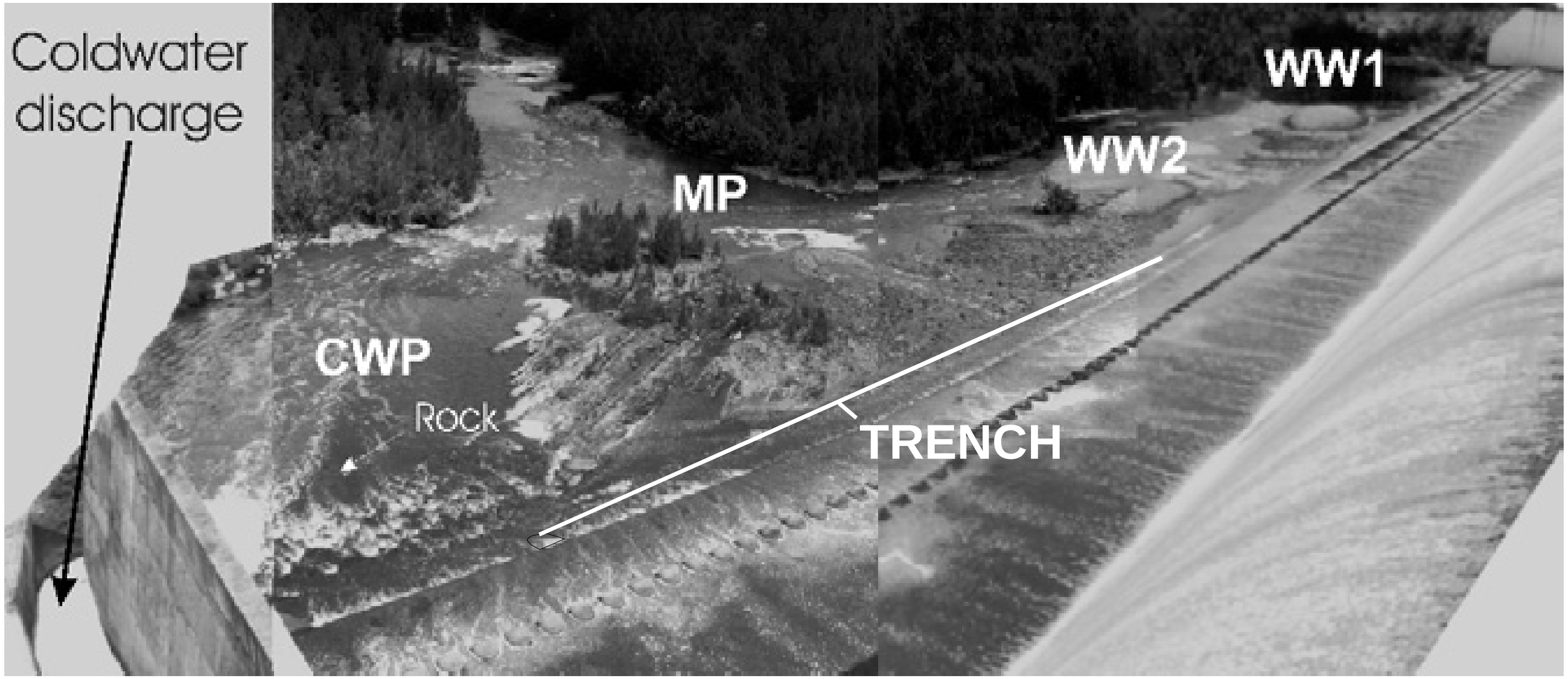


Figure 4.2. River environment immediately below Tallowa dam. Warm-water pools WW1 and WW2 are fed entirely from spillway flows. The cold-water pool (CWP) is fed largely from discharges from the base of the dam and some spillway flow. The mixing pool (MP) is fed from WW2, CWP and a small amount of spillway flow. The upstream limit of migration is the trench located immediately below the spillway. The rock identified within CWP is situated within spillway flows adjacent to the cold-water discharge. This is the site of accumulation of large numbers of Australian bass

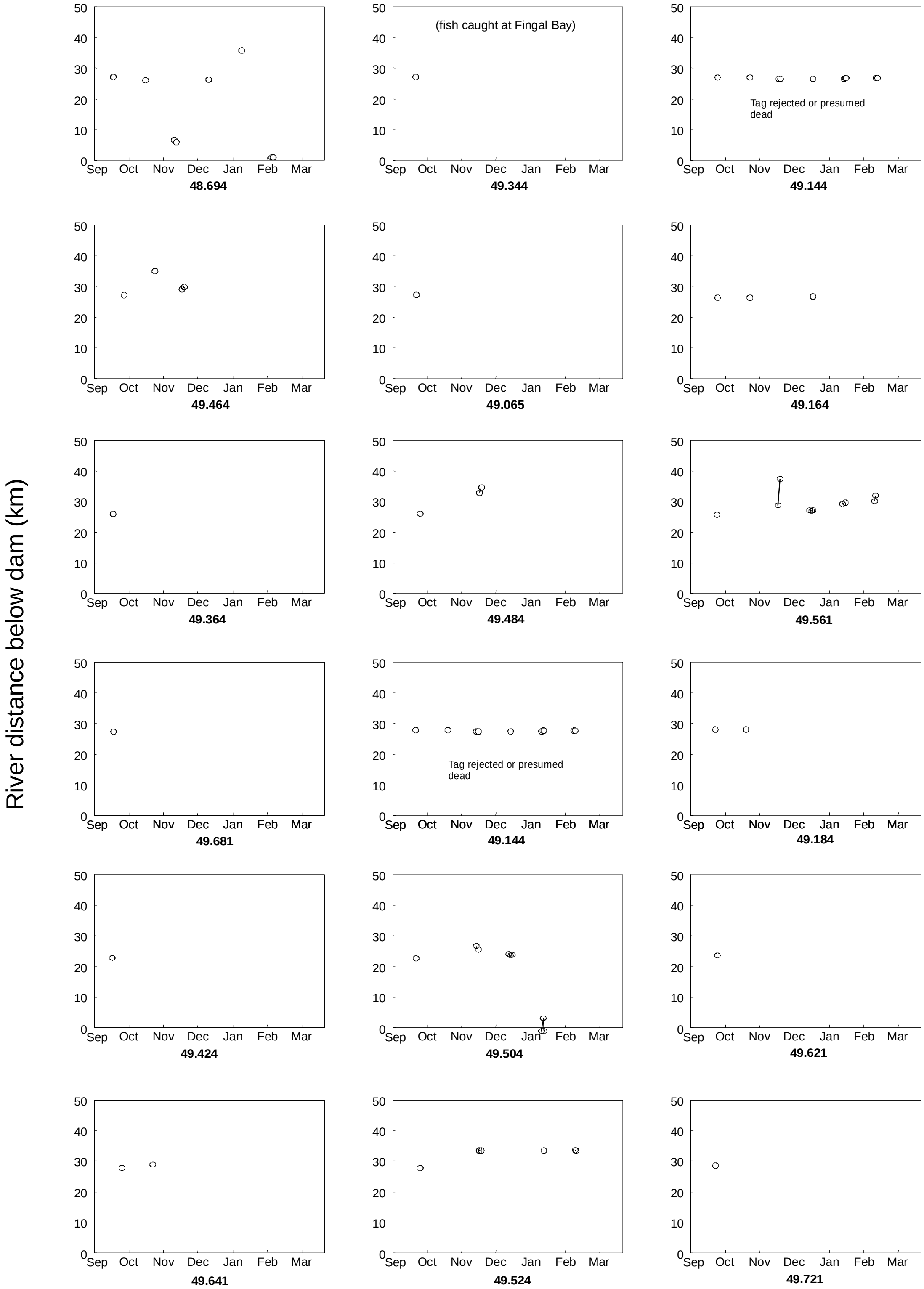


Figure 4.3. Individual trajectories of striped mullet between September 1999 and March 2000. The location of each fish on each sampling occasion is given as the distance below Tallowa Dam. The transmitter frequency of each tag is given below the graph for each fish.

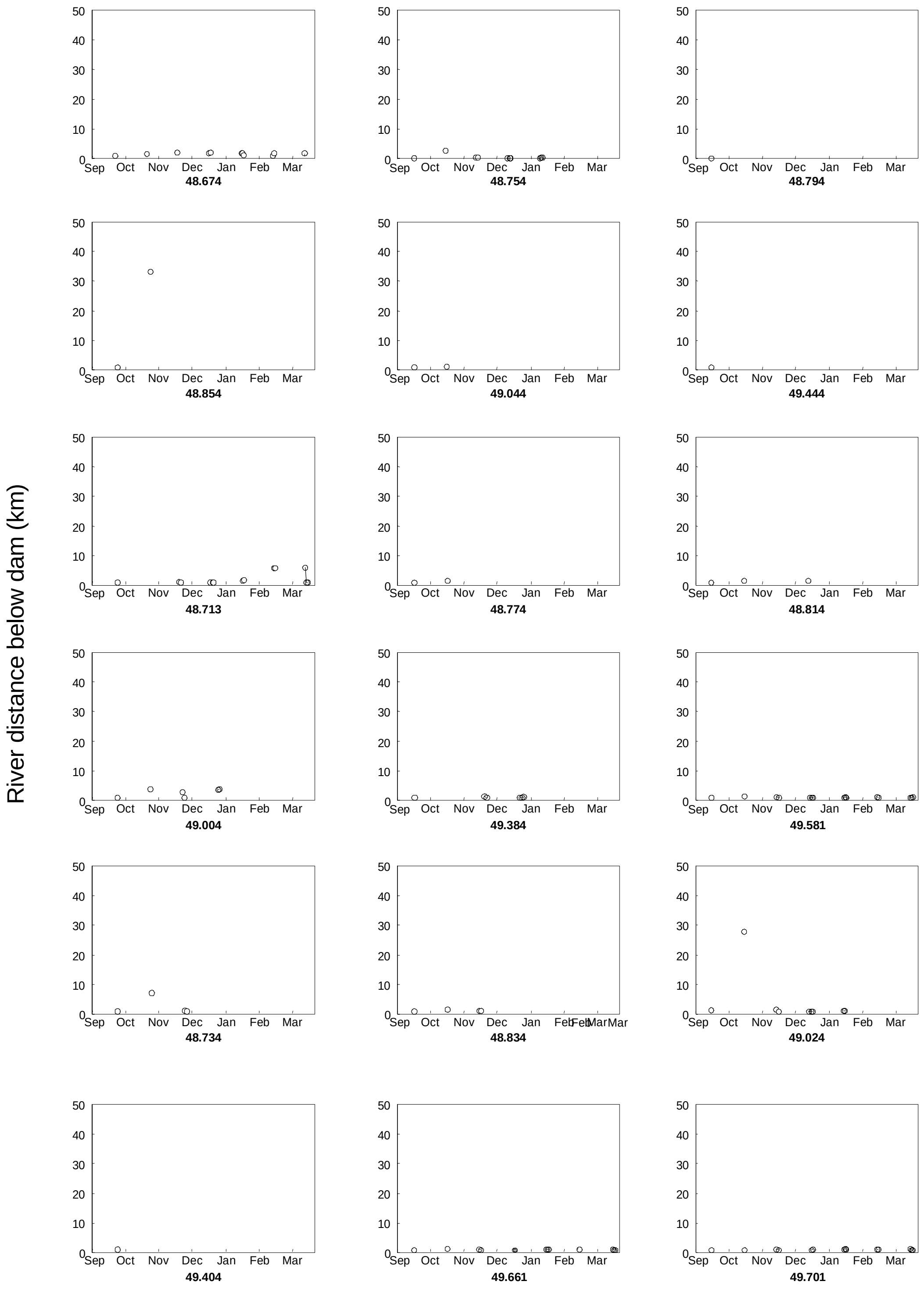


Figure 4.4. Individual trajectories of Australian bass between September 1999 and March 2000. The location of each fish on each sampling occasion is given as the distance below Tallowa Dam. The transmitter frequency of each tag is given below the graph for each fish.

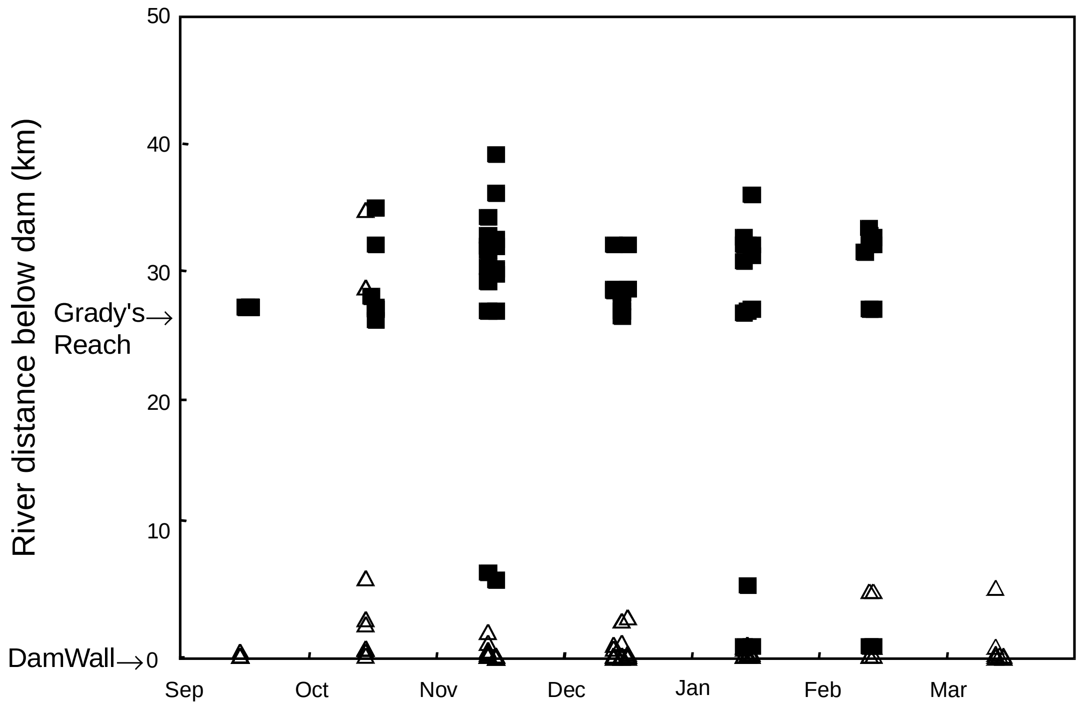


Figure 4.5. Distances from the dam wall of detected Australian bass (Δ) and striped mullet (■) between September 1999 and March 2000. The location of each detected fish on each sampling occasion is given as the distance below Tallowa Dam.

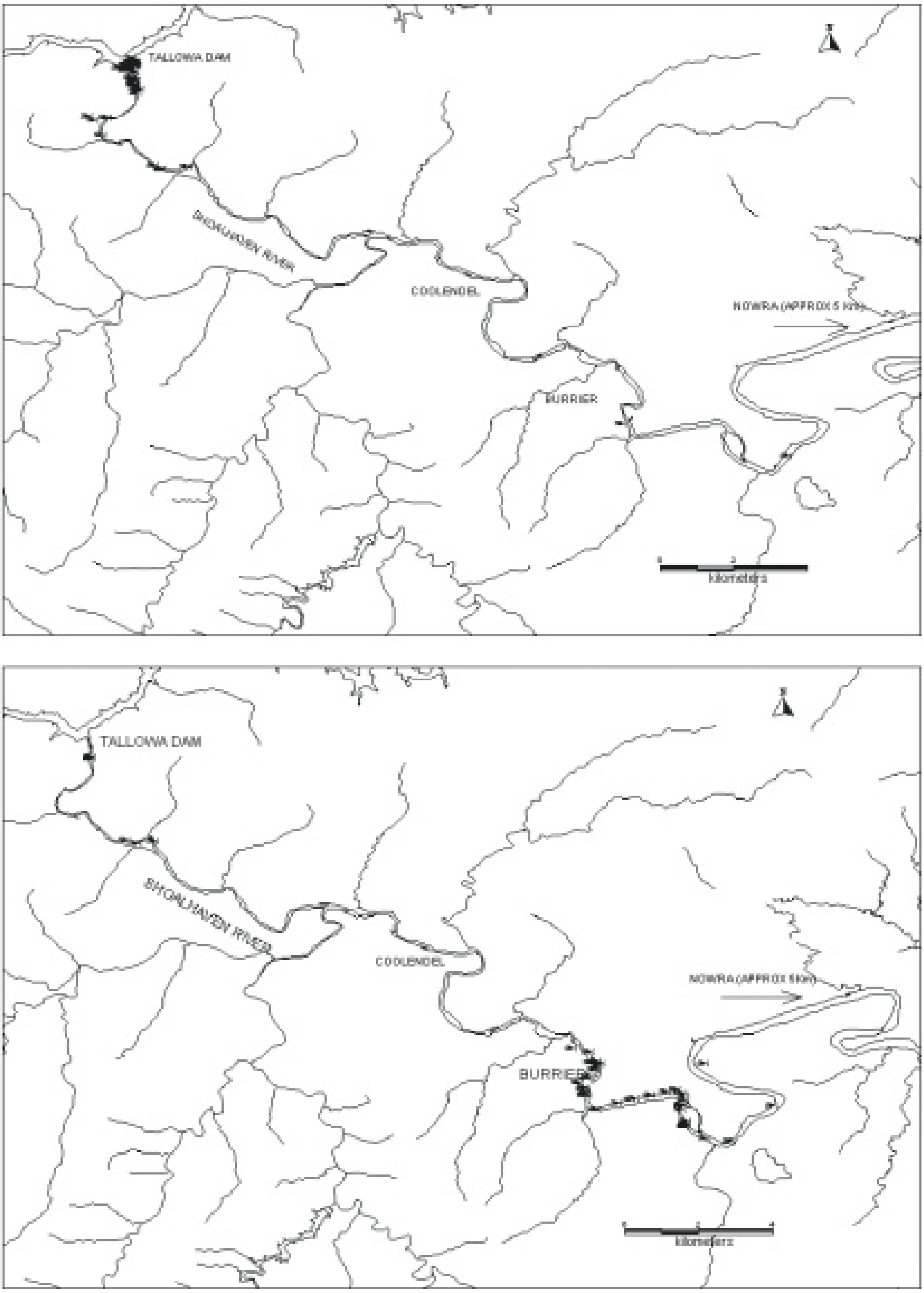


Figure 4.6. Detection location of *(a)* Australian bass and *(b)* striped mullet in Shoalhaven River downstream of Tallowa Dam.

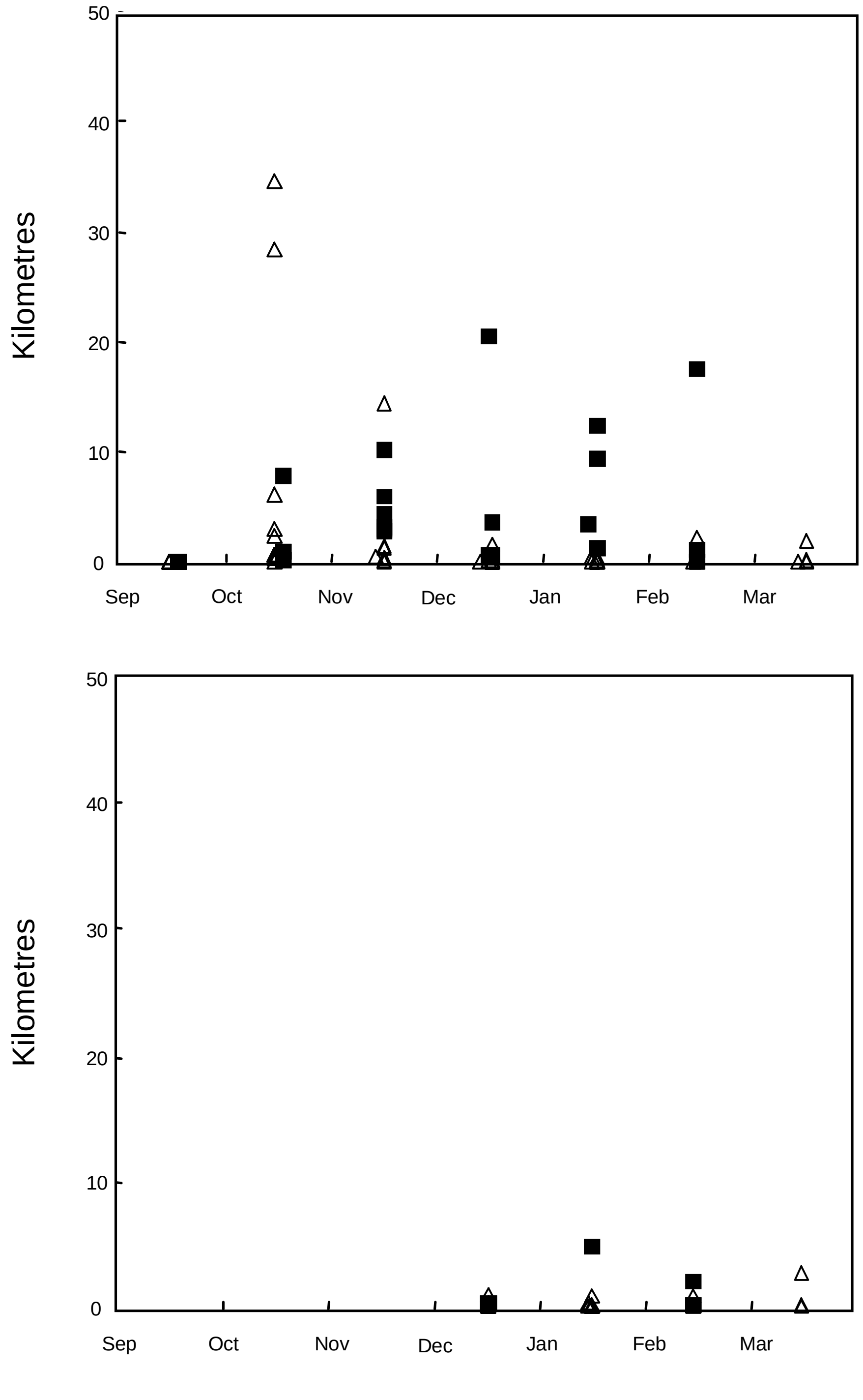


Figure 4.7. Distances travelled by individual Australian bass (Δ) and striped mullet (■) between September 1999 and March 2000, *(a)* Mean monthly distances travelled from last known location, *(b)* Mean daily distances travelled between consecutive days.

Two of the eighteen striped mullet (48.694, 49.504 kHz) made large-scale movements upstream (19,570 m, 27,641 m) from their release point (Fig. 4.3). One of these (48.694 kHz) made a subsequent large downstream movement (20,485 m) in December 1999, returning to the region immediately below the release point. This individual was later detected (February 2000) below the dam wall indicating a second large-scale movement upstream (35,064 m) had occurred. For the remaining sampling period both were undetected after arriving at the dam wall (Fig. 4.3). One striped mullet (49.344 kHz) was not detected at any time after release, but was subsequently recaptured by a commercial fisher in Fingal Bay, approximately 300 km north of the Shoalhaven River. Upon examination, the fish was in excellent condition and the surgical incision had completely healed.

Several large-scale downstream movements were also undertaken by individual striped mullet (Fig. 4.3) (49.464, 49.484, 49.561, 49.524 kHz), (7,735 m, 7,005 m, 3,114 m, 5,533 m respectively) followed by upstream movement to return to the vicinity of their release point (5,698 m, 1,844 m, 2,169 m, 3,443 m). Two of these individuals (49.464 and 49.484 kHz) went undetected following these upstream movements. The remaining two (49. 561, 49.524 kHz) continued to make intermittent small-scale movements throughout the period sampled (Fig. 4.3).

Individual Australian bass were detected more frequently (42%) than striped mullet (26%). Australian bass were more frequently detected within the five pools below the dam wall (72.1%) compared to reaches further downstream (22%)(Figs 4.5 and 4.6b). The log likelihood G-test for Australian bass indicated a significant difference ($p<0.001$) in the detection frequency between the five habitats below the dam wall. Australian bass were most frequently detected in the cold water pool (87.3%) with significantly smaller frequencies occurring in warm water pool two (5.06%) and equally small detection frequencies for both the trench and mixing pool (3.79%) (Figs. 4.5 and 4.6*b*).

Tracking was discontinued when battery failure made the transmitter signals too weak to detect.

4.5. Discussion

For intraperitoneal biotelemetry to be used to examine fish behaviour, it must be assumed that the presence of the transmitter itself does not alter the behaviour of the subject. This assumption has been shown to be valid in other species, based on a study examining the effects of intraperitoneally implanted dummy transmitters on the behaviour of Atlantic salmon (Moore *et al.* 1990), which found no effect on growth, feeding, swimming ability or general behaviour of fish examined. In contrast, Gowans *et al*. (1999) found that some Atlantic salmon migrated downstream to the estuary as a post-surgery response, indicating un-natural behaviour of tagged fish. As a preliminary study of the movements of Australian bass and striped mullet, it is assumed that detected movements reflect the natural behaviour of these species. However, this assumption requires more detailed investigation.

This study identified a tendency for adult Australian bass to accumulate directly below the cold water outlet at the dam wall. Conversely, striped mullet largely remained within the lower reaches where they were originally captured. Excursions of individuals from initial capture location were inconsistent for both species. Neither species showed any general tendency to travel far from their release point, although a small number of large excursions were recorded. These observations are consistent with those of previous studies (Harcup *et al.* 1984, Smithson and Johnston 1999) which found populations of brown trout (*Salmo trutta*), creek chub (*Semotilus atromaculatus*) black-spotted topminnow (*Fundulus olivaceus*) and green sunfish (*Lepomis cyanellus*) to remain largely within a home range, with a small proportion of populations undertaking large excursions, and this proportion constantly turning over. Harris (1988) reported that male Australian bass tend to establish home ranges in lowland river habitats, whilst females predominate in lagoons and upland lotic habitats, often returning to the same pool after spawning (Harris 1983). Three of the eighteen Australian bass (49.404, 49.444, 48.794 kHz) and seven of the eighteen striped mullet (49.344, 49.065, 49.063, 49.681, 49.184, 49.242, 49.621, 49.721 kHz) were only detected in the first month sampling (September 1999) and were undetected thereafter.

4.5.1. Australian bass

All Australian bass were collected and tagged at the base of Tallowa Dam. Collection of Australian bass for the purpose of tracking was not possible further downstream, because large bass were rarely sampled in lower reaches. Australian bass have been noted to exhibit marked sex segregation and dimorphism, with female fish migrating to upstream habitats following spawning in spring, whilst smaller males remain nearer to their estuarine spawning zone (Harris 1983). This segregation may explain the lack of large Australian bass collected during September within lower reaches of the Shoalhaven River, however large numbers of juveniles (<100mm) have been recorded at the base of the dam. As a result of sampling all individuals from the base of the dam, behaviour of Australian bass during upstream migrations could not be determined.

Spawning migrations of Australian bass to saline waters is known to occur during winter months, between late June and early September (Harris 1986). The period during which tracking took place (late September-March) was designed to fall within the freshwater phase of the spawning cycle of Australian bass, because transmitters could not be detected within saline waters. Consequently no large population migrations were observed during the period studied.

Female Australian bass have been observed to display pool selectivity, in that they return to the same pool following spawning (Harris 1983). The homing tendencies of adult female Australian bass may explain the limited movement observed in the potentially female biased sample used in this study. Homing behaviour is not restricted to Australian bass. Murray cod (*Maccullochella peelii*), another percichthyid native to the Murray-Darling River system, also return to the same snag following spawning migrations (Koehn 1995).

4.5.2. Striped mullet

Sampling was conducted for large mullet directly below the dam wall, however large numbers of adult striped mullet were only encountered at Grady's, 27 kilometres downstream of the dam. Other components of this study recorded relatively low numbers of adult striped mullet directly below Tallowa Dam, with only juveniles present in large numbers (Appendix 1). Mature female striped mullet were observed within Lake Yarrunga shortly after construction of Tallowa Dam (Bishop 1979), indicating adult striped mullet once occurred in the upper reaches of the Shoalhaven and Kangaroo Rivers. Impounding of rivers alters the frequency and magnitude of intermediate sized flow events, which serve as migratory cues for several fish species, including striped mullet (Thomson 1963, Eicher 1982, Harris 1983). Flow regulation by Tallowa Dam may consequently be supressing the migratory behaviour of adult striped mullet, contributing to their absence immediately below Tallowa Dam. However, Tallowa Dam spills relatively frequently, so that the effects of the dam on flow as a cue for upstream migration are likely to be much less severe than the effects of other structures, such as Warragamba Dam in the Hawkesbury-Nepean River System, which rarely spills. Large numbers of juvenile striped mullet (<200 mm) observed at the base of Tallowa Dam indicate juvenile migration to the dam wall is common, and that this species is likely to use a fishway to continue their upstream migration. Use of fishways by large numbers of juvenile striped mullet has also been documented in other studies (Kowarsky and Ross 1980, Russell 1991, Stuart 1997). These findings indicate that the proposed fishway on Tallowa Dam needs to be able to pass fish of various sizes, ranging from large Australian bass up to 550 mm, to striped mullet as small as 50 mm.

Striped mullet are known to undertake spawning migrations in May-August, moving in a northerly direction between rivers (Kesteven 1953, Virgona *et al.* 1998). The individual recaptured at Fingal

Bay in May was reproductively mature, and was caught as part of a shoal at the time when commercial fishers target striped mullet during their spawning migration. This finding suggests that other mullet that were tagged and not subsequently detected may have also migrated to sea. Furthermore, it provides evidence that the tagging procedures did not interfere with the fish's natural behaviour. The period during which radio tracking took place (late September-March) was designed to fall within the freshwater phase of the spawning cycle of striped mullet, because radio frequencies could not be detected within saline waters. Consequently no large population migrations of striped mullet were observed during the period studied.

4.5.3. Implications for future study

In future radio telemetry studies of the spawning migrations and return of Australian bass, it would be desirable to insert tags up to six months before they undertake spawning migration (June-September) to minimise effects of surgery and handling on gonad maturation and hormonal control of behaviour. Transmitters would consequently require a battery life of approximately 12 months. Telemetry also has application in following the dispersal of fish through Lake Yarrunga and river habitats upstream after construction of a fishway.

4.5.4. Implications for fishway design

Australian bass were located below the cold water outlet of Tallowa Dam on 87% of occasions when this species was detected below the dam. It appears this species is attracted by the strongest flow source, and will tolerate cool water temperatures (12.7-17.3ºC) in order to remain within the area of highest flow. Cold water avoidance has been observed in other migrating species such as silver perch (*Bidyanus bidyanus*) and Murray cod (Astles *et al.* 2000). It is likely that attraction to higher flows at the base of the dam would be increased by raising water temperature at the base of the dam to ambient temperature of surface waters in the impoundment. Combining the strongest source of flow with warmer water temperatures is likely to provide increased attraction to the fishway entrance for other species as well.

Both species displayed limited large-scale movements over the period studied. Striped mullet mostly remained where they were captured and tagged, 27 km downstream of Tallowa Dam. Australian bass also remained mostly where they were captured and tagged, at the base of the dam. However, it is anticipated that extended tracking over a full year would provide more information on movements of individual species. The findings of the present study, in conjunction with other components of this project (see Appendix 1) indicate the proposed fishway needs to provide passage to all size classes of Australian bass, and a high proportion of juvenile striped mullet. The attraction flow for the fishway needs to be the primary source of flow below the dam, and of suitable temperature to provide ideal attractions flows towards the fishway.

5. FINE-SCALE FISH DISTRIBUTIONS BELOW TALLOWA DAM AND CONSIDERATIONS FOR FISHWAY DESIGN.

5.1.1. Summary

High fishways have the ability to rehabilitate the fish communities of the Shoalhaven River displaced by the construction of Tallowa Dam. High fishways have been installed internationally with varied success. As with conventional fishways designed with insufficient consideration of species biology and behaviour may fail to provide effective fish passage. A fishway design for Tallowa Dam should also allow for the potential future modifications necessary for installation of a hydro-electric power station or implementation of environmental flows. To be effective, a high fishway at Tallowa Dam needs to provide passage for all species requiring passage into the upper reaches of the catchment, operate over 95% of flows, and attract fish into the entrance of the fishway. Fish species sampled from within the Shoalhaven catchment ranged in size from an average of 31 mm to 391 mm, with 59% of all individuals being < 50mm long. A flow of 3,500 Ml day^{-1} represents the maximum flow under which the fishway must remain operable, corresponding to 95% of flows. A suitable location of the fishway entrance will be determined by existing knowledge of the behaviour of fish at fishways, aspects of the biology of Australian fish, and data from this study. However, design considerations will be influenced by the ability to control or modify the flow and temperature of waters discharged from the base of the dam and from the spillway, and ability to relocate of the upstream limit of migration.

5.2. Introduction

Migratory fishes represent 88% of the freshwater fish species in the Shoalhaven River. Tallowa Dam has caused significant changes to this fish community, resulting in a loss of biodiversity within the system (see chapter 3). Consequently, potential exists for a high fishway to rehabilitate fish communities both upstream and downstream of the dam by allowing natural migration to restore fish populations upstream (Marsden et al. 1997; Healthy Rivers Commission of New South Wales, 1999). Rehabilitation through construction of a fishway is the most appropriate method of restoring the aquatic ecosystem upstream of the dam. The alternatives to fishway construction include the removal of Tallowa Dam or the continual stocking of all species whose upstream migration is obstructed. Removal of the dam is clearly inappropriate and continued restocking is impossible given the current inability to artificially breed a majority of the species that would require rehabilitation.

The construction of fishways on high dams has led to recoveries of fish populations both upstream and downstream of barriers. Populations of Atlantic salmon (*Salmo salar*) in the Garonne River in France increased from 50-100 individuals sampled between 1987 and 1992, to 250 sampled in 1994 after the construction of a fish lift (Travade *et al.* 1998). Further, approximately 86,000 Allice shad (*Alosa alosa*), a species noted to have difficulties overcoming barriers due to behavioural restrictions, were also observed to use the Garonne River fish lift in 1995 (Travade *et al.* 1998). Similarly, populations of adult American shad (*Alosa sapidissima*) increased from 4,000 to over 80,000 between 1984 and 1992 as a result of the construction of a fish lift on the Susquehanna River in the USA (Cada 1998).

5.2.1. High Fishways

High fishways are commonly based on either fish lock or fish lift design concepts, whilst fish pumps offer a more novel alternative (Marsden *et al.* 1997; Department of Public Works and Services 1999). Detailed descriptions of high fishway structures were provided in the Marsden *et al.* (1997) Stage 2 comprehensive report. Fish locks have been constructed in Canada, Ireland, Scotland, Russia, Uruguay and the USA, on barriers up to 61 m (Clay 1995). Between 1960 and 1975 a number of poorly designed unsuccessful fish-locks were built in France (Larinier 1998). A dominant feature in the failure of these fishways was the location of the entrance in relation to the area of greatest flow (Travade *et al.* 1998). Subsequently, a further eight appropriately designed fish locks have been constructed, and have passed large numbers of fish (Larinier 1998). Fish lifts have been used on structures up to 100 m high in Canada, Finland, France (Travade *et al.* 1998), Russia and the USA (Cada 1998) as described in Clay (1995). With appropriately designed entrances, these fish lifts have been used by 78,000-86,000 individuals of some species (Travade *et al.* 1998). The fish lift on the Susquehanna River passed 4.7 – 35.1% of American Shad accumulating below the dam wall between 1972 –1980 (Cada 1998). Fish pumps have provided fish passage for elvers on the Trevallyn Power Station Dam in Tasmania, Australia (Marsden *et al.* 1997) and temporarily on the Snake River, USA (Eicher 1982). Both fish pump fishways were capable of transporting fish vertically over 20 m. The fish-pump design was recommended as the most appropriate design for Tallowa dam (Eicher 1982).

The highest barrier fitted with a fishway within New South Wales is Yarrawonga Weir on the Murray River with an 11 m fish lock. The proposed construction of a high fishway at Tallowa Dam represents a significant step in the development of high fishways for similar high dams across Australia, and will make an important contribution to managing fish passage on an international scale.

5.2.2. Fishway design considerations

For a fishway to be considered effective, it must be capable of transporting small fish, such as the juveniles of diadromous species and adults of small species, as well as adults of large species. Secondly, the fishway must remain operational over a wide range of conditions. NSW Fisheries guidelines recommend that fishway designs should be effective over 95% of flows until drown-out of the structure, or 50% of tailwater levels until drownout (Mallen-Cooper, 2000). Additionally, the fishway structure must be robust enough to cope with large flooding events. And finally, fish must be capable on finding the fishway entrance.

The attraction of fish into a fishway is one of the most important components of fishway design (Clay 1995, Marsden *et al.* 1997). The three most important factors determining the success of entrance design are water temperature, flow and location (Clay 1995). Migratory fish in the process of moving upstream tend to swim towards areas of the greatest flow. Therefore, for fishways to be successful, the entrance to the fishway should either be the source of, or be adjacent to the dominant flow at the base of the dam. One of the most common reasons for the failure of fishways to provide fish passage is poor location of the entrance with respect to flow (Northcote 1998, Travade *et al.* 1998, Williams 1998). It has also been established that migrating fish are influenced by water temperature (Northcote 1998). In Australia, it has been shown that cold water currents may be avoided by migrating fish (Lake 1967, Koehn *et al.* 1997, Astles *et al.* 2000). In addition, the entrance of the fishway should be located at the upstream limit of migration, otherwise fish may accumulate at the base of the dam upstream of the fishway entrance. If fish are unable or unwilling to enter the fishway, the technology used to lift fish across the barrier will be irrelevant (Eicher 1982).

Understanding the complex distribution of flows and temperatures downstream of Tallowa Dam, and the impacts this environment has on the population structure and distribution of fish communities below the dam wall, is crucial to developing a successful fishway design. This chapter provides information on the distribution of fish below Tallowa Dam, in relation to the distribution of flow, water quality and habitat. This information will enable informed decisions to be made regarding fishway design in subsequent stages of the project.

5.3. Methods

5.3.1. Sites

The area directly below the dam wall is a complex series of pools, runs and rapids originating from water from both the spillway as well as water discharged from the outlet works on the northern abutment of the dam. Flows released below the dam average 90 – 180 Ml day^{-1}. Five distinct pool habitats were identified downstream of the dam (Fig. 5.1). A trench (or channel) running along the base of the spillway receives warm waters from the surface of the storage as it passes over the spillway and distributes flow to the remaining pools. The southernmost pool, at the foot of the southern abutment of the dam receives water directly from the trench. A second warm-water pool, receives water flowing from the first warm-water pool in addition to the trench during moderate spillway flows. A cold-water pool at the foot of the northern abutment of the dam is fed largely from water released from the base of the dam, with additional water from the trench that is derived from the spillway. A mixing pool is located at the confluence of the second warm-water pool and the cold-water pool.

5.3.2. Sampling

Habitats at the base of the dam were sampled three times using the boat electrofisher, *FRV Pole volt*. *FRV Pole volt* is a 3.6 metre, flat bottom aluminium electrofishing boat equipped with a 2.5 kW Smith-Root Model GPP 2.5 H/L. The electrofishing equipment was operated at between 500 and 1000 V DC, 4 to 8 amps pulsed at 120 Hz and 70-90% duty cycle, depending on conductivity. The entire site was sampled via 15 replicated 2 minute electrofishing shots. As this site is partitioned into a series of pools, surveys II, III and IV sampled 4-5 shots from the first warm-water pool, 3 shots in the second warm-water pool, 3-4 shots in the cold-water pool and 4 shots in mixing pool.

Water temperature, dissolved oxygen, pH and conductivity were measured from the first warm water pool and the cold water pool during surveys II (December 1998) and III (March 1999).

5.3.3. Analytical methods

Species abundances were analysed to determine the distribution of fish assemblages among habitats below the dam. Multivariate analyses were done using PRIMER 4.0 (Plymouth Marine Laboratory) to perform hierarchical agglomerative classification analysis and multi-dimensional scaling (MDS) ordinations in two dimensions based on the Bray-Curtis similarity measure. One-way ANOSIM (ANalysis Of SIMilarities) comparisons (Clarke 1993) were done to identify differences in fish assemblage composition between poolsv within site DST8. ANOSIM is a non-parametric multivariate analogue of analysis of variance, based on rank similarities among all samples.

Species abundances per replicate shot were transformed to the fourth root for analysis of similarities between pools. Both classification and ordination were done on similarities among pools to determine the distribution of fish assemblages within the pools below the dam wall. Pools fed directly from the spillway did not differ significantly, and were pooled before comparisons with the cold-water and mixing pools. SIMilarity PERcentage (SIMPER) analyses were used to identify species responsible for observed differentiation between pools.

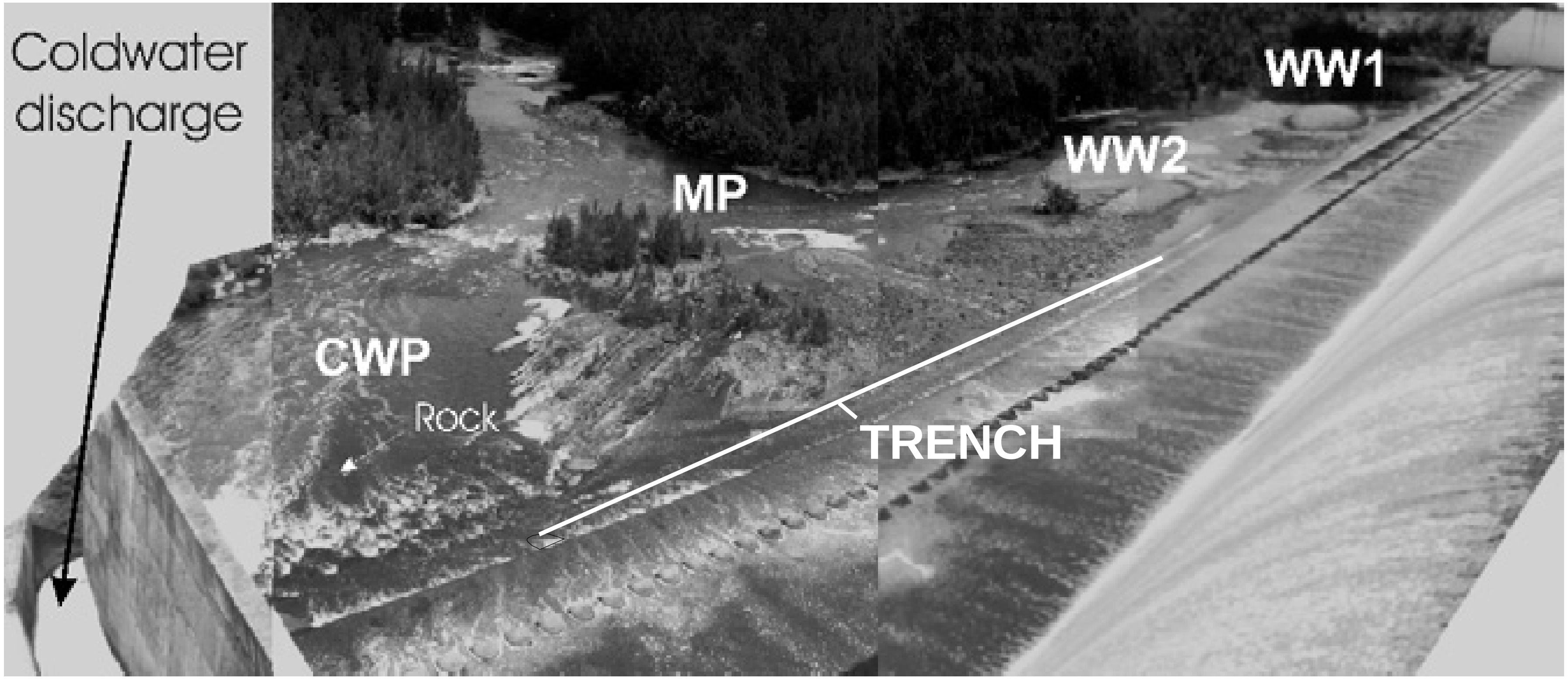


Figure 5.1. Riverine environment immediately below Tallowa Dam. WW1 and WW2 are pools fed entirely by warm water from the spillway, CWP is fed largely by cold water released from the base of the dam in addition to some spillway flow and MP is fed by a mixture of warm water from WW2, and cold water from CWP in addition to a small amount of spillway flow. The upstream limit of migration is the TRENCH located immediately below the spillway. The rock identified within CWP is situated within spillway flows adjacent to the cold-water discharge. This is the site of accumulation of large numbers of Australian bass.

5.4. Results

5.4.1. Size range of species within the system.

The smallest fish species caught in the Shoalhaven River system during sampling for this project was the dwarf flat-headed gudgeon (*Philypnodon* sp.1), with a mean length of 31 ± 1 mm, and a minimum of 11 mm. Long-finned eels were the largest species, with a mean length of 400 ± 50 mm and a maximum observed length of 1,900 mm. The length frequency distribution of all individuals sampled from the 12 sites within the catchment indicate that 59% of individuals within the system are under 50 mm in length and 79% are under 100 mm (Fig. 5.2). Fish less than 100 mm represent adults and juveniles of small species in addition to juveniles of larger catadromous and amphidromous species.

5.4.2. River flow at Baron Flat (500m downstream of Tallowa Dam).

A flow profile of the Shoalhaven River 500 m downstream of Tallowa Dam wall, indicates that on 95% of days between 30 May, 1991 and 21 March, 2000, river flow was lower than 3,593 Ml day^{-1} (Fig. 5.3), with a mean (± SE) flow of 1,121 ± 62 Ml day^{-1}. The origin of flow is divided between water from the spillway and water discharged from the base of the dam on the northern abutment. Water is discharged from the base of the dam at a typical rate of 180 Ml day^{-1} with a minimum of 90 Ml day^{-1} to provide environmental flows. During periods of drought, environmental flows can be reduced further. During periods of flood, discharges
from the base of the dam can be increased to a maximum of 3,600 Ml day^{-1}. On average, flows in excess of 180 Ml day^{-1} result from reservoir overflow from the spillway.

5.4.3. Water quality

There are distinct water quality differences between flows originating from the spillway and discharged from the base of the dam. Of the four water quality variables examined, only pH was similar for both flows (mean pH value from spillway = 7.42 ± 0.12, mean pH value for outlet = 6.93 ± 0.11) (Fig. 5.4). Conductivity of water discharged from the base of the dam (mean conductivity = 907 ± 34 µs cm^{-2}) was marginally higher than water from the spillway (mean conductivity = 650 ± 156 µs cm^{-2} (Fig. 5.4). Similarly, dissolved oxygen availability was higher in water discharged from the base of the dam (% saturation for outlet = 98 ± 4% versus spillway = 93 ± 2% (Fig. 5.4). The mean temperature of water discharged from the base of the dam was considerably colder than water from the spillway (17.5 ± 0.75 ^{o}C versus 25.5± 0.19 ^{o}C).

5.4.4. Distribution of fish below the dam wall.

Fish assemblages in different habitats below the dam wall displayed a graded response to water temperatures (Fig. 5.5). No differences were detected among fish assemblages in warm water habitats (warm water pool 1, warm water pool 2 and the trench) ($p > 0.05$) (Table 5.1). The fish assemblage in the cold water pool was significantly different from that in the warm water habitats ($p< 0.05$) with greater abundances of striped mullet (*Mugil cephalus*) and long-finned eels (*Anguilla reinhardtii*) in the warmer water, each species accounting for 12% of the dissimilarity between assemblages in the two habitats. Australian bass (*Macquaria novemaculeata*) and carp (*Cyprinus carpio*) were more abundant in the cold-water pool than in WW1, WW2 and the trench, contributing to 20% and 10% of the dissimilarity between assemblages. The fish assemblage in the mixing pool also differed from the assemblage in the cold water pool ($p< 0.05$) but not from that in the warm water pools ($p > 0.05$). Most species were more abundant in the mixing pool with only Australian bass and Australian smelt more abundant in the higher flows of cold water pool. Long-finned eels, striped mullet, freshwater mullet (*Myxus petardi*) and carp remained downstream in the warm waters of the mixing pool adjacent to the higher flows of cold water.

5.5. Discussion

The most appropriate fishway design for Tallowa Dam may require three stages:

STAGE 1: An entry section to attract fish and draw them into a collection chamber ;

STAGE 2: A lift mechanism to transport fish from the collection chamber up to the top of the dam.

STAGE 3: A release section (if necessary) to transport fish from the lift to the water in the impoundment.

5.5.1. Fish size

Almost 60% of individuals sampled within the catchment were less than 50 mm long (Fig. 5.2). For the fishway to be successful in passing all species requiring fish passage at the dam, the design must account for the small size of most fish potentially using the fishway. Stage 1 of the fishway must account for the abundance of small fish by ensuring that water velocity does not exceed the swimming capacity of these small fish. Velocities greater than 1.4 ms^{-1} have been found to prevent migration of juvenile Australian bass and barramundi (*Lates calcarifer*) through fishways (Mallen-Cooper 1992). With slopes of 1:20 m, vertical-slot fishways create velocities less than 1.4 ms^{-1} and have been shown to provide fish passage for a broad range of species (Mallen-Cooper 1992, Mallen-Cooper *et al.* 1995, Stuart and Berghuis 1999, Stuart and Mallen-Cooper 1999). A vertical-slot fishway on the Fitzroy River, Queensland, passed 23,000 fish from 29 species, with a size range of 25 – 640 mm (Stuart and Mallen-Cooper 1999). The size range of fish within the Shoalhaven River is similar to that of the Fitzroy River, so that a similar design would be appropriate for passing fish through stage 1 of the Tallowa Dam fishway.

Stage 2 of the fishway must account for the small size of many of the fish transported. Using fine mesh for screens used in the fishway will ensure that small individuals are successfully transported. However, fine screens may accumulate debris and introduce maintenance problems. A compromise may be needed between the size of fish accommodated and the reliability of operation.

The small size of fish also introduces the problem of predation by larger individuals whilst passing through the fishway. Anti-predation devices within holding bays have not previously been incorporated into the design of fishways. If a number of fish species of various sizes are to be confined in holding bays between cycles of the stage 2 fishway, predation of larger fish on smaller individuals may reduce the efficiency of the fishway.

5.5.2. Flow

For the fishway to be operable over 95% of mean daily flows, stage 1 should operate under flows up to 3,593 Ml day^{-1} (Fig. 5.3). Supply of water to the fishway should be provided from the impoundment to ensure continuous fish passage during periods of low flow.

5.5.3. Entrance location

Three dominant factors influencing entrance design are temperature, flow and location. Fish species sampled below the dam showed distinct responses to the different temperatures and flows associated with releases over the spillway and through the outlet valve. There were detectable

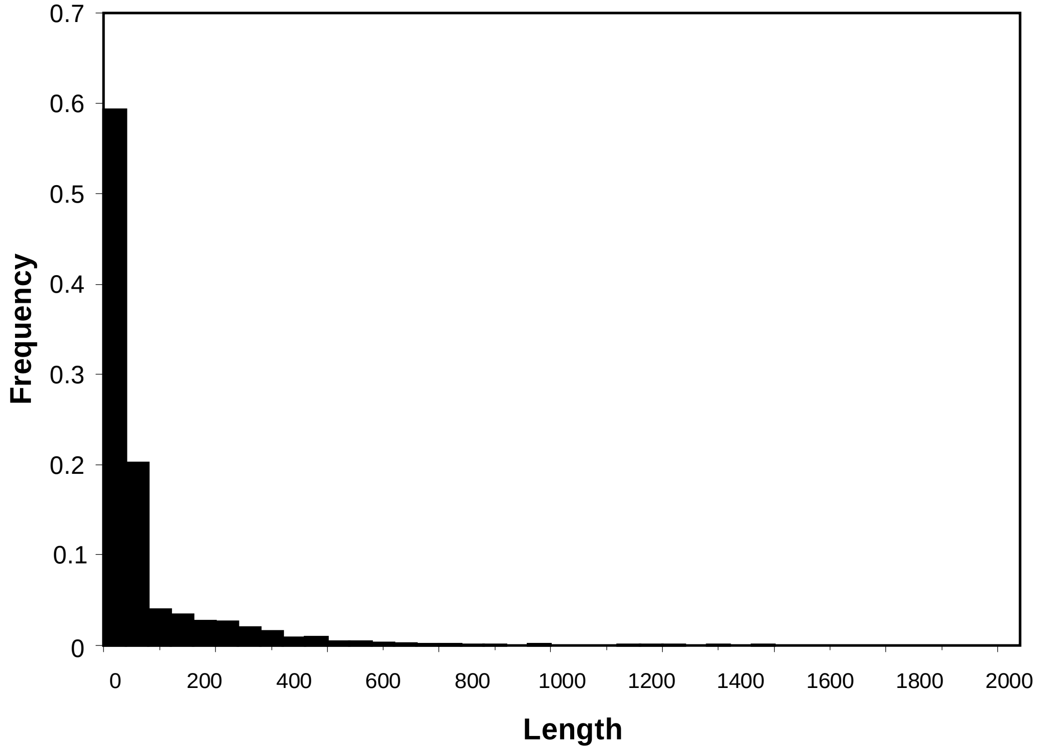


Figure 5.2 Size frequency distribution of fish sampled within the Shoalhaven catchment.

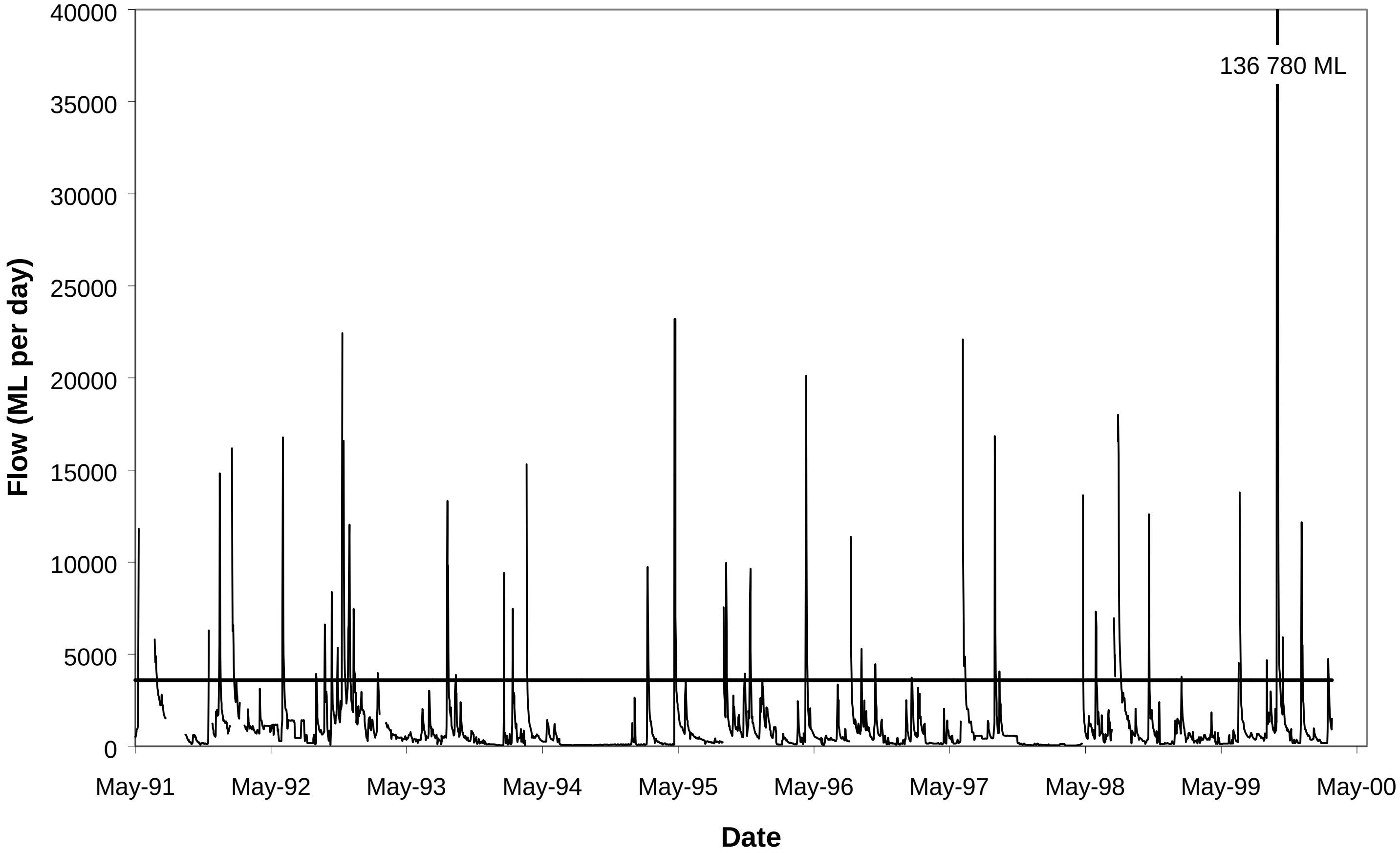


Figure 5.3 River flow measured 500 m downstream of Tallowa Dam from 30 May, 1991 – 21 March, 2000. The horizontal line crossing the figure represents the river flow which is exceeded only 5% of the time. This flow (~ 3500 Ml day^{-1}) is the maximum flow under which the fishway should remain functional. Data supplied by the *Sydney Catchment Authority*

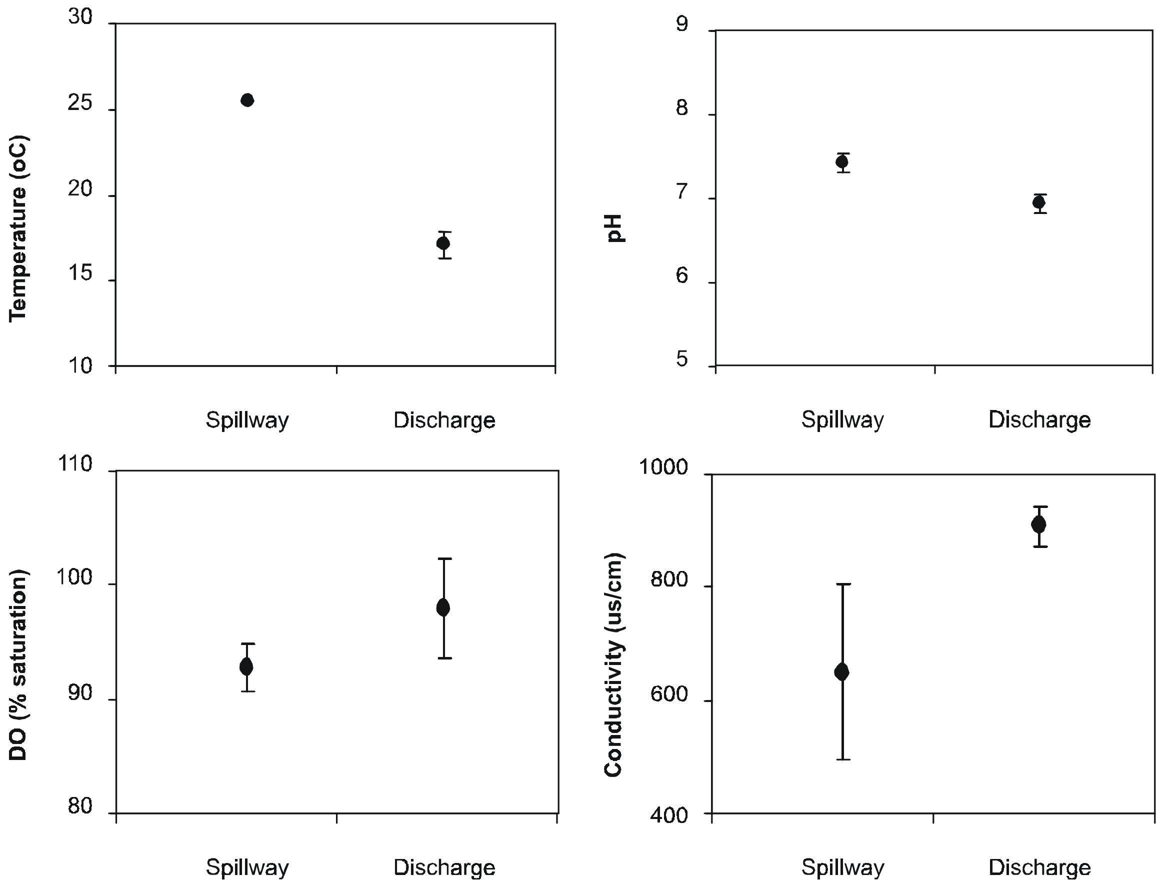


Figure 5.4. Water quality measurements at the base of Tallowa Dam of water originating from the spillway and water discharged from the outlet at the base of the dam. Values are the mean of all measurements taken at the surface and at a depth of 1metre assessed during surveys II and III.

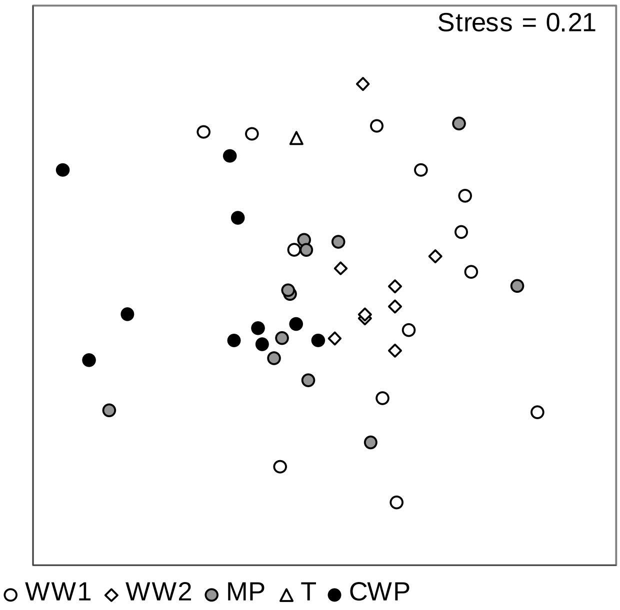


Figure 5.5 Multi-dimensional scaling ordination of fish assemblages directly downstream of Tallowa Dam based on similarities between pool habitats. Pool labels represent warm water pools (WW1 and WW2), the trench at the base of the dam wall (T), the cold water pool (CWP) and the mixing pool where cold water and warm water converge (MP). The horizontal axis represents a cline in water temperature with temperature decreasing from right to left.

Table 5.1. Summary of one-way analysis of similarity comparisons between fish assemblages within pools immediately downstream of Tallowa Dam.

Comparison	*R* – value	Probability > *R*
Among warm-water pools: (WW1, WW2 and T)	0.103	0.114
Warm-water v cold-water pool	0.229	0.009
Warm-water v mixing pool	0.083	0.13
Warm-water + mixing pool v cold-water pool	0.164	0.008

differences between the fish communities congregating in different habitats below the dam. Australian bass and Australian smelt were found to accumulate in areas of maximum flow, regardless of water temperature. Long-finned eels, striped mullet, freshwater mullet and carp were also attracted to flow but avoided lower temperature water from the outlet valve and remained within warmer waters from the spillway adjacent to the higher flows released from the outlet. No species accumulated in the trench at the upstream limit of migration in preference to areas of high flow. Because different species accumulate in different locations, several factors must be addressed to ensure effective entrance design. If the fishway is to pass individuals of all species needing to migrate, the entrance must be located in an area where all species accumulate. This can be achieved by: (i) simplifying the complex flow and pool associations below the dam wall; (ii) reducing or eliminating the temperature differences between spillway and outlet flows; and (iii) relocating the upstream limit of migration downstream to guide all species to the fishway entrance.

Spillway flows are currently dispersed across the full 350 m of the spillway. Based on spillway flows alone, this makes it difficult to identify a specific location where fish will congregate. In addition, spillway flows are inconsistent, with no flows recorded from the spillway for 26% of the time between May 1991 and March 2000. In contrast, flow from the outlet is restricted to a point source at the extreme northern end of the spillway. Outlet flows are released at between 90 Ml – 180 Ml day^{-1} to provide environmental flows (excluding periods of drought or flood), and provide relatively constant attraction flows. All species have demonstrated an attraction to flow below the dam, but with the exception of Australian bass and Australian smelt, all avoid the colder water discharged from the outlet valve. Neither the spillway nor the outlet offer simple solutions for location of the fishway entrance. To overcome the diffuse spillway flows, two practical solutions exist. The first is to remove the two warm water pools and the top part of the mixing pool by infilling with rocks, so all spillway flow is directed into the cold water pool. As these pools become isolated or dry out during the 26% of time when the spillway flows stop, this option is likely to be effective and inexpensive. The second alternative is to raise a lip at the base of the spillway, to direct flow into the cold water pool. Both these options simplify flow patterns below the wall by concentrating the area of greatest flow. Filling in the warm water pools also restricts fish access to a smaller area below the dam and increases the likelihood of fish finding the entrances to the fishway. All flows and the upstream limit of migration will be localised in the cold water pool.

During periods of low flow, when warmer spillway flows cease, attraction of fish within the cold water pool will be hampered by the cooler temperatures of the water released through the outlet. To maintain attraction to the fishway entrance, it is preferable that the outlet structure be modified to release warm water. Sherman (2000) presented seven options for mitigation of cold water discharge which should be evaluated for Tallowa Dam. These are: destratification; surface pumps; multilevel offtakes; trunnions; submerged weirs; stilling basins; and modified release rules.

In addition to the detrimental effects of cold-water pollution, water drawn from the base of the dam contains traces of iron and hydrogen sulphide and other metals (Healthy Rivers Commission, 1999) . These compounds are characteristic of releases of cold anoxic waters from impoundments (Hillman 1979, Walker *et al.* 1979, Greene *et al.* 1997). During periods of low spillway flow, these chemicals were observed as a film coating the substratum downstream of the outlets during sampling for this project and were also detected as elevated conductivity of the discharge waters. Consequently broader water quality issues than temperature alone need to be addressed to maintain fish attraction during periods of low flow.

Modification of flow distribution and enhanced management of releases from the base of the dam are essential for the proposed fishway to be effective. If either, or both of these solutions can not be implemented, a third solution involves relocation of the upstream limit of migration to a section of the river downstream of the point where the fish assemblages become segregated by flow and temperature preferences. This solution requires the construction of a low weir at the downstream end of the mixing pool to prevent fish moving into the complex pool system below the dam. Further, the entire flow would pass over the weir as a mixture of both spillway and outlet flows. Fish accumulating below the weir could be directed into the entrance of a vertical-slot fishway, leading them to the base of the fishway to be trapped and transported over the dam.

Fish migrating upstream have been demonstrated to accumulate in areas of greatest flow rather than continue upstream into weaker flows (Stuart and Berghuis 1997, Williams 1998). The reluctance of golden perch to travel past strong spillway flows to follow weaker attraction flows into a fish lock on Eden Bann Weir in Queensland has been identified as the main problem in the operation of this fishway (Stuart and Berghuis, 1997). Below Tallowa Dam Australian bass, Australian smelt, striped mullet, freshwater mullet, long-finned eels and carp have also been noted to accumulate in greatest numbers downstream of the outlet valve rather than continuing up to the base of the dam itself. This behaviour poses problems in attracting fish into a fishway structure where the attraction flow to the entrance to the fishway is weaker than the flow released from the dam. Flows through the fishway are recommended to be at least 1-5% of total river flow (Larinier, 1990) A small weir to guide fish towards the fishway entrance, combined with redirected spillway flow has the potential to overcome this problem below Tallowa Dam.

Release

The final consideration in fishway design is the effectiveness of releasing fish into the impoundment above the fishway (and their potential for downstream migration). Fish need to be released in a location where they will not become entrained in water flowing over the spillway, through existing outlet works or other future structures such as a hydro-electric facility.

The survival of fish passing over the spillway has not been assessed. Downstream migration can be affected by spillway design with barriers producing free-falls over 30 m causing extensive damage to large fish, with resultant heavy mortalities (Eicher 1982). However, dams such as Tallowa, with inclined spillways that do not involve a free-fall, and where water plunges into a deep pool result in much lower injury rates (Bell and DeLacey 1972, Ruggles 1980, Clay 1995). Anecdotal evidence exists in angler's catches that large species such as Australian bass survive passing over the Tallowa Dam spillway, but this issue, and resultant effects on downstream fish migration requires further investigation. The use of radio-telemetry to determine the behaviour of fish introduced into the impoundment would provide valuable information relevant to design of the release component of the fishway.

REFERENCES

Allibone, R. M. 1999. 'Impoundment and introductions:their impacts on native fish of the upper Waipori River, New Zealand', *Journal of the Royal Society of New Zealand*, **29,** 291-299.

Almodóvar, A. and Nicola, G. G. 1999. 'Effects of a small hydropower station upon brown trout *Salmo trutta* L. in the River Hoz Seca (Tagus basin, Spain) one year after regulation', *Regulated Rivers: Research and Management*, **15,** 477-484.

Astles, K. L., Winstanley, R. K. and Harris, J. H. 2000. Experimental study of the effects of cold water pollution on native fish. Water Management Fund Report. NSW Fisheries, Office of Conservation and Cooperative Research Centre for Freshwater Ecology, Cronulla

Auty, E. H. 1978. 'Reproductive behaviour and early development of the empire fish *Hypseleotris compressus*', *Australian Journal of Marine and Freshwater Research*, **29,** 585-597.

Axford, S. N. 1991. 'Some factors affecting catches in Yorkshire rivers', in Cowx, I. G. (Ed.), *Rehabilitation of Freshwater Fisheries*, Fishing News Books, Oxford. pp. 143-153.

Barlow, C. G. and Bock, K. 1984. 'Predation of fish in farm dams by cormorants, *Phalacrocorax spp.*', *Australian Wildlife Research* **11,** 559-566.

Bell, M. C. and DeLacey, A. C. 1972. 'A compendium on the survival of fish passing through spillways and conduits'. US Army Corps of Engineers, North Pacific division, Portland, Oregon.

Beumer, J. P. 1996. 'Family Anguillidae: Freshwater Eels' in McDowall, R. M. (ed.), *The Freshwater Fishes of South-eastern Australia*, (2nd edn), Reed, Sydney. pp. 39-43.

Bishop, K. A. 1979. 'Fish and aquatic macroinvertebrate communities of a coastal river (Shoalhaven River, New South Wales) during the development of a water diversion scheme'. Unpublished M.Sc. thesis, Macquarie University.

Bishop, K. A. and Bell, J. D. 1978. 'Observations on the fish fauna below Tallowa Dam (Shoalhaven River, New South Wales) during flow stoppages', *Australian Journal of Marine and Freshwater Research*, **29,** 543 - 549.

Bishop, K. A. and Walsh, J. 1984. 'Report on sampling in Tallowa Dam impoundment', Unpublished report. NSW Fisheries, Cronulla.

Bray, J.R. and Curtis, J.T. 1957. 'An ordination of the upland forest communities of Southern Wisconsin', *Ecological Monographs*, **27,** 325-349.

Cada, G. F. 1998. 'Fish passage mitigation at hydroelectric power projects in the United States' in M. Jungwirth, S. Schmutz and S. Weiss (eds.) *Fish Migration and fish bypasses*. Fishing News Books, Oxford. pp. 208 – 219.

Cadwallader, P. L. 1978. 'Some causes of the decline in range and abundance of native fishes in the Murray-Darling River system', *Proceedings of the Royal Society of Victoria*, **90,** 211-224.

Clarke, K. R. 1993. 'Non-parametric multivariate analyses of changes in community structure', *Australian Journal of Ecology*, **18,** 117-143.

Clay, C. H. 1995. *Design of fishways and other fish facilities (second edition)*. Lewis Publishers, London.

De Mérona, B. and Albert, P. 1999. 'Ecological monitoring of fish assemblages downstream of a hydroelectric dam in French Guiana (South America)', *Regulated Rivers: Research and Management*, **15,** 39-351.

Dufty, S. 1986. ‘Genetic and morphological divergence between populations of Macquarie Perch (*Macquaria australasica*) East and West of the Great Dividing Range’, Unpublished Honours thesis. University of New South Wales.

Eicher, G.J. 1982. A fish passage facility program for New South Wales. Report for NSW Fisheries

Elson, P. F. 1962. ‘Predator-prey relationships between fish-eating birds and Atlantic salmon’, *Fisheries Research Board of Canada, Bulletin 133*.

Faragher, R. A., 2000. The distribution and abundance of Australian grayling (*Prototroctes maraena* Gunther), a threatened species in New South Wales. In prep.

Faragher, R.A. and Harris, J.H. 1994 ‘The historical and current status of freshwater fish in New South Wales’, *Australian Zoologist* **29**(2-4), 166-176.

Faragher, R. A. and Rodgers, M. 1997. ‘Performance of sampling-gear types in the New South Wales Rivers Survey’, in Harris J. H. and Gehrke, P. C. (eds), *Fish and Rivers in stress: The NSW Rivers Survey*, NSW Fisheries and Cooperative Research Centre for Freshwater Ecology, Cronulla. pp. 251-268.

Feltham, M. J. and MacLean, J. C. 1996. ‘Carlin tag recoveries as an indicator of predation on salmon smolts by gooseanders and red-breasted mergansers’, *Journal of Fish Biology*, **48,** 270-282.

Gehrke, P. C., Astles, K. L. and Harris, J. H. 1999. ‘Within catchment effects of flow alteration on fish assemblages in the Hawkesbury-Nepean River system, Australia’, *Regulated Rivers: Research and Management*, **15,** 181-198.

Gehrke, P. C. Brown, P. Schiller, C. B. Moffatt, D. B. and Bruce, A. M. 1995. ‘River regulation and fish communities in the Murray-Darling river system, Australia’, *Regulated Rivers: Research and Management*, **11,** 363-375.

Gehrke, P. C. and Harris, J. H., 1996. ‘Fish and Fisheries of the Hawkesbury-Nepean River System”, *Final Report to the Sydney Water Corporation*, NSW Fisheries and Cooperative Research Centre for Freshwater Ecology, Cronulla.

Gehrke, P. C. and Harris, J. H., 2000. ‘Large-scale patterns in species richness and composition of temperate riverine fish communities, south-eastern Australia’, *Marine and Freshwater Research*, **51,** 165-182.

Gehrke, P. C. and Harris, J. H. 2001. ‘Regional-scale differences between fish communities in regulated and unregulated rivers in New South Wales, Australia’, *Regulated Rivers: Research and Management*, in press.

Gowans, A.R.D., Armstrong, J.D. and Priede, I.G. 1999. 'Movements of adult Atlantic salmon in relation to a hydroelectric dam and fish ladder', *Journal of Fish Biology* **54,** 713-726.

Greene, G. R., Rogers, J. G., Romney, J. S., Marsden, T. J., Gehrke, P. C. and Harris, J. H., 1997, Rehabilitating dammed environments – options for a high fishway at Tallowa Dam, ANCOLD Conference, Sydney.

Haeseker, S.L.; Carmichael, J.T.; Hightower, J.E. 1996, 'Summer distribution and condition of striped bass within Albemarle Sound, North Carolina', *Transactions of the American Fisheries Society* **125,** 690-704.

Harcup, M.F, Williams, R. and Ellis, D.M. 1984. 'Movements of brown trout, *Salmo trutta* L., in the River Gwyddon, South Wales', *Journal of Fish Biology* **24,** 415-426.

Harris, J. H. 1983. ‘The Australian bass, *Macquaria novemaculeata*’, Unpublished Ph.D. thesis, University of New South Wales.

Harris, J. H. 1984a. ‘Impoundment of coastal drainages of south-eastern Australia and a review of its relevance to fish migration’, *Australian Zoologist*, **21,** 235-250.

Harris, J.H. 1984b. ‘A survey of fishways in streams of coastal south-eastern Australia’, *Australian Zoologist* **21,** 219-34.

Harris, J.H. 1988. 'Demography of Australian bass, *Macquaria novemaculeata* (Perciformes, Percichthyidae), in the Sydney Basin', *Australian Journal of Marine and Freshwater Research* **39,** 355-69.

Harris, J. H. and Gehrke, P. C. (Eds) 1997. *Fish and rivers in stress: The NSW Rivers survey*, NSW Fisheries and Cooperative Research Centre for Freshwater Ecology, Cronulla. 298 pp.

Harris, J. H. and Mallen-Cooper, M. 1994. ‘Fish-passage development in the rehabilitation of fisheries in mainland south-eastern Australia', in Cowx, I. G. (ed.), *Rehabilitation of Freshwater Fisheries* Fishing News Books, Oxford. pp. 185-193.

Harris, J. H. and Rowland, S. J., 1996. ‘Family Percichthyidae: Australian freshwater cods and basses’, in McDowall, R. M. (ed.), *The Freshwater Fishes of South-eastern Australia*, (2nd edn), Reed, Sydney. pp. 150-163.

Harris J.H., Thorncraft G.A. and Wem P. 1998, ‘Evaluation of rock-ramp fishways in Australia’ in M. Jungwirth, S. Schmutz and S. Weiss,(eds) *Fish Migration and Fish Bypasses*. Fishing News Books, Oxford. pp. 331-347.

Healthy Rivers Commission 1999. Independent inquiry into the Shoalhaven River system.. Healthy Rivers Commission of New South Wales, Sydney.

Herbert, B. W., Peeters, J. A., Graham, P. A. and Hogan, A. E. 1995. *Freshwater and Aquatic Habitat Survey of Cape York Peninsula*, State of Queensland and the Commonwealth of Australia, Canberra.

Hickley, P. 1994. ‘Stocking and introduction of fish – a synthesis', in Cowx, I. G. (Ed.), *Rehabilitation of Freshwater Fisheries* Fishing News Books, Oxford. pp. 247-254.

Hillman, T. J. 1979. ‘The River Murray in relation to lakes Hume and Mulwala’, *Australian Society for Limnology Newsletter* **17,** 29-33.

Holmquist, J. G., Schmidt-Gengenbach, J. M. and Yoshioka, B. B. 1998. ‘High dams and marine-freshwater linkages: Effects on native and introduced fauna in the Caribbean’, *Conservation Biology*, **12,** 621-630.

Kennedy, G. J. A. and Greer, J. E., 1988. ‘Predation by cormorants, *Phalacrocorax carbo* L., on the salmonid populations of an Irish river’, *Aquaculture and Fisheries Management*, **19,** 159-170.

Kesteven, G.L. 1953. 'Further results of tagging of sea mullet, *Mugil cephalus* Linnaeus, on the eastern Australian coast', *Australian Journal of Marine and Freshwater Research* **4,** 251-306.

Knights, B.C. and Lasee, B.A. 1996. 'Effects of implanted transmitters on adult bluegills at two temperatures', *Transactions of the American Fisheries Society* **125,** 440-449.

Koehn, J. 1997. 'Habitats and movements of freshwater fish in the Murray-Darling Basin' in R. J. Banens and R. Lehane (eds). *1995 Riverine Environment Research Forum.* Murray-Darling Basin Commission, Canberra. pp. 27-32.

Koehn, J. Doeg, T. Harrington, D. and Milledge, G 1997. 'Dartmouth Dam: Effects on the downstream aquatic fauna' in R. J. Banens and R. Lehane (eds). *1995 Riverine Environment Research Forum,* Murray-Darling Basin Commission, Canberra. pp. 47-56.

Kowarsky, J. and Ross, A. H., 1981. ‘Fish movement upstream through a central Queensland (Fitzroy River) coastal fishway’, *Australian Journal of Marine and Freshwater Research*, **32,** 93-109.

Lake, J.S. 1967. ‘Principal Fishes of the Murray Darling River System’ in A. H. Weatherley (Ed) *Australian inland waters and their fauna: eleven studies*. Australian National University: Canberra. pp. 192 – 213.

Larinier, M. 1990. ‘Experience in France: fish pass design criteria and downstream migration problems’, in S. Komura (ed.) *Proceedings of the International Symposium on Fishways 1990.* Gifu, Japan. pp. 65 – 74.

Larinier, M. 1998. ‘Upstream and downstream fish passage. Experience in France’, in M. Jungwirth, S. Schmutz and S. Weiss (eds) *Fish Migration and fish bypasses*. Fishing News Books, Oxford. Pp. 127 – 145.

Larson H. K. and Hoese, D. F. 1996. ‘Family Gobiidae, subfamilies Eleotridinae and Butinae: Gudgeons', in McDowall, R. M. (ed.), *The Freshwater Fishes of South-eastern Australia*, (2nd edn), Reed, Sydney. pp. 200-219.

Leggett, R. and Merrick, J. R. 1987. *Australian native fishes for aquariums,* J. R. Merrick Publications, Sydney.

Llewellyn, L. C. 1983. ‘The distribution of fish in New South Wales’, *Australian Society for Limnology, Special Publication No. 7*.

Lucas, M.C. 1989. 'Effects of implanted dummy transmitters on mortality, growth and tissue reaction in rainbow trout, *Salmo gairdneri* Richardson', *Journal of Fish Biology* **35,** 577-587.

Lucas, M. C. and Frear, P. A. 1997. ‘Effects of a flow-gauging weir on the migratory behaviour of adult barbel, a riverine cyprinid’, *Journal of Fish Biology,* **50,** 382-396.

Mallen-Cooper, M. 1992. 'Swimming ability of juvenile Australian bass, *Macquaria novemaculeata* (Streindachner), and juvenile barramundi, *Lates calcarifer* (Bloch), in an experimental vertical slot fishway', *Australian Journal of Marine Freshwater Research* **43**, 823-834.

Mallen-Cooper, M. 1993*a*. 'Habitat changes and declines of freshwater fish in Australia: what is the evidence and do more?', Sustainable Fisheries through Sustaining Fish Habitat: Australian Society for Fish Biology Workshop. Department of Primary Industries and Energy Bureau of Resource Science.

Mallen-Cooper, M. 1993b. ‘Fishways in Australia; past problems, present successes and future opportunities’, ANCOLD Bulletin 93, 22-33.

Mallen-Cooper, M. 1994 ‘How high can a fish jump?’, New Scientist 16 April 1994 142(1921), 32-37.

Mallen-Cooper, M. 1996 ‘Fishways and freshwater fish migration in south-eastern Australia’, Ph.D. thesis, University of Technology, Sydney.

Mallen-Cooper, M. 2000. 'Review of fish passage in NSW', Report for NSW Fisheries.

Mallen-Cooper, M., Stuart, I.G., Hides-Pearson, F., and Harris, J. H. 1995. ‘Fish migration in the Murray River and assessment of the Torrumbarry Fishway’, *Final report for Natural Resources Management Strategy Project N002.* NSW Fisheries Research Institute and Cooperative Research Centre for Freshwater Ecology.

Marsden, T.L. and Gehrke, P.C. 1996. 'Fish passage in the Hawksbury River System' in Gehrke, P.C. and Harris, J.H. (eds) *Fish and fisheries of the Hawskbury-Nepean River System*. chapter 11. Final Report to the Sydney Water Corporation. NSW Fisheries Research Institute and Cooperative Research Center for Freshwater Ecology.

Marsden, T. J., Gehrke, P. C. and Harris, J. H. 1997. 'Tallowa Dam High Fishway Project. Stage 2 Comprehensive report', NSW Fisheries and Cooperative Research Centre for Freshwater Ecology, Cronulla.

Marsden, T. J. and Harris, J. H. 1996. 'Tallowa Dam high fishway project. Preliminary report', NSW Fisheries Research Institute.

McDowall, R. M. (Ed.) 1996. *The Freshwater Fishes of South-eastern Australia* (2nd edn.), Reed, Sydney.

McGlashan, D. J. and Hughes, J. M. 2000. 'Low levels of genetic differentiation among populations of the freshwater fish *Hypseleotris compressa* (Gobiidae: Eleotridinae): implications for its biology, population connectivity and history', *Heredity* (in press).

Moore, A., Russell, I.D. and Potter, E.C.E. 1990. 'The effects of intraperitoneally implanted dummy acoustic transmitters of the behaviour and physiology of juvenile Atlantic salmon, *Salmo salar* L.', *Journal of Fish Biology* **37,** 713-721.

Moring, J. R. 1993. 'Anadromous stocks', in Kohler, C. C. and Hubert, W. A. (eds), *Inland Fisheries Management in North America*, American Fisheries Society, Bethesda. pp. 553-580.

Northcote, T.G. 1978. 'Migration strategies and production in freshwater fisheries', in S.D. Gerking, (ed.) Ecology *of Freshwater Fish Production.* Blackwell Scientific Publications, Oxford. pp. 326-359.

Northcote, T. G. 1998. 'Migratory behaviour of fish and its significance to movement through riverine fish passage facilities', in M. Jungwirth, S. Schmutz and S. Weiss (eds) *Fish Migration and fish bypasses.* Fishing News Books, Oxford. pp; 3 – 18.

Orth, D. J. and White, R. J. 1993. 'Stream habitat management', in Kohler, C. C. and Hubert, W. A. (eds), *Inland Fisheries Management in North America*, American Fisheries Society, Bethesda. pp. 205-230.

Peter, A. 1998. 'Interruption of the river continuum by barriers and the consequences for migratory fish', in. Jungwirth, M., Schmutz, S. and Weiss, S. (eds), *Fish Migration and Fish Bypasses*, Fishing News Books, Oxford. pp. 99-112.

Pethebridge, R., Lugg, A. and Harris, J.H. 1998. 'Obstructions to fish passage in New South Wales South Coast streams', NSW Fisheries Office of Conservation and Cooperative Research Centre for Freshwater Ecology, Sydney. 69 pp.

Pollard, D. A., Llewellyn, L. C. and Tilzey, R. D., 1980. 'Management of freshwater fish and fisheries',. in Williams, W. D. (ed.) *An Ecological Basis for Water Resource Management*, John Wiley and Sons, London. pp. 227-270.

Reynolds, L.F. 1983. Migration patterns of five fish species in the Murrray-Darling River System', *Australian Journal of Marine and Freshwater Research* **34,** 57-71.

Ribeiro, M. C. L. B., Petrere, M. and Juras, A. A. 1995. 'Ecological integrity and fisheries ecology of the Araguaia-Tocantins River basin, Brazil', *Regulated Rivers: Research and Management,* **11,** 363-375.

Ruggles, C. E. 1980. 'A review of the downstream migration of Atlantic salmon', *Canadian Technical Reports on Fish and Aquatic Sciences* **952,** 37.

Russell, D. J., 1991. 'Fish movements through a fishway on a tidal barrage in subtropical Queensland', *Proceedings of the Royal Society of Queensland*, **101,** 109-118.

Sheldon, F. and Walker, K.F. 1997. ‘Changes in biofilms induced by flow regulation could explain extinctions of aquatic snails in the lower River Murray, Australia’, *Hydrobiologia* **347**, 97-108.

Sherman, B. 2000. Scoping options for mitigating cold water discharges from dams', CSIRO Land and Water, Canberra, Consultancy report.

Smithson, E.B. and Johnston, C.E. 1999. 'Movement patterns of stream fishes in a Ouachita highlands stream: An examination of the restricted movement paradigm', *Transactions of the American Fisheries Society* **128,** 847-853.

Sokal, R.R. and Rohlf, K.J. 1995. *Biometry. (3rd edn)*. W.H. Freeman and Company New York.

Stephenson, W.S. and Burgess, D. 1980. ‘Skewness of data in the analysis of species-in-sites-in-times’, *Proceedings of the Royal Society of Queensland*, **91,** 331-342.

Stuart, I.G. 1997. 'Assessment of a modified vertical slot fishway, Fitzroy River, Queensland', Department of Primary Industries, Queensland.

Stuart, I. G. and Berghuis, A. P. 1997. 'Assessment of Eden Bann weir Fishlock, Fitzroy River, Queensland', Department of primary Industries, Queensland.

Stuart, I. G. and Berghuis, A. P. 1999. 'Passage of native fish in a modified vertical-slot fishway on the Burnett River barrage, South-eastern Queensland', Department of primary Industries, Queensland.

Stuart, I. G. and Mallen-Cooper, M. 1999. ‘An assessment of the effectiveness of a vertical-slot fishway for non-salmonid fish at a tidal barrier on a large tropical/subtropical river’. *Regulated Rivers: Research and Management* **15,** 575-590.

Thomson, J.M. 1963. 'Synopsis of the biological data on the grey mullet *Mugil cephalus* Linnaeus 1758', C.S.I.R.O *Fisheries Synopsis* No. 1, 54pp.

Thorncraft, G. and Harris, J.H. 1997a. ‘Yarrawonga Weir Fishway Report’, Report to the Murray-Darling Basin Commission. NSW Fisheries Research Institute and Cooperative Research Centre for Freshwater Ecology, Cronulla. 23 pp.

Thorncraft, G. and Harris, J.H. 1997b. ‘Rock-ramp and lock fishways as tools for solving fish-passage problems in New South Wales, Australia’, in A.P. Berghuis, P.E. Long and I.G. Stuart, (eds), Second National Fishway Technical Workshop Proceedings. Rockhampton, June 1997. Department of Primary Industries, Brisbane. pp. 203-226.

Thorncraft, G. and Harris, J.H. 2000. ‘Fish passage and fishways in New South Wales: a status report’, Cooperative Research Centre for Freshwater Ecology Technical Report 1/2000', NSW Fisheries Office of Conservation and the Cooperative Research Centre for Freshwater Ecology, Sydney. 32 pp.

Travade, F., Larinier, M., Boyer-Bernard, S. and Dartiguelongue, J. 1998. ‘Performance of four fish pass installations recently built on two rivers in South-west France’, in M. Jungwirth, S. Schmutz and S. Weiss (eds) *Fish Migration and fish bypasses*. Fishing News Books, Oxford. pp. 146 – 170.)

Virgona, J., Deguara, K. and Sullings, D. 1998. 'Assessment of the stocks of sea mullet in New South Wales and Queensland waters', NSW Fisheries, Cronulla.

Walker, K. F., Hillman, T. J. and Williams, W. D. 1979. ‘The effects of impoundment on rivers: An Australian case study’, *Verhandlungen. Internationale Vereinigung für Theoretische und Angewandte Limnologie* **20,** 2695-2701.

Walker, K. F., Thoms, M. C. and Sheldon, F. 1992. ‘Effects of weirs on the littoral environment of the River Murray, South Australia’, in Boon, P. J., Calow, P. A. and Petts, G. E. (eds), *River Conservation and Management.* Wiley, Chichester. pp. 271-292.

Walsh, M.G., Kimberly, A.B. and Isely, J.J. 2000. 'Effects of implantation method and temperature on mortality and loss of simulated transmitters in hybrid striped bass', Transactions of the American Fisheries Society 129, 539-544.

Ward, J.V. and Stanford, J.A. 1989. ‘Riverine ecosystems: the influence of man on catchment dynamics and fish ecology’, in D.P. Dodge, (ed.), *Proceedings of the International Large Rivers Symposium.* Canadian Special Publication on Fisheries and Aquatic Sciences **106,** 56-64.

Welcomme, R. L. 1985. ‘River Fisheries’, *FAO Fisheries Technical Paper 262.* 330 pp.

Welcomme, R. L. 1998. ‘Evaluation of stocking and introductions as management tools’, in Cowx, I. G. (ed.) *Stocking and Introduction of Fish*, Fishing News Books, Oxford. pp. 397-413.

Williams, J. G. 1998. ‘Fish passage in the Columbia River, USA and its tributaries: Problems and solutions’ in M. Jungwirth, S. Schmutz and S. Weiss (eds) Fish Migration and fish bypasses. Fishing News Books, Oxford. pp. 180 – 191.

APPENDIX 1: SITE DETAILS

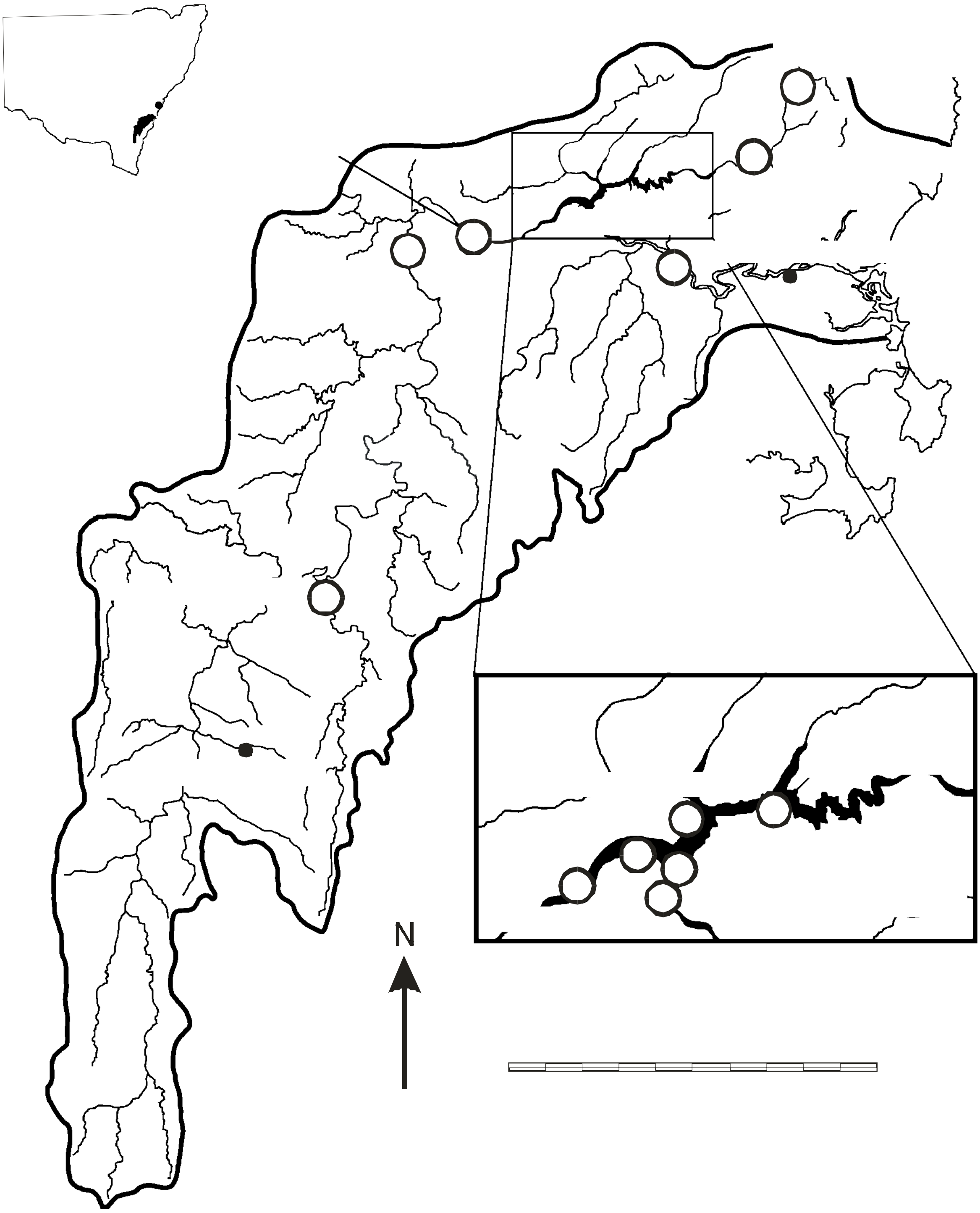


Figure 1. Sites sampled above and below Tallowa Dam to investigate the effects of the dam on fish communities in the Shoalhaven River system. Sites 1 and 3 were sampled during previous surveys but were not sampled during this study.

Table 1. Site details

Reach	Site	Site name	Latitude	Longitude	Altitude
Upper reaches	11	Mongarlowe River	35° 14’ 50”	149° 54’ 56”	550
Shoalhaven River	12	Tolwong Mines	34° 49’ 53”	150° 2’ 29”	130
	2	Fossicker’s Flat	34° 49’ 17”	150° 11’ 9”	70
Kangaroo River	4	Upper Kangaroo Valley	34° 39’ 3”	150° 36’ 12”	120
	5	Kangaroo Valley	34° 43’ 17”	150° 31’ 15”	60
Lake Yarrunga	14	Beehive Point	34° 45’ 6”	150° 22’ 15”	50
	6	Sawyer’s Spur	34° 45’ 41”	150° 19’ 36”	50
	7	Paul’s Lookout	34° 46’ 36”	150° 18’ 11”	50
	13	Monarch Bluff	34° 47’ 14”	150° 15’ 34”	50
Downstream of Tallowa	8	Directly under dam	34° 46’ 23”	150° 18’ 52”	30
	9	500m downstream of	34° 46’ 36”	150° 18’ 56”	30
	10	Burrier pump station	34° 52’ 1”	150° 25’ 51”	< 10

Sites 1 and 3 were not sampled during this stage of the project.

Site No.	11	**Stream Name**	Mongarlowe River
Site Name:	Mongarlowe River	**Reach Code**	UR

Substratum	Grade
Bedrock	F
Boulder	O
Cobble	A
Gravel	F
Sand	A
Mud/silt	O
Clay	R
Unknown	

Plants	Grade
Native Trees	F
Exotic Trees	R
Shrubs	F
Terrestrial Grass	F
Rushes, Sedges	O
Littoral Grasses	F
Floating Macrophytes	O
Submerged Macrophytes	O
Algae	F

Cover	Grade
Rock	F
Timber	F
Undercuts	O
Plant Litter	F

Grades
Abundant
Frequent
Occasional
Rare

Survey	Temp °C	D.O. (mg/L)	PH	Conductivity (μS/cm)	Turbidity (H,M,L,C)	Flow (H,M,L)	Velocity (F/M/S)
Apr-98	-	-	-	-	-	-	-
Nov-98	18.7	6.99	5.5	65.5	L	M	M
Feb-99	21.9	9.915	7.035	30	L	M	M
Nov-99	-	-	-	-	-	-	-

Figure 2. Habitat details for site 11, Mongarlowe River.

Site No.	12	**Stream Name**	Shoalhaven River
Site Name:	Tolwong Mines	**Reach Code**	SR

Substratum	Grade
Bedrock	A
Boulder	F
Cobble	O
Gravel	O
Sand	A
Mud/silt	F
Clay	R
Unknown	

Plants	Grade
Native Trees	A
Exotic Trees	R
Shrubs	A
Terrestrial Grass	A
Rushes, Sedges	O
Littoral Grasses	O
Floating Macrophytes	O
Submerged Macrophytes	O
Algae	F

Cover	Grade
Rock	A
Timber	F
Undercuts	O
Plant Litter	A

Grades
Abundant
Frequent
Occasional
Rare

Survey	Temp °C	D.O. (mg/L)	pH	Conductivity (µS/cm)	Turbidity (H,M,L,C)	Flow (H,M,L)	Velocity (F/M/S)
Apr-98	-	-	-	-	-	-	-
Nov-98	22.23	8.33	7.3	78	L	M	S
Feb-99	21.36	8.78	6.46	68.6	L	L	S
Nov-99	-	-	-	-	-	-	-

Figure 3. Habitat details for site 12, Tolwong Mines.

Site No.	2	**Stream Name**	Shoalhaven River
Site Name:	Fossicker's Flat	**Reach Code**	SR

Substratum	Grade
Bedrock	A
Boulder	A
Cobble	A
Gravel	A
Sand	A
Mud/silt	O
Clay	-
Unknown	-

Plants	Grade
Native Trees	A
Exotic Trees	-
Shrubs	A
Terrestrial Grass	O
Rushes, Sedges	O
Littoral Grasses	-
Floating Macrophytes	-
Submerged Macrophytes	-
Algae	A

Cover	Grade
Rock	A
Timber	R
Undercuts	A
Plant Litter	A

Grades
Abundant
Frequent
Occasional
Rare

Survey	Temp °C	D.O. (mg/L)	PH	Conductivity (µS/cm)	Turbidity (H,M,L,C)	Flow (H,M,L)	Velocity (F/M/S)
Apr-98	-	-	-	-	-	-	-
Nov-98	24.56	8.66	7.35	.086	L	M	S
Feb-99	22.35	8.69	7.25	.069	L	L	S
Nov-99	-	-	-	-	-	-	-

Figure 4. Habitat details for site 2, Fossickers Flat.

Site No.	4	**Stream Name**	Kangaroo River
Site Name:	Upper Kangaroo River	**Reach Code**	KR

Substratum	Grade
Bedrock	A
Boulder	A
Cobble	F
Gravel	O
Sand	O
Mud/silt	R
Clay	R
Unknown	-

Plants	Grade
Native Trees	A
Exotic Trees	R
Shrubs	O
Terrestrial Grass	O
Rushes, Sedges	O
Littoral Grasses	O
Floating Macrophytes	-
Submerged Macrophytes	-
Algae	O

Cover	Grade
Rock	A
Timber	O
Undercuts	A
Plant Litter	O

Grades
Abundant
Frequent
Occasional
Rare

Survey	Temp °C	D.O. (mg/L)	pH	Conductivity (μS/cm)	Turbidity (H,M,L,C)	Flow (H,M,L)	Velocity (F/M/S)
Apr-98	-	-	-	-	-	-	-
Nov-98	15.7	11.215	-	7.235	C	L	S
Feb-99	19.35	11.535	7.025	.034	L	H	M
Nov-99	-	-	-	-	-	-	-

Figure 5. Habitat details for site 4, Upper Kangaroo River.

Site No.	5	**Stream Name**	Kangaroo River
Site Name:	Kangaroo Valley, Hampden Bridge	**Reach Code**	KR

Substratum	Grade
Bedrock	A
Boulder	O
Cobble	F
Gravel	F
Sand	A
Mud/silt	R
Clay	-
Unknown	-

Plants	Grade
Native Trees	A
Exotic Trees	R
Shrubs	A
Terrestrial Grass	O
Rushes, Sedges	-
Littoral Grasses	O
Floating Macrophytes	-
Submerged Macrophytes	-
Algae	O

Cover	Grade
Rock	A
Timber	F
Undercuts	F
Plant Litter	O

Grades
Abundant
Frequent
Occasional
Rare

Survey	Temp °C	D.O. (mg/L)	PH	Conductivity (µS/cm)	Turbidity (H,M,L,C)	Flow (H,M,L)	Velocity (F/M/S)
Apr-98	-	-	-	-	-	-	-
Nov-98	19.5	5.68	-	100.8	L	M	M
Feb-99	19.5	10.26	6.34	39	H	M	M
Nov-99	-	-	-	-	-	-	-

Figure 6. Habitat details for site 5, Kangaroo Valley.

Site No.	14	**Stream Name**	Lake Yarrunga
Site Name:	Beehive Point	**Reach Code**	LY

Substratum	Grade
Bedrock	F
Boulder	O
Cobble	O
Gravel	O
Sand	R
Mud/silt	A
Clay	-
Unknown	-

Plants	Grade
Native Trees	A
Exotic Trees	R
Shrubs	A
Terrestrial Grass	O
Rushes, Sedges	O
Littoral Grasses	O
Floating Macrophytes	R
Submerged Macrophytes	O
Algae	F

Cover	Grade
Rock	A
Timber	A
Undercuts	O
Plant Litter	A

Grades
Abundant
Frequent
Occasional
Rare

Survey	Variation by Depth	Temp °C	D.O. (mg/L)	PH	Conductivity (μS/cm)	Turbidity (H,M,L,C)	Level (H/M/L)
Apr-98	Above Thermocline	-	-	-	-	-	-
	Below Thermocline	-	-	-	-	-	-
Nov-98	Above Thermocline	21.48	7.37	6.63	.0828	L	H
	Below Thermocline	18.8	1.77	6.16	.086	L	H
Feb-99	Above Thermocline	24.98	7.402	7.05	70.8	L	M
	Below Thermocline	22.02	.1325	6.51	82.25	L	M
Nov-99	Above Thermocline	-	-	-	-	-	-
	Below Thermocline	-	-	-	-	-	-

Figure 7. Habitat details for site 14, Beehive Point.

Site No.	6	**Stream Name**	Lake Yarrunga
Site Name:	Sawyer's Spur	**Reach Code**	LY

Substratum	**Grade**
Bedrock	F
Boulder	O
Cobble	R
Gravel	O
Sand	R
Mud/silt	F
Clay	O
Unknown	-

Plants	**Grade**
Native Trees	A
Exotic Trees	-
Shrubs	A
Terrestrial Grass	F
Rushes, Sedges	O
Littoral Grasses	R
Floating Macrophytes	-
Submerged Macrophytes	R
Algae	A

Cover	**Grade**
Rock	A
Timber	F
Undercuts	O
Plant Litter	A

Grades
Abundant
Frequent
Occasional
Rare

Survey	**Variation by Depth**	**Temp °C**	**D.O. (mg/L)**	**PH**	**Conductivity (μS/cm)**	**Turbidity (H,M,L,C)**	**Level (H/M/L)**
Apr-98	Above Thermocline	-	-	-	-	-	-
	Below Thermocline	-	-	-	-	-	-
Nov-98	Above Thermocline	21.84	7.826	7.44	83.4	L	H
	Below Thermocline	19.13	4.16	7.50	86	L	H
Feb-99	Above Thermocline	25.06	8.02	7.20	66	L	M
	Below Thermocline	-	-	-	-	-	-
Nov-99	Above Thermocline	-	-	-	-	-	-
	Below Thermocline	-	-	-	-	-	-

Figure 8. Habitat details for site 6, Sawyer's Spur

Site No.	7	**Stream Name**	Lake Yarrunga
Site Name:	Paul's Lookout	**Reach Code**	LY

Substratum	Grade
Bedrock	A
Boulder	F
Cobble	O
Gravel	-
Sand	R
Mud/silt	O
Clay	O
Unknown	-

Plants	Grade
Native Trees	A
Exotic Trees	-
Shrubs	A
Terrestrial Grass	O
Rushes, Sedges	R
Littoral Grasses	R
Floating Macrophytes	O
Submerged Macrophytes	R
Algae	A

Cover	Grade
Rock	A
Timber	A
Undercuts	A
Plant Litter	A

Grades
Abundant
Frequent
Occasional
Rare

Survey	Variation by Depth	Temp °C	D.O. (mg/L)	PH	Conductivity (µS/cm)	Turbidity (H,M,L,C)	Level (H/M/L)
Apr-98	Above Thermocline	-	-	-	-	-	-
	Below Thermocline	-	-	-	-	-	-
Nov-98	Above Thermocline	23.2	8.10	7.32	0.084	M	H
	Below Thermocline	22.4	7.55	7.29	0.084	M	H
Feb-99	Above Thermocline	24.6	7.56	7.23	62	L	M
	Below Thermocline	24.6	6.69	7.06	62	L	M
Nov-99	Above Thermocline	-	-	-	-	-	-
	Below Thermocline	-	-	-	-	-	-

Figure 9. Habitat details for site 7, Paul's Lookout.

Site No.	13	**Stream Name**	Lake Yarrunga
Site Name:	Monarch Bluff	**Reach Code**	LY

Substratum	**Grade**
Bedrock	A
Boulder	A
Cobble	O
Gravel	F
Sand	O
Mud/silt	A
Clay	R
Unknown	

Plants	**Grade**
Native Trees	A
Exotic Trees	
Shrubs	A
Terrestrial Grass	A
Rushes, Sedges	F
Littoral Grasses	O
Floating Macrophytes	O
Submerged Macrophytes	
Algae	A

Cover	**Grade**
Rock	A
Timber	A
Undercuts	A
Plant Litter	A

Grades
Abundant
Frequent
Occasional
Rare

Survey	Variation by Depth	Temp °C	D.O. (mg/L)	PH	Conductivity (μS/cm)	Turbidity (H,M,L,C)	Level (H/M/L)
Apr-98	Above Thermocline	-	-	-	-	-	-
	Below Thermocline	-	-	-	-	-	-
Nov-98	Above Thermocline	22.7	7.60	6.915	83	L	H
	Below Thermocline	-	-	-	-	-	-
Feb-99	Above Thermocline	25.65	7.33	6.99	53		
	Below Thermocline	22.73	1.923	6.71	73	L	M
Nov-99	Above Thermocline	-	-	-	-	-	-
	Below Thermocline	-	-	-	-	-	-

Figure 10. Habitat details for site 13, Monarch Bluff.

Site No.	8	**Stream Name**	Shoalhaven River
Site Name:	Directly D/S of Tallowa Dam	**Reach Code**	DST

Substratum	Grade
Bedrock	O
Boulder	O
Cobble	A
Gravel	A
Sand	O
Mud/silt	F
Clay	
Unknown	

Plants	Grade
Native Trees	A
Exotic Trees	
Shrubs	F
Terrestrial Grass	R
Rushes, Sedges	R
Littoral Grasses	R
Floating Macrophytes	R
Submerged Macrophytes	R
Algae	A

Cover	Grade
Rock	A
Timber	O
Undercuts	
Plant Litter	O

Grades
Abundant
Frequent
Occasional
Rare

Survey	Variation by Depth	Temp °C	D.O. (mg/L)	PH	Conductivity (µS/cm)	Turbidity (H,M,L,C)	Flow (H,M,L)	Velocity (F,M,S)
Apr-98	Cold Water Outlet	-	-	-	-	-	-	-
	Spillway	-	-	-	-	-	-	-
Nov-98	Cold Water Outlet	15.65	10.175	7.1	73.5	L	H	F
	Spillway	25.6	7.388	7.645	84	L	M	M
Feb-99	Cold Water Outlet	18.65	8.045	6.755	97.5	L	H	F
	Spillway	24.9	7.58	7.195	46	L	M	M
Nov-99	Cold Water Outlet	-	-	-	-	-	-	-
	Spillway	-	-	-	-	-	-	-

Figure 11. Habitat details for site 8, Directly below Tallowa Dam.

Site No.	9	**Stream Name**	Shoalhaven River
Site Name:	500m Downstream of Dam	**Reach Code**	DST

Substratum	Grade
Bedrock	A
Boulder	A
Cobble	A
Gravel	F
Sand	O
Mud/silt	F
Clay	R
Unknown	

Plants	Grade
Native Trees	A
Exotic Trees	
Shrubs	O
Terrestrial Grass	O
Rushes, Sedges	R
Littoral Grasses	R
Floating Macrophytes	
Submerged Macrophytes	F
Algae	A

Cover	Grade
Rock	A
Timber	O
Undercuts	F
Plant Litter	R

Grades
Abundant
Frequent
Occasional
Rare

Survey	Temp °C	D.O. (mg/L)	pH	Conductivity (μS/cm)	Turbidity (H,M,L,C)	Flow (H,M,L)	Velocity (F/M/S)
Apr-98	-	-	-	-	-	-	-
Nov-98	20.8	10.5	-	103	M	H	F
Feb-99	23.775	10.67	6.81	72	M	H	F
Nov-99	-	-	-	-	-	-	-

Figure 12. Habitat details for site 9, 500m downstream of Tallowa Dam.

Site No.	10	**Stream Name**	Shoalhaven River
Site Name:	Burrier Pump Station	**Reach Code**	DST

Substratum	Grade
Bedrock	F
Boulder	F
Cobble	F
Gravel	F
Sand	A
Mud/silt	O
Clay	
Unknown	

Plants	Grade
Native Trees	A
Exotic Trees	R
Shrubs	F
Terrestrial Grass	F
Rushes, Sedges	O
Littoral Grasses	A
Floating Macrophytes	
Submerged Macrophytes	O
Algae	O

Cover	Grade
Rock	A
Timber	O
Undercuts	F
Plant Litter	O

Grades
Abundant
Frequent
Occasional
Rare

Survey	Temp °C	D.O. (mg/L)	pH	Conductivity (µS/cm)	Turbidity (H,M,L,C)	Flow (H,M,L)	Velocity (F/M/S)
Apr-98	-	-	-	-	-	-	-
Nov-98	17.66	8.26	6.45	93	L	M	S
Feb-99	24.36	7.73	7.22	64.3	M	L	S
Nov-99	-	-	-	-	-	-	-

Figure 13. Habitat details for site 10, Burrier Pump Station.

APPENDIX 2: SPECIES BIOLOGY

Table 2. List of fish species recorded in or presumed to occur in the Shoalhaven River system.

Family	Scientific name	Common name	Comments
Mordaciidae	*Mordacia mordax*	Short-headed lamprey	
Anguillidae	*Anguilla australis*	Short-finned eel	
	Anguilla reinhardtii	Long-finned eel	
Clupeidae	*Potamalosa richmondia*	Freshwater herring	
Galaxiidae	*Galaxias brevipinnis*	Climbing galaxias	
	Galaxias olidus	Mountian galaxias	
	Galaxias maculatus	Common jollytail	
Salmonidae	*Salmo trutta*	Brown trout	Stocked
	Salvelinus fontinalis	Brook char	Stocked
	Oncorhynchus mykiss	Rainbow trout	Stocked
Retropinnidae	*Retropinna semoni*	Australian smelt	
Prototroctidae	*Prototroctes maraena*	Australian grayling	Threatened
Cyprinidae	*Carassius auratus*	Goldfish	Alien
	Cyprinus carpio	Carp	Alien
Plotosidae	*Tandanus tandanus*	Freshwater catfish	M-D
Poeciliidae	*Gambusia holbrooki*	Gambusia	Alien
Atherinidae	*Atherinosoma microstoma*	Smallmouthed	Estuarine / marine
Pseudomugilida	*Pseudomugil signifer*	Southern blue-eye	
Scorpaenidae	*Notesthes robusta*	Bullrout	
Chandidae	*Ambassis marianus*	Estuary perchlet	Estuarine / marine
Percichthyidae	*Macquaria australasica*	Macquarie perch	Threatened M-D
	Macquaria novemaculeata	Australian bass	
	Macquaria colonorum	Estuary perch	
Terapontidae	*Bidyanus bidyanus*	Silver perch	Escapee
Sparidae	*Acanthopagrus australis*	Yellow-finned bream	Estuarine / marine
Monodactylidae	*Monodactylus argenteus*	Silver batfish	Estuarine / marine
Percidae	*Perca fluviatilis*	Redfin perch	Alien
Mugilidae	*Myxus petardi*	Freshwater mullet	
	Myxus elongatus	Sand mullet	Estuarine / marine
	Mugil cephalus	Striped mullet	
	Aldrichetta forsteri	Yelloweyed mullet	Estuarine / marine
	Liza argentea	Flat-tail mullet	Estuarine / marine
Bovichtidae	*Pseudaphis urvilli*	Congolli	Estuarine / marine
Gobiidae	*Philypnodon grandiceps*	Flat-headed gudgeon	
	Philypnodon sp.1	Dwarf flat-headed	
	Gobiomorphus coxii	Cox's gudgeon	
	Gobiomorphus australis	Striped gudgeon	
	Hypseleotris compressa	Empire gudgeon	
	Hypseleotris galii	Fire-tailed gudgeon	
	Hypseleotris klunzingeri	Western carp gudgeon	M-D
	Pseudogobius sp. 9	Blue spot goby	Estuarine / marine
	Redigobius macrostoma	Largemouth goby	Estuarine / marine
	Amoya bifrenatus	Bridled goby	Estuarine / marine
	Afurcagobius tamarensis	Tamar river goby	Estuarine / marine

M-D: Species not currently recognised as native to the south coast of New South Wales. Possibly introduced from the Murray-Darling River system.

Table 3: Migratory status and occurrence of fish species in each reach: UR Upper reaches; SR Shoalhaven River; KR Kangaroo River; LY Lake Yarrunga; DST Downstream of Tallowa Dam.

	Species	UR	SR	KR	LY	DST
Undefined migratory behaviour	*Carassius auratus*			●		●
	Gambusia holbrooki	●	●		●	
	Hypseleotris klunzingeri	●			●	
	Philypnodon grandiceps		●	●	●	●
	Philypnodon sp.1			●	●	●
	Pseudomugil signifer					
	Tandanus tandanus				●	●
Potamodromous	*Bidyanus bidyanus*					
	Cyprinus carpio		●	●	●	●
	Galaxias olidus					
	Gobiomorphus coxii		●	●	●	●
	Hypseleotris galii					
	Macquaria australasica	●				
	Oncorhynchus mykiss					
	Perca fluviatilis					
	Retropinna semoni		●	●	●	●
	Salmo trutta	○				○
	Salvelinus fontinalis					
Anadromous	*Mordacia mordax*					●
Amphidromous	*Galaxias brevipinnis*	●				
	Gobiomorphus australis					●
	Hypseleotris compressa#					●
	Prototroctes maraena					
Catadromous	*Anguilla australis*	●	●		●	●
	Anguilla reinhardtii	●	●	●	●	●
	Galaxias maculatus					●
	Macquaria colonorum					●
	Macquaria novemaculeata		○	○	○	●
	Mugil cephalus					●
	Myxus petardi					●
	Notesthes robusta					●
	Potamalosa richmondia					●
Marine – estuarine	*Acanthopagrus australis*					●
	Afurcagobius tamarensis					
	Aldrichetta forsteri					
	Ambassis marianus					
	Amoya bifrenatus					
	Atherinosoma microstoma					
	Liza argentea					
	Monodactylus argenteus					
	Myxus elongatus					
	Pseudaphritis urvilli					
	Pseudogobius sp. 9					

○ Stocked population, ● Naturally occurring population or not intentionally stocked.

Table 4. Historical, current and potential distributions of fish species in the Shoalhaven River system. UR Upper reaches; SR Shoalhaven River; KR Kangaroo River; LY Lake Yarrunga; DST Downstream of Tallowa Dam.

Family	Species	UR	SR	KR	LY	DST	
Mordaciidae	*Mordacia mordax*					●	
Anguillidae	*Anguilla australis*	●	●		●	●	
	Anguilla reinhardtii	●	●	●	●	●	
Clupeidae	*Potamalosa richmondia*					●	
Galaxiidae	*Galaxias brevipinnis*	●		❍	❍	❍	Bishop (1979). Llewellyn (1983).
	Galaxias olidus	●		❍	❍		Bishop (1979). Llewellyn (1983).
	Galaxias maculatus	❍				●	Llewellyn (1983).
Salmonidae	*Salmo trutta*	●				●	Stocked: Boro Creek 91, 93; Corang River 87, 88, 92; Endrick River 87, 88; Fitzroy Falls (Yarrunga Creek) 84, 98; Jembaicumbene Creek 95; Jerrabattgulla Creek 95; Mongarlowe River 96, 97;Shoalhaven River (below dam) 95; Shoalhaven River (Welcome reef) 93.
	Oncorhynchus mykiss	❍					Stocked: Barrengarry River 86, 87, 89; Bundanoon Creek 82, 83, 87; Corang River 83, 84, 86, 92,96; Endrick River 83, 84, 86, 96; Fitzroy Falls (Yarrunga Creek) 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 86, 87, 88, 89, 90, 91, 92, 93, 96, 98; Jembaicumbene Creek 89; Jerrabattgulla Creek 84; Mongarlowe River 84; Nadgigomar Creek 83; Shoalhaven River (Welcome reef) 80.
	Salvelinus fontinalis	❍					Stocked: Fitzroy Falls (Yarrunga Creek) 73, 74, 75, 76, 77; Shoalhaven River 71. Occured in the upper Mongarlowe River (Bishop 1979). Failed to establish.
	Salmo salar	❍					Observed in Yarrunga creek (above Fitzroy falls) 78 (Bishop 1979).
Retropinnidae	*Retropinna semoni*	❍	●	●	●	●	Llewellyn (1983).
Prototroctidae	*Prototroctes maraena*			❍		❍	*c.* 500 sampled on 27/11/76. *c.* 40 on 2/12/76, 16 on 3/12/76 and 2 on 22/12/76 at site 8 (Bishop and Bell, 1978). One male sampled from Yalwal Creek on 14/7/1994 (Faragher 1999). Observed at Kangaroo valley in 1902 (Stead (1903) and 72 (Dean 73). Other creek 1901 (Stead 1903).- Yalwal creek (Llewellyn 1983).
Cyprinidae	*Carassius auratus*	❍		●		●	Bishop (1979) and Llewellyn (1983).
	Cyprinus carpio		●	●	●	●	
Plotosidae	*Tandanus tandanus*				●	●	

Family	Species	UR	SR	KR	LY	DST	
Poeciliidae	*Gambusia holbrooki*	●	●	●	●		
Atherinidae	*Atherinosoma microstoma*						Shoalhaven within species range. May occur further down the estuary. Not strictly freshwater but moves into brackish waters (McDowall, 1996).
Pseudomugilida	*Pseudomugil signifer*						Shoalhaven within species range (McDowall, 1996).
Scorpaenidae	*Notesthes robusta*					●	
Chandidae	*Ambassis marianus*						Shoalhaven within species range. May occur further down the estuary (McDowall, 1996).
Percichthyidae	*Macquaria ambigua*		?				Stocked into farm dams in Braidwood area. No escapees reported (Bishop 1979).
	Macquaria australasica	●		❍		❍	Sampled at site 8 on 22/12/76 (Bishop and Bell, 1978), as well as in 60, 62 and 72 by Williams. Sampled in Kangaroo valley in 60 (Williams 1960). Sampled from Kangaroo valley in 85-86 (Dufty 1986). Sampled at site 10 and site 12 (Llewellyn 1983).
	Macquaria novemaculeata		❍	●	❍	●	Stocked: Danjera Creek 81, 96, 98; Fitzroy Falls (Yarrunga Creek) 96, 98; Flat rock Creek 96; Shoalhaven River (below dam) 90; Tallowa dam 90, 94, 98. Original distribution extended as far as the Corang River (Webb 1973).
	Macquaria colonorum					●	
Terapontidae	*Bidyanus bidyanus*			?			Unconfirmed reports by local anglers of recent captures in the Kangaroo River. Likely escapee from known stocking of farm dams within catchment.
Sparidae	*Acanthopagrus australis*					●	Normally occurs lower in estuary.
Monodactylida	*Monodactylus argenteus*						May occur further down the estuary (Harris and Gehrke, 1997).
Percidae	*Perca fluviatilis*	?	?	?	?	?	McDowall (1996) indicates possible occurrence in Shoalhaven River.
Mugilidae	*Myxus petardi*				❍	●	Some individuals trapped in Lake Yarrunga (Bishop 1979).
	Myxus elongatus					❍	Sampled at site 10 in 96 (Harris and Gehrke, 1997).
	Mugil cephalus				❍	●	Large schools trapped in Lake Yarrunga after dam construction (Bishop, 1979).
	Aldrichetta forsteri						Shoalhaven within species range. May occur further down the estuary (McDowall, 1996).
	Liza argentea						Shoalhaven within species range. May occur further down the estuary (McDowall, 1996).
Bovichtidae	*Pseudaphritis urvilli*						Shoalhaven within species range (McDowall, 1996).
Gobiidae	*Philypnodon grandiceps*		●	●	●	●	
	Philypnodon sp.1			●	●	●	

Table 4 (cont.). Historical, current and potential distributions of fish species in the Shoalhaven River system. UR Upper reaches; SR Shoalhaven River; KR Kangaroo River; LY Lake Yarrunga; DST Downstream of Tallowa Dam.

Family	Species	UR	SR	KR	LY	DST	
Gobiidae (cont.)	*Gobiomorphus coxii*	❍	●	●	●	●	Llewellyn (1983).
	Gobiomorphus australis				❍	●	Some individuals trapped in Lake Yarrunga (Bishop, 1979).
	Hypseleotris compressa					●	
	Hypseleotris galii						Shoalhaven within species range (McDowall, 1996).
	Hypseleotris klunzingeri	●			●		
	Pseudogobius sp. 9						Shoalhaven within species range. May occur further down the estuary (McDowall, 1996).
	Redigobius macrostoma						Shoalhaven within species range. May occur further down the estuary (McDowall, 1996).
	Amoya bifrenatus						Shoalhaven within species range. May occur further down the estuary (McDowall, 1996).
	Afurcagobius tamarensis						Shoalhaven within species range. May occur further down the estuary (McDowall, 1996).

● Observed in current survey
❍ Observed in previous assessments but not sampled during our study
(shaded) Potential distribution

APPENDIX 3: STAGE 3(II) SAMPLING DATA

Table 5. List of fish species sampled in each reach during this study: UR Upper reaches; SR Shoalhaven River; KR Kangaroo River; LY Lake Yarrunga; DST Downstream of Tallowa Dam.

Family	**Species**	Reach					**Number of regions**
		U	SR	K	LY	DST	
Mordaciidae	*Mordacia mordax*					●	1
Anguillidae	*Anguilla australis*	●	●		●	●	4
	Anguilla reinhardtii	●	●	●	●	●	5
Clupeidae	*Potamalosa richmondia*					●	1
Galaxiidae	*Galaxias brevipinnis*	●					1
	Galaxias maculatus					●	1
	Galaxias olidus	●					1
Salmonidae	*Salmo trutta*	○				○	2
Retropinnidae	*Retropinna semoni*		●	●	●	●	4
Cyprinidae	*Carassius auratus*			●		●	2
	Cyprinus carpio		●	●	●	●	4
Plotosidae	*Tandanus tandanus*				●	●	2
Poeciliidae	*Gambusia holbrooki*	●	●		●		3
Scorpaenidae	*Notesthes robusta*					●	1
Percichthyidae	*Macquaria australasica*	●					1
	Macquaria novemaculeata		○	○	○	●	4
	Macquaria colonorum					●	1
Sparidae	*Acanthopagrus australis*					●	1
Mugilidae	*Myxus petardi*					●	1
	Mugil cephalus					●	1
Gobiidae	*Philypnodon grandiceps*		●	●	●	●	4
	Philypnodon sp.1			●	●	●	3
	Gobiomorphus australis					●	1
	Gobiomorphus coxii		●	●	●	●	4
	Hypseleotris compressa					●	1
	Hypseleotris klunzingeri	●			●		2

○ Stocked population
● Naturally occurring or not intentionally stocked population

Table 6. Abundances of fish sampled within the Shoalhaven River system.

Species	Survey	Upper Reaches	Shoalhaven River		Kangaroo River		Within Lake Yarrunga				Below Tallowa Dam			Total
		11	**12**	**2**	**4**	**5**	**13**	**7**	**14**	**6**	**8**	**9**	**10**	
Anguillidae														
Anguilla reinhardtii	1	2	1	2	21	14	1	0	6	6	94	41	**24**	
	2	2	15	6	19	21	3	5	1	9	171	28	41	
	3	2	11	9	14	6	0	6	1	9	134	29	14	
	4	4	30	3	20	7	2	0	3	3	348	38	9	
	Total	**10**	**57**	**20**	**74**	**48**	**6**	**11**	**11**	**27**	**747**	**136**	**88**	**1235**
Anguilla australis	1	0	0	2	0	0	0	3	0	0	4	2	**0**	
	2	1	0	1	0	0	0	0	0	0	0	0	0	
	3	0	0	1	0	0	0	3	0	0	4	1	6	
	4	0	3	0	0	0	0	0	0	0	24	1	0	
	Total	**1**	**3**	**4**	**0**	**0**	**0**	**6**	**0**	**0**	**32**	**4**	**6**	**56**
Clupeidae														
Potamalosa richmondia	1	0	0	0	0	0	0	0	0	0	0	0	**0**	
	2	0	0	0	0	0	0	0	0	0	0	0	0	
	3	0	0	0	0	0	0	0	0	0	200	11	59	
	4	0	0	0	0	0	0	0	0	0	0	0	4	
	Total	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**200**	**11**	**63**	**274**
Galaxiidae														
Galaxias brevipinnis	1	8	0	0	0	0	0	0	0	0	0	0	**0**	
	2	0	0	0	0	0	0	0	0	0	0	0	0	
	3	8	0	0	0	0	0	0	0	0	0	0	0	
	4	4	0	0	0	0	0	0	0	0	0	0	0	
	Total	**20**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**		**0**	**20**

Table 6 (cont.). Species abundances of fish sampled within the Shoalhaven River system.

Species	Survey	Upper Reaches 11	Shoalhaven River 12	2	Kangaroo River 4	5	Within Lake Yarrunga 13	7	14	6	Below Tallowa Dam 8	9	10	Total
Galaxias maculatus	1	0	0	0	0	0	0	0	0	0	70	1	**0**	
	2	0	0	0	0	0	0	0	0	0	0	0	0	
	3	0	0	0	0	0	0	0	0	0	0	0	0	
	4	0	0	0	0	0	0	0	0	0	0	0	3	
	Total	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**70**	**1**	**3**	**74**
Galaxias olidus	1	0	0	0	0	0	0	0	0	0	0	0	**0**	
	2	11	0	0	0	0	0	0	0	0	0	0	0	
	3	0	0	0	0	0	0	0	0	0	0	0	0	
	4	0	0	0	0	0	0	0	0	0	0	0	0	
	Total	**11**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**11**
Gobiidae														
Gobiomorphus australis	1	0	0	0	0	0	0	0	0	0	34	11	1	
	2	0	0	0	0	0	0	0	0	0	5	5	8	
	3	0	0	0	0	0	0	0	0	0	11	51	6	
	4	0	0	0	0	0	0	0	0	0	4	27	12	
	Total	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**54**	**94**	**27**	**175**
Gobiomorphus coxii	1	0	0	0	20	0	1	0	0	0	77	31	**1**	
	2	0	16	4	16	0	0	0	2	2	71	59	1	
	3	0	10	6	16	1	4	4	2	1	35	0	0	
	4	0	17	2	26	1	0	1	0	0	0	3	1	
	Total	**0**	**43**	**12**	**78**	**2**	**5**	**5**	**4**	**3**	**183**	**93**	**3**	**431**
Hypseleotris compressa	1	0	0	0	0	0	0	0	0	0	0	0	**6**	
	2	0	0	0	0	0	0	0	0	0	0	0	11	
	3	0	0	0	0	0	0	0	0	0	0	0	6	
	4	0	0	0	0	0	0	0	0	0	0	2	0	
	Total	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**2**	**23**	**25**

Species	Survey	Upper Reaches 11	Shoalhaven River 12	2	Kangaroo River 4	5	Within Lake Yarrunga 13	7	14	6	Below Tallowa Dam 8	9	10	Total
Hypseleotris klunzingeri	1	6	0	0	0	0	0	0	0	0	0	0	0	
	2	2	0	0	0	0	0	0	0	0	0	0	0	
	3	0	0	0	0	0	0	0	0	0	0	0	0	
	4	2	0	0	0	0	0	1	0	0	0	0	0	
	Total	**10**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**11**
Philypnodon grandiceps	1	0	1	0	0	81	20	65	45	25	2	1	**0**	
	2	0	9	1	0	88	37	62	221	89	42	1	7	
	3	0	4	2	0	72	35	118	119	150	20	134	2	
	4	0	5	2	0	245	110	285	401	133	75	241	3	
	Total	**0**	**19**	**5**	**0**	**417**	**202**	**530**	**786**	**397**	**139**	**377**	**12**	**2884**
Philypnodon sp1	1	0	0	0	0	7	0	3	1	1	0	0	**0**	
	2	0	0	0	0	1	4	12	10	5	2	0	0	
	3	0	0	0	0	1	2	1	5	5	1	0	0	
	4	0	0	0	0	1	5	8	9	6	1	0	1	
	Total	**0**	**0**	**0**	**0**	**10**	**11**	**24**	**25**	**17**	**4**	**0**	**1**	**92**
Mordaciidae														
Mordacia mordax	1	0	0	0	0	0	0	0	0	0	0	0	**0**	
	2	0	0	0	0	0	0	0	0	0	0	0	0	
	3	0	0	0	0	0	0	0	0	0	0	0	0	
	4	0	0	0	0	0	0	0	0	0	0	0	1	
	Total	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**1**
Mugilidae														
Mugil cephalus	1	0	0	0	0	0	0	0	0	0	17	6	33	
	2	0	0	0	0	0	0	0	0	0	375	18	48	
	3	0	0	0	0	0	0	0	0	0	186	109	59	
	4	0	0	0	0	0	0	0	0	0	145	24	58	
	Total	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**723**	**157**	**198**	**1078**

Table 6 (cont.). Species abundances of fish sampled within the Shoalhaven River system.

Species	Survey	Upper Reaches	Shoalhaven River		Kangaroo River		Within Lake Yarrunga				Below Tallowa Dam			Total
		11	12	2	4	5	13	7	14	6	8	9	10	
Myxus elongatus	1	0	0	0	0	0	0	0	0	0	0	0	**0**	
	2	0	0	0	0	0	0	0	0	0	0	0	0	
	3	0	0	0	0	0	0	0	0	0	0	0	0	
	4	0	0	0	0	0	0	0	0	0	0	0	0	
	Total	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Myxus petardi	1	0	0	0	0	0	0	0	0	0	0	12	**8**	
	2	0	0	0	0	0	0	0	0	0	17	4	110	
	3	0	0	0	0	0	0	0	0	0	0	16	50	
	4	0	0	0	0	0	0	0	0	0	42	0	123	
	Total	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**59**	**32**	**291**	**382**
Percichthyidae														
Macquaria australasica	1	4	0	0	0	0	0	0	0	0	0	0	**0**	
	2	0	0	0	0	0	0	0	0	0	0	0	0	
	3	2	0	0	0	0	0	0	0	0	0	0	0	
	4	0	0	0	0	0	0	0	0	0	0	0	0	
	Total	**6**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**6**
Macquaria novemaculeata	1	0	0	6	0	29	7	7	11	12	9	35	**14**	
	2	0	3	3	0	3	0	11	7	7	390	6	37	
	3	0	0	2	0	2	3	5	4	4	197	27	48	
	4	0	0	2	0	1	1	2	17	0	107	21	19	
	Total	**0**	**3**	**13**	**0**	**35**	**11**	**25**	**39**	**23**	**703**	**89**	**118**	**1059**
Macquaria colonorum	1	0	0	0	0	0	0	0	0	0	0	0	**0**	
	2	0	0	0	0	0	0	0	0	0	0	0	1	
	3	0	0	0	0	0	0	0	0	0	0	0	0	
	4	0	0	0	0	0	0	0	0	0	0	0	0	
	Total	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**1**

Species	Survey	Upper Reaches	Shoalhaven River		Kangaroo River		Within Lake Yarrunga				Below Tallowa Dam			Total
		11	12	2	4	5	13	7	14	6	8	9	10	
Plotosidae														
Tandanus tandanus	1	0	0	0	0	0	2	7	5	2	0	0	**0**	
	2	0	0	0	0	0	0	0	1	1	3	0	0	
	3	0	0	0	0	0	0	2	0	1	2	1	0	
	4	0	0	0	0	0	0	2	0	4	0	0	1	
	Total	**0**	**0**	**0**	**0**	**0**	**2**	**11**	**6**	**8**	**5**	**1**	**1**	**34**
Retropinnidae														
Retropinna semoni	1	0	186	61	153	1018	365	360	360	68	699	221	**35**	
	2	0	52	315	7	217	78	154	209	266	582	451	128	
	3	0	457	274	570	447	256	176	41	576	230	1977	425	
	4	0	92	58	84	180	511	68	210	145	150	419	72	
	Total		**787**	**708**	**813**	**1862**	**1210**	**758**	**820**	**1055**	**1661**	**3068**	**660**	**13402**
Scorpaenidae														
Notesthes robusta	1	0	0	0	0	0	0	0	0	0	0	0	**0**	
	2	0	0	0	0	0	0	0	0	0	1	0	3	
	3	0	0	0	0	0	0	0	0	0	0	0	0	
	4	0	0	0	0	0	0	0	0	0	0	1	1	
	Total	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**1**	**4**	**6**
Sparidae														
Acanthopagrus australis	1	0	0	0	0	0	0	0	0	0	0	0	**0**	
	2	0	0	0	0	0	0	0	0	0	0	0	0	
	3	0	0	0	0	0	0	0	0	0	0	0	1	
	4	0	0	0	0	0	0	0	0	0	0	0	0	
	Total	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**1**

Table 6 (cont.). Species abundances of fish sampled within the Shoalhaven River system.

Species	Survey	Upper Reaches	Shoalhaven River		Kangaroo River		Within Lake Yarrunga				Below Tallowa Dam			Total
		11	12	2	4	5	13	7	14	6	8	9	10	
Cyprinidae														
Carassius auratus	1	0	0	0	0	0	0	0	0	0	0	0	**2**	
	2	0	0	0	0	1	0	0	0	0	0	0	0	
	3	0	0	0	0	0	0	0	0	0	1	0	0	
	4	0	0	0	0	0	0	0	0	0	0	0	0	
	Total	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**1**	**0**	**2**	**4**
Cyprinus carpio	1	0	5	5	0	0	2	5	2	3	20	15	1	
	2	0	3	5	0	1	6	6	0	1	29	13	0	
	3	0	3	0	0	0	4	1	2	0	19	0	5	
	4	0	8	2	0	0	3	7	5	3	22	5	1	
	Total	**0**	**19**	**12**	**0**	**1**	**15**	**19**	**9**	**7**	**90**	**33**	**7**	**212**
Poeciliidae														
Gambusia holbrooki	1	13	1	0	0	0	0	0	0	0	0	0	**0**	
	2	0	0	0	0	0	2	0	0	2	0	0	0	
	3	5	0	0	0	0	13	24	15	15	0	0	0	
	4	1	0	0	0	0	0	0	0	14	0	0	0	
	Total	**19**	**1**	**0**	**0**	**0**	**15**	**24**	**15**	**31**	**0**	**0**	**0**	**105**
Salmonidae														
Salmo trutta	1	0	0	0	0	0	0	0	0	0	1	0	0	
	2	2	0	0	0	0	0	0	0	0	2	0	0	
	3	0	0	0	0	0	0	0	0	0	3	0	0	
	4	0	0	0	0	0	0	0	0	0	3	0	0	
	Total	**2**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**9**	**0**	**0**	**11**
Total Number of fish		**79**	**932**	**774**	**965**	**2376**	**1477**	**1414**	**1715**	**1568**	**4681**	**4099**	**1510**	**21590**
Total Number of species		**8**	**8**	**7**	**3**	**8**	**9**	**11**	**9**	**9**	**17**	**15**	**20**	**26**

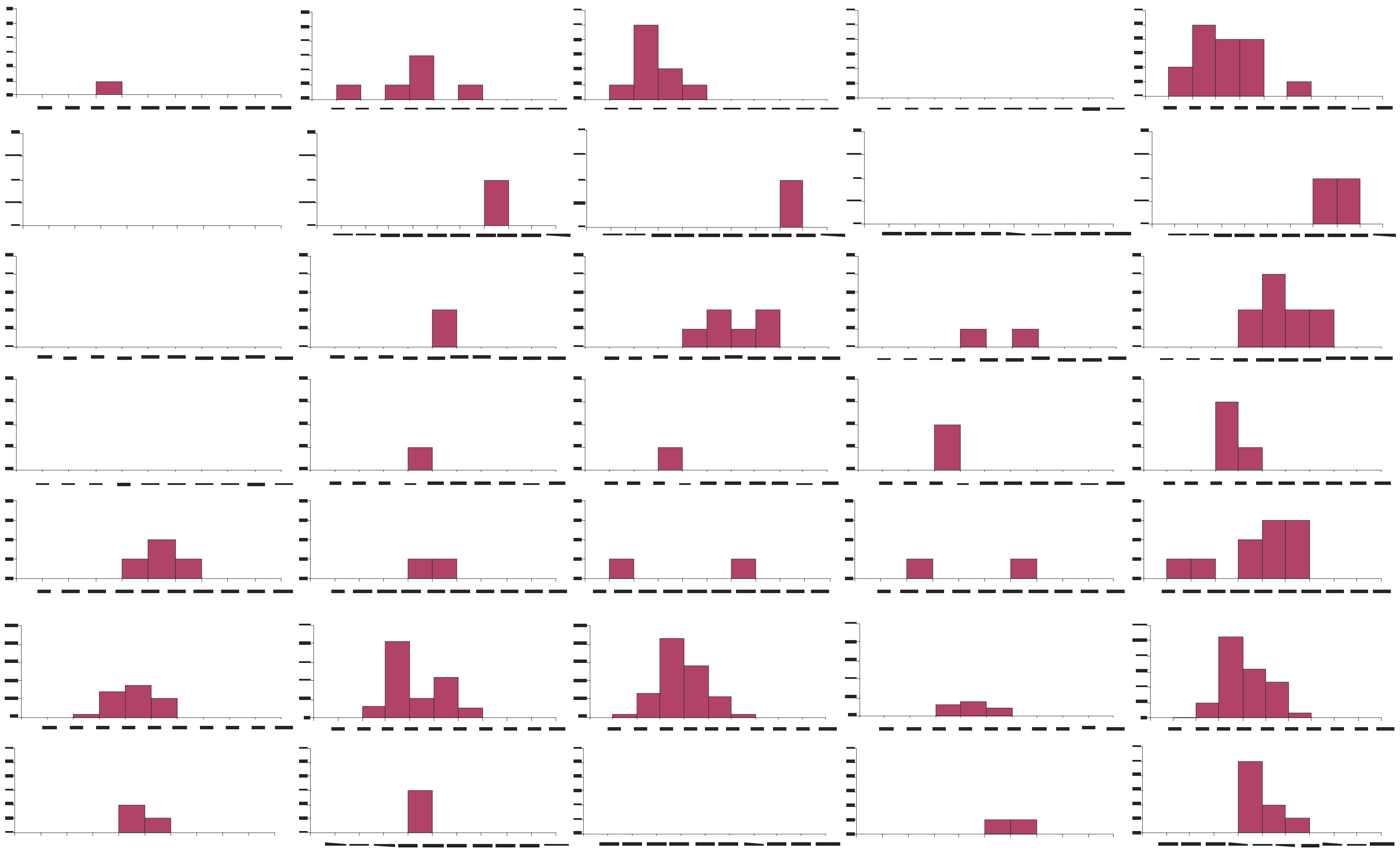


Figure 14: Length frequency distributions for fish sampled at site 2, Fossickers Flat, Shoalhaven River. X axis = size classes (mm) Y axis = number of fish per class.

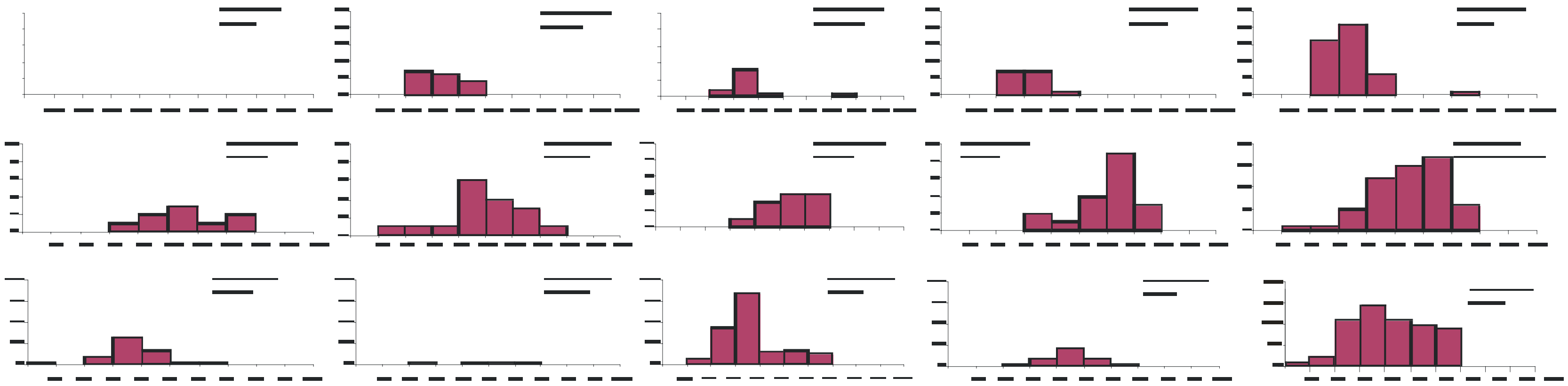


Figure 15: Length frequency distributions for fish sampled at site 4, Upper Kangaroo Valley, Kangaroo River. X axis = size classes (mm) Y axis = number of fish per class.

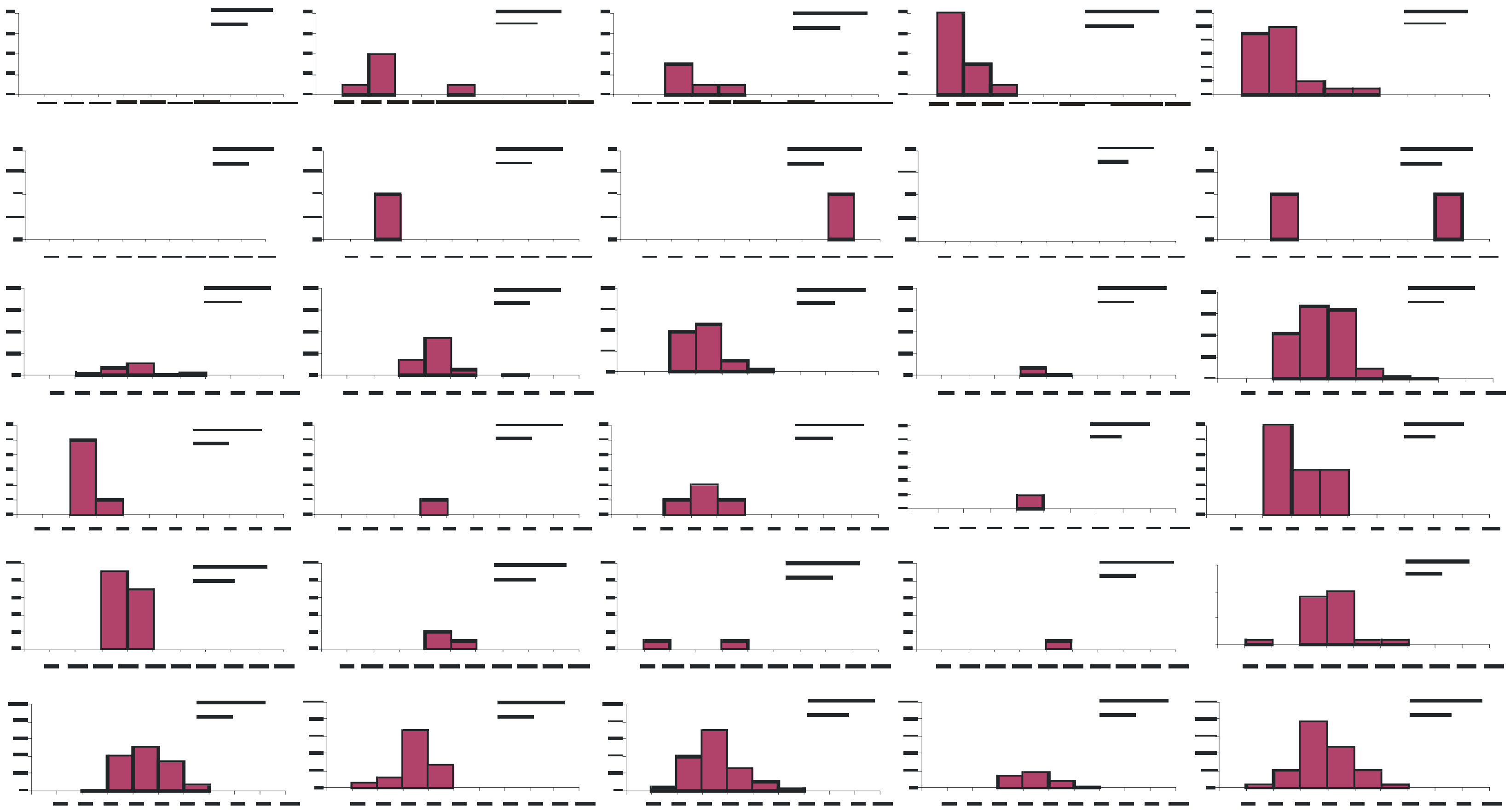


Figure 16: Length frequency distributions for fish sampled at site 5, Kangaroo Valley, Kangaroo River. X axis = size classes (mm) Y axis = number of fish per class.

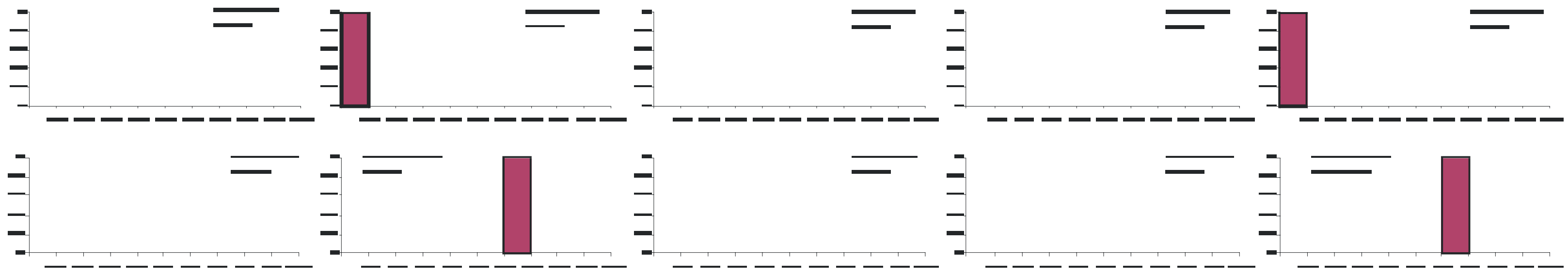


Figure 16 (cont.): Length frequency distributions for fish sampled at site 5, Kangaroo Valley, Kangaroo River. X axis = size classes (mm) Y axis = number of fish per class.

Figure 17: Length frequency distributions for fish sampled at site 6, Sawyer's Spur, Lake Yarrunga. X axis = size classes (mm) Y axis = number of fish per class.

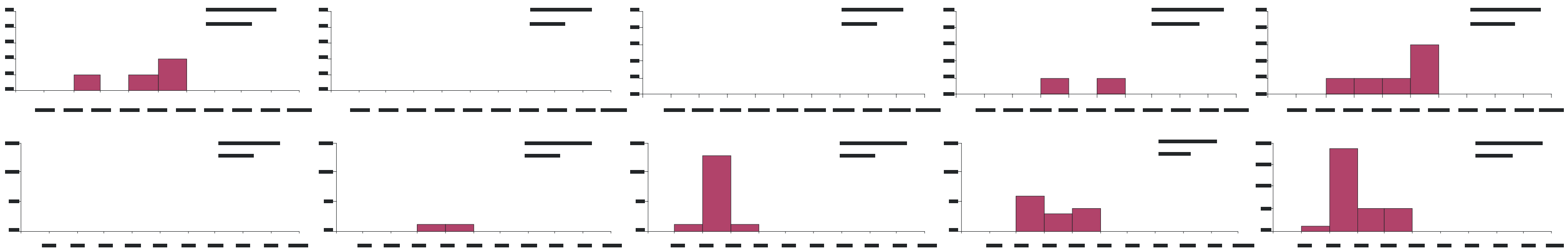


Figure 17 (cont.): Length frequency distributions for fish sampled at site 6, Sawyer's Spur, Lake Yarrunga. X axis = size classes (mm) Y axis = number of fish per class.

Figure 18: Length frequency distributions for fish sampled at site 7, Paul's Lookout, Lake Yarrunga. X axis = size classes (mm) Y axis = number of fish per class.

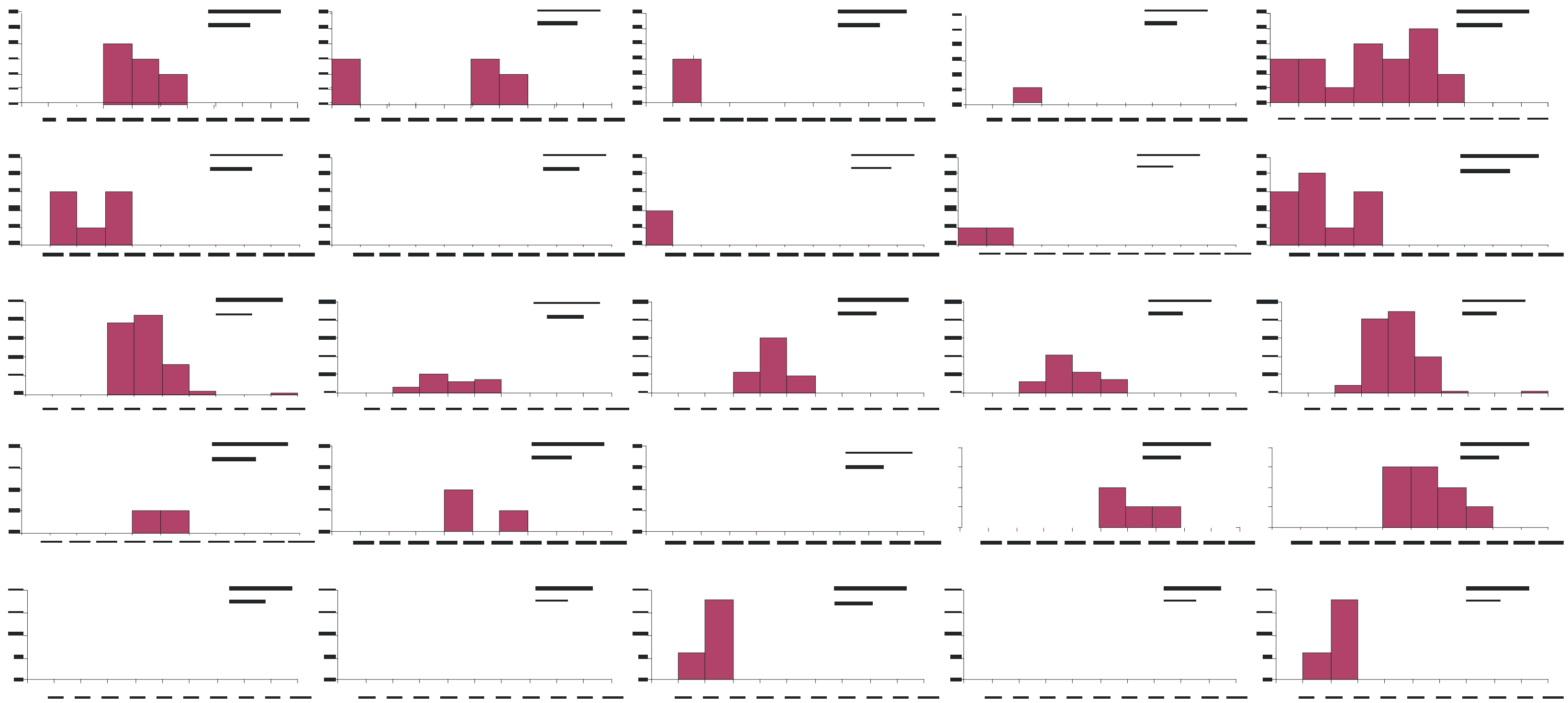


Figure 18 (cont.): Length frequency distributions for fish sampled at site 7, Paul's Lookout, Lake Yarrunga. X axis = size classes (mm) Y axis = number of fish per class.

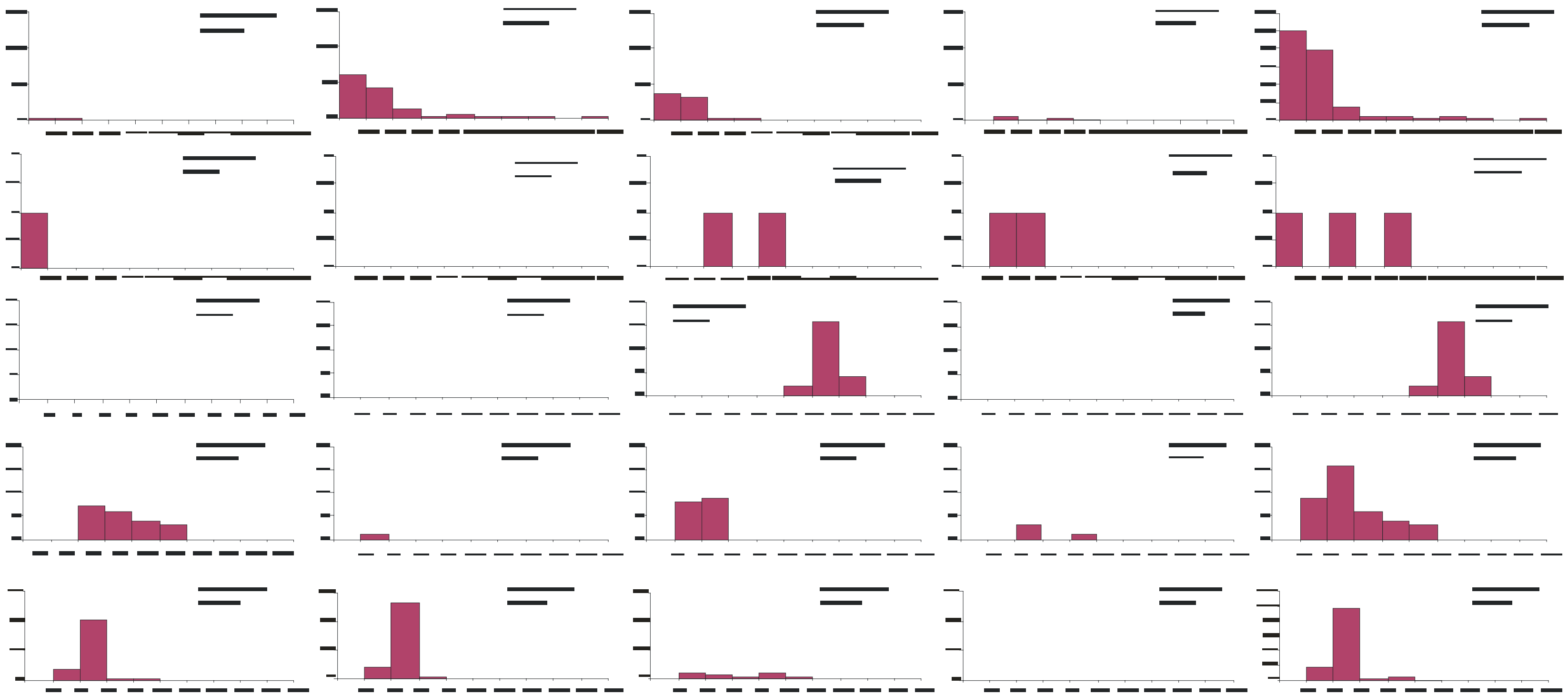


Figure 19:Length frequency distributions for fish sampled at site 8, directly downstream of dam, Shoalhaven River. X axis = size classes (mm) Y axis = number of fish per class.

Figure 19 (cont.): Length frequency distributions for fish sampled at site 8, directly downstream of dam, Shoalhaven River. X axis = size classes (mm) Y axis = number of fish per class.

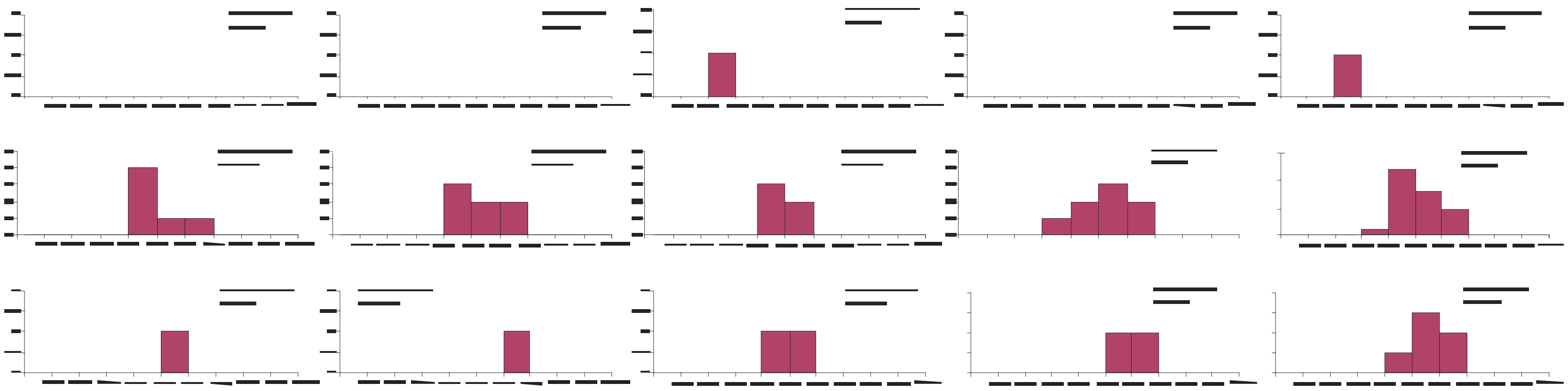


Figure 19 (cont.): Length frequency distributions for fish sampled at site 8, directly downstream of dam, Shoalhaven River. X axis = size classes (mm) Y axis = number of fish per class.

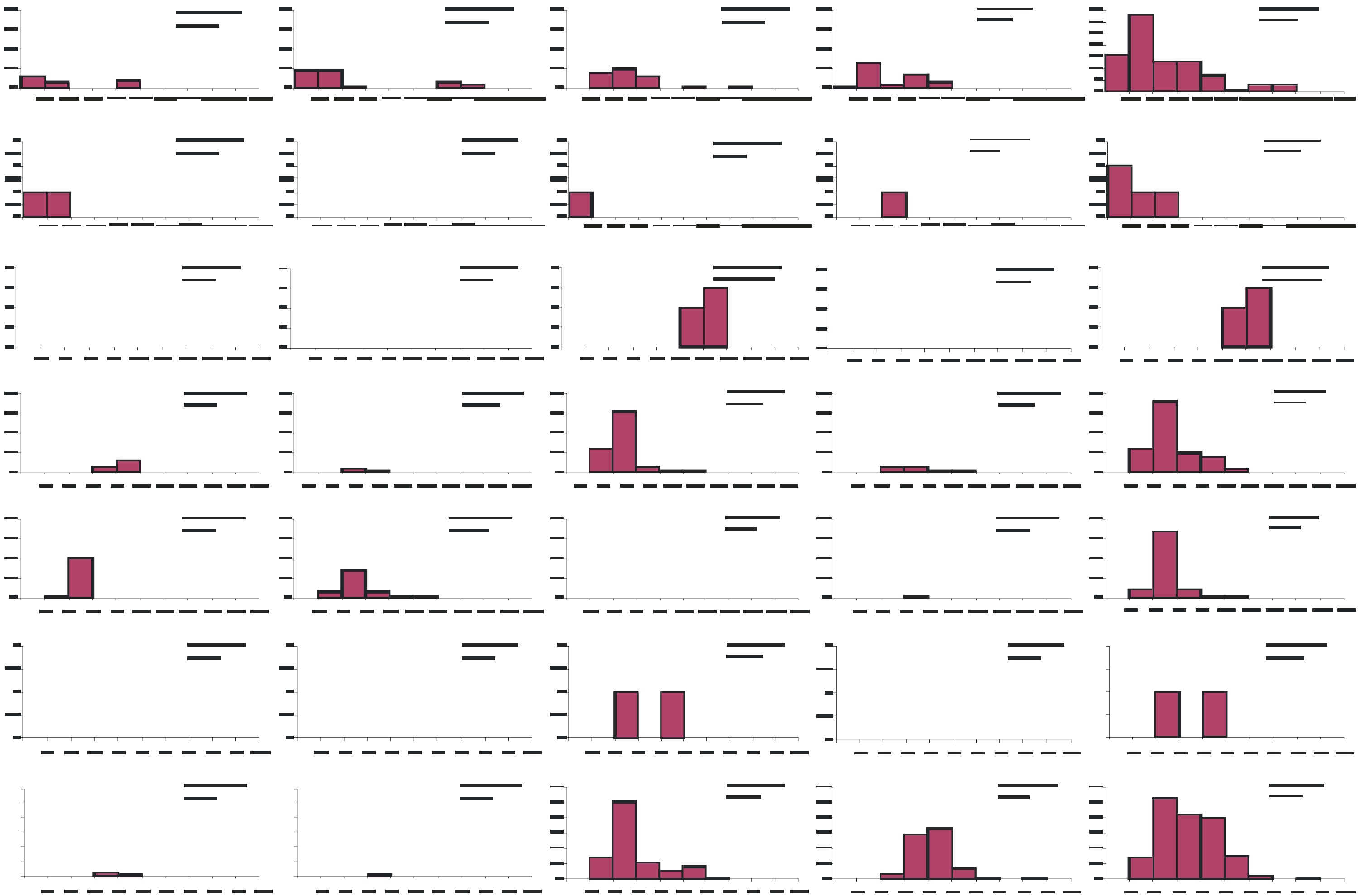


Figure 20: Length frequency distributions for fish sampled at site 9, 500m downstream of dam, Shoalhaven River. X axis = size classes (mm) Y axis = number of fish per class.

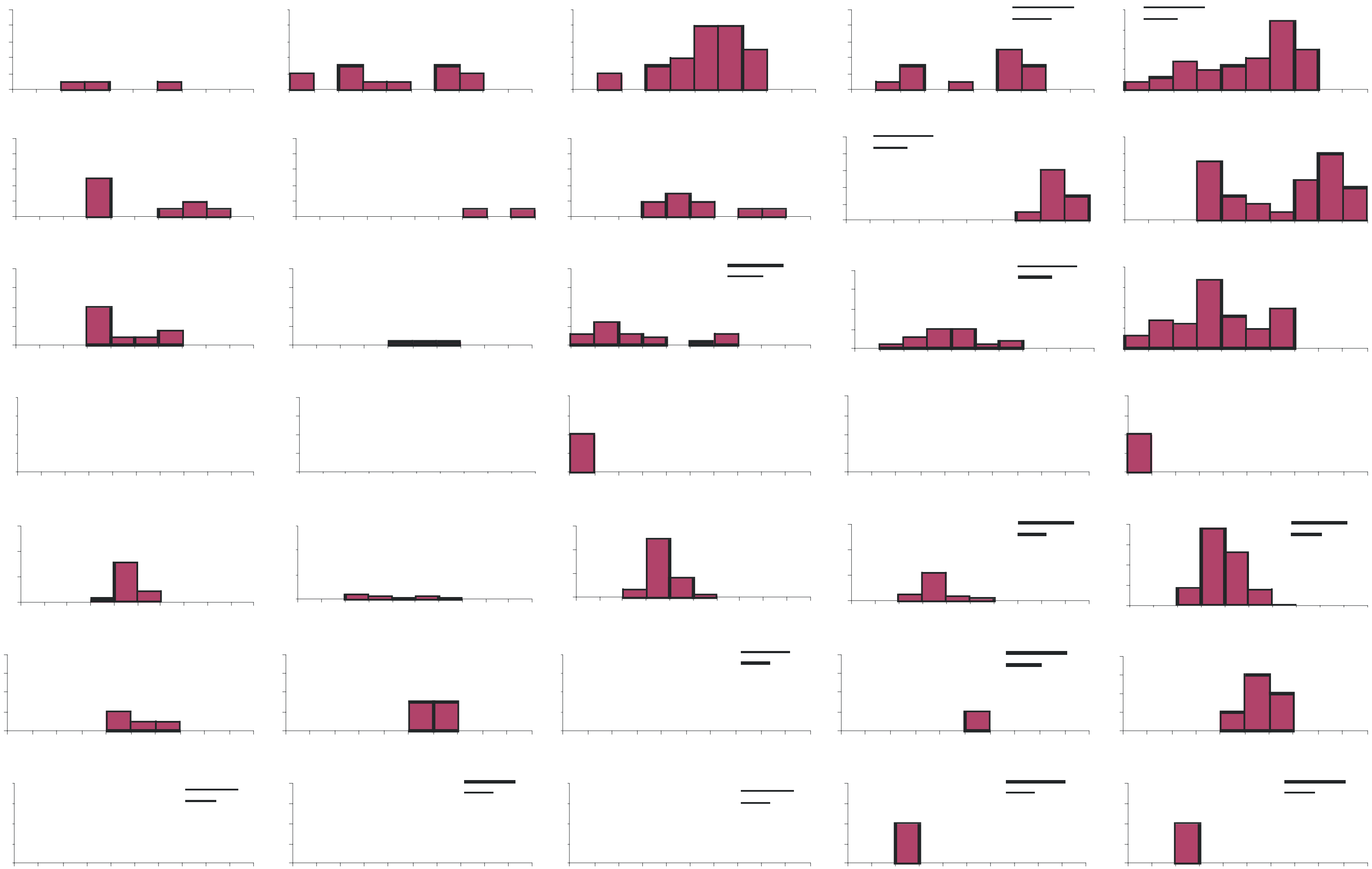


Figure 20 (cont.): Length frequency distributions for fish sampled at site 9, 500m downstream of dam, Shoalhaven River. X axis = size classes (mm) Y axis = number of fish per class.

Figure 21: Length frequency distributions for fish sampled at site 10, Burrier Pump Station, Shoalhaven River. X axis = size classes (mm) Y axis = number of fish per class.

Figure 21 (cont.): Length frequency distributions for fish sampled at site 10, Burrier Pump Station, Shoalhaven River. X axis = size classes (mm) Y axis = number of fish per class.

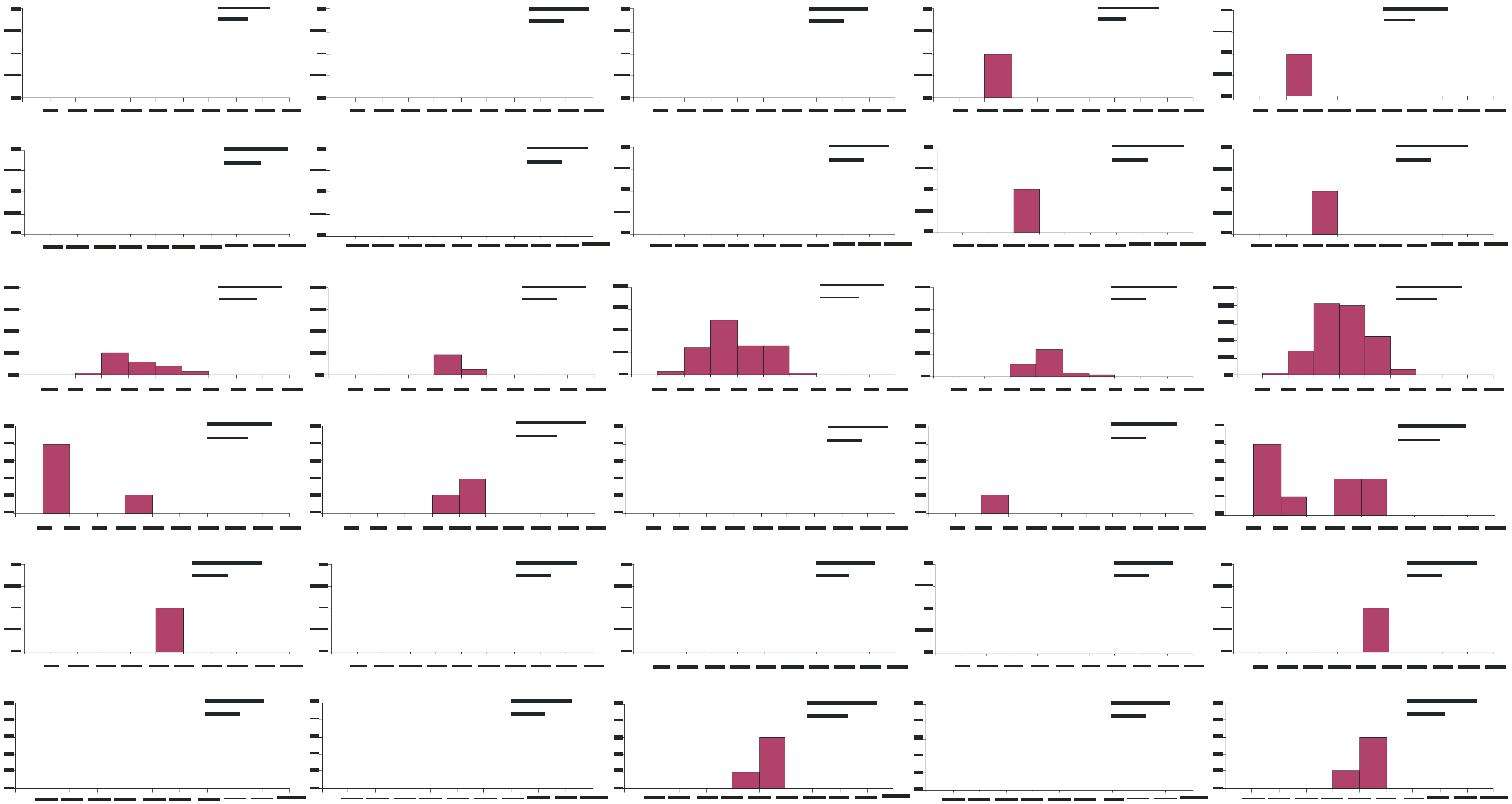


Figure 21 (cont.): Length frequency distributions for fish sampled at site 10, Burrier Pump Station, Shoalhaven River. X axis = size classes (mm) Y axis = number of fish per class.

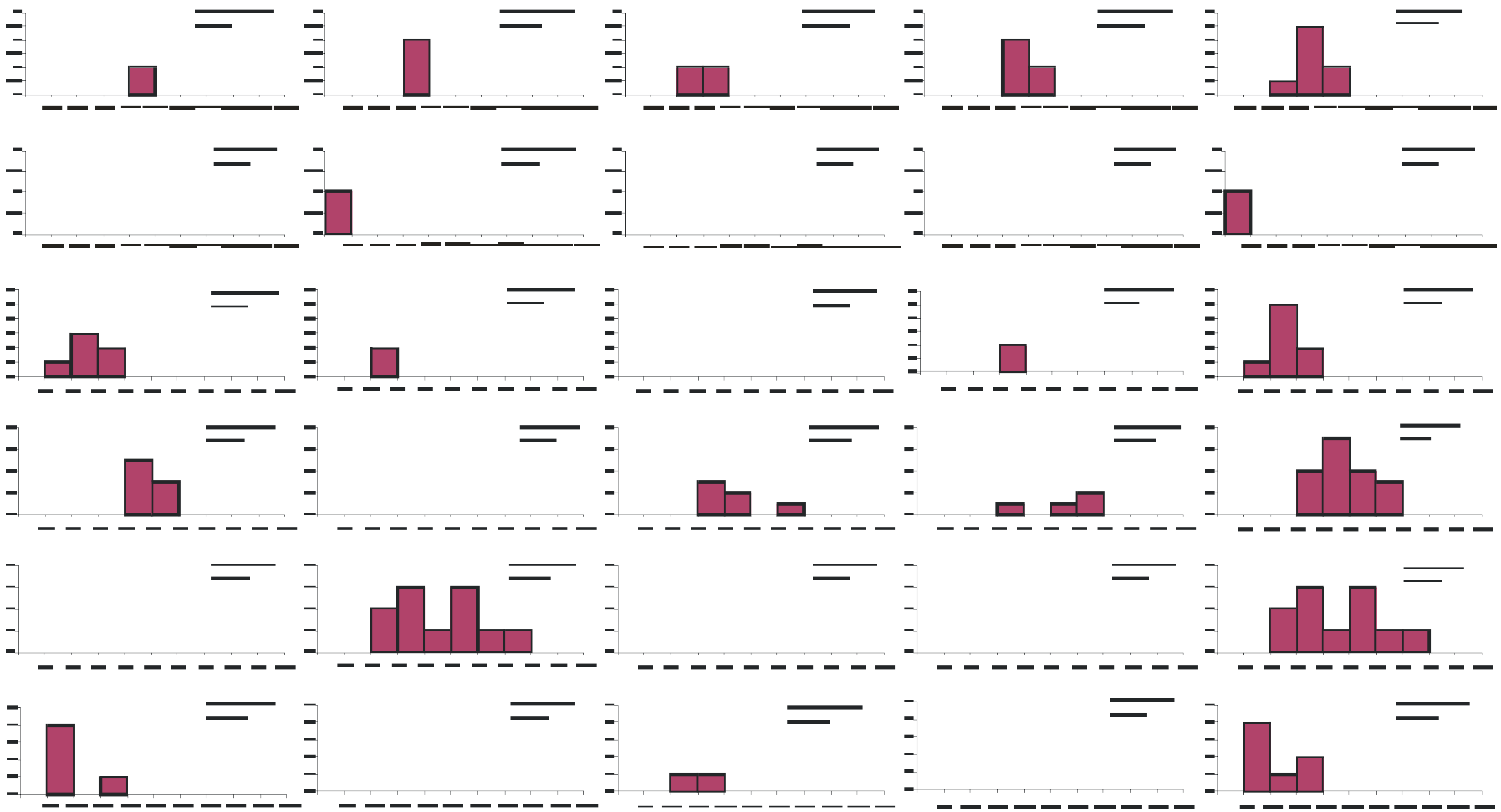


Figure 22: Length frequency distributions for fish sampled at site 11, Mongarlowe River, Mongarlowe River. X axis = size classes (mm) Y axis = number of fish per class.

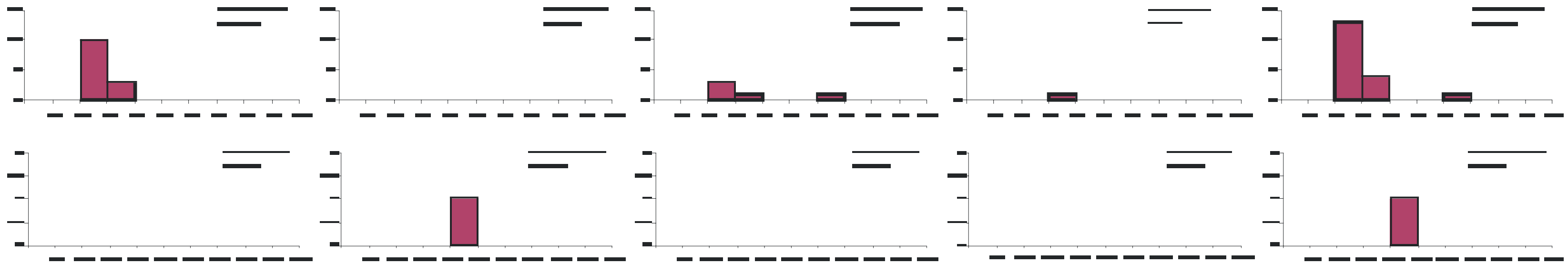


Figure 22 (cont.): Length frequency distributions for fish sampled at site 11, Mongarlowe River, Mongarlowe River. X axis = size classes (mm) Y axis = number of fish per class.

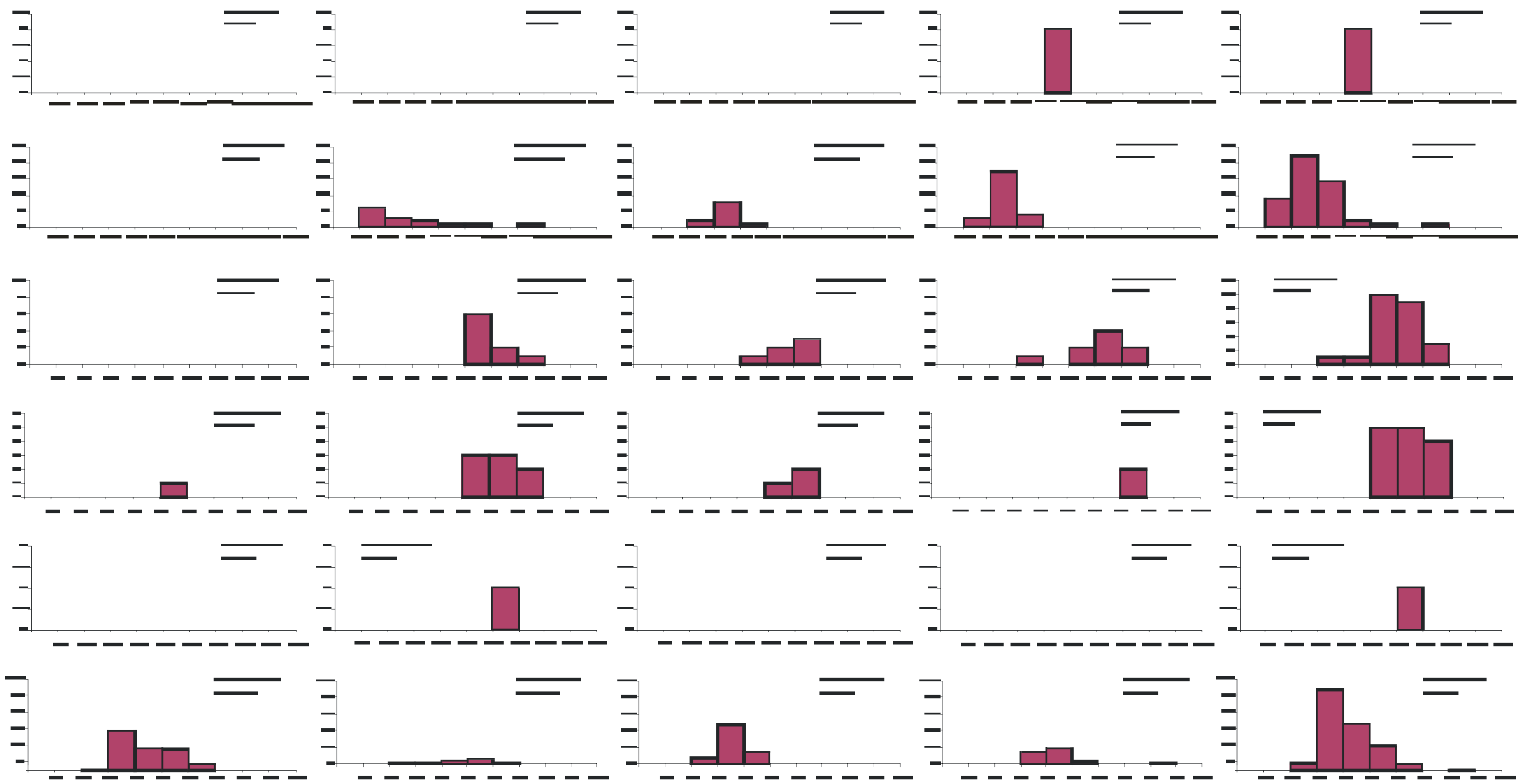


Figure 23: Length frequency distributions for fish sampled at site 12, Tolwong Mines, Shoalhaven River. X axis = size classes (mm) Y axis = number of fish per class.

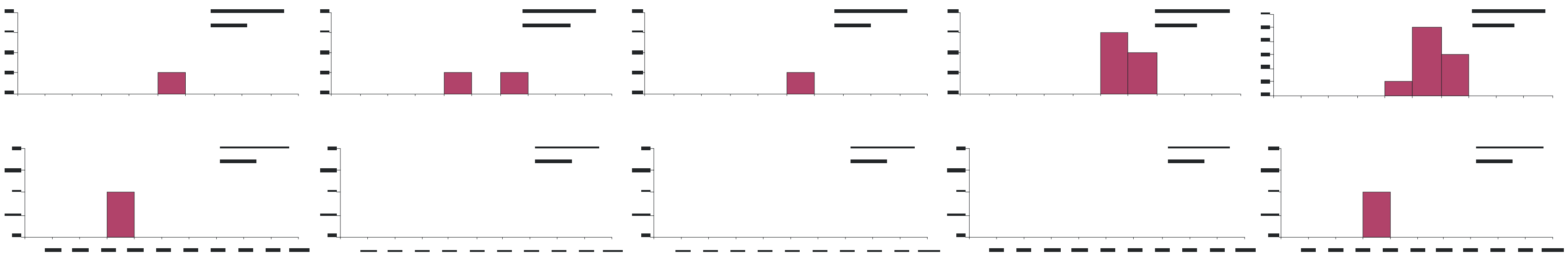


Figure 23 (cont.): Length frequency distributions for fish sampled at site 12, Tolwong Mines, Shoalhaven River. X axis = size classes (mm) Y axis = number of fish per class.

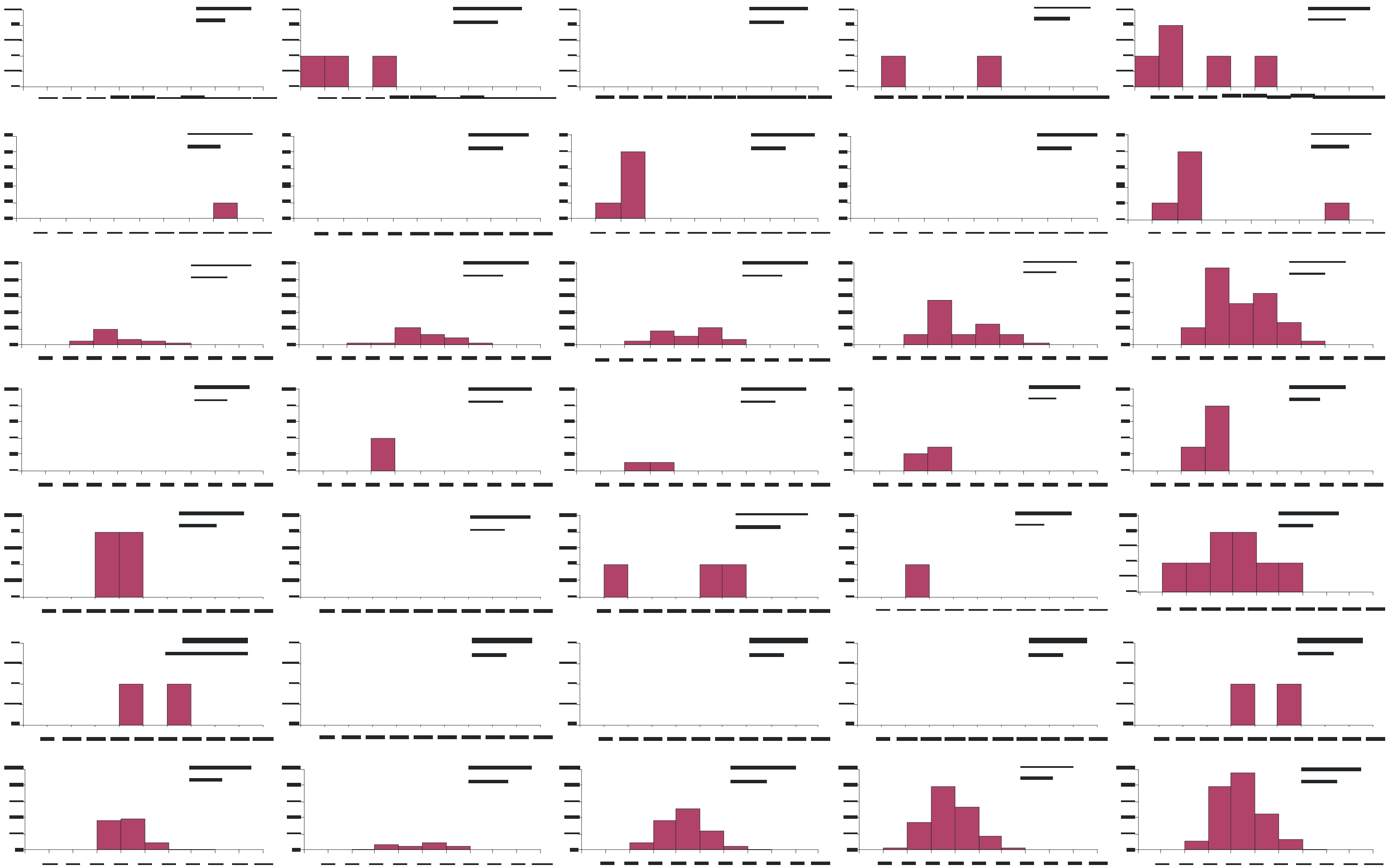


Figure 24: Length frequency distributions for fish sampled at site 13, Monarch Bluff, Lake Yarrunga. X axis = size classes (mm) Y axis = number of fish per class.

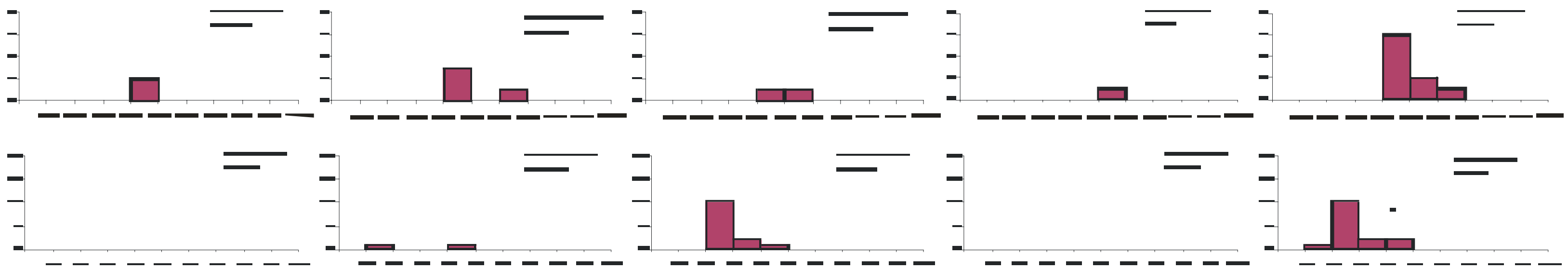


Figure 24 (cont.): Length frequency distributions for fish sampled at site 13, Monarch Bluff, Lake Yarrunga. X axis = size classes (mm) Y axis = number of fish per class.

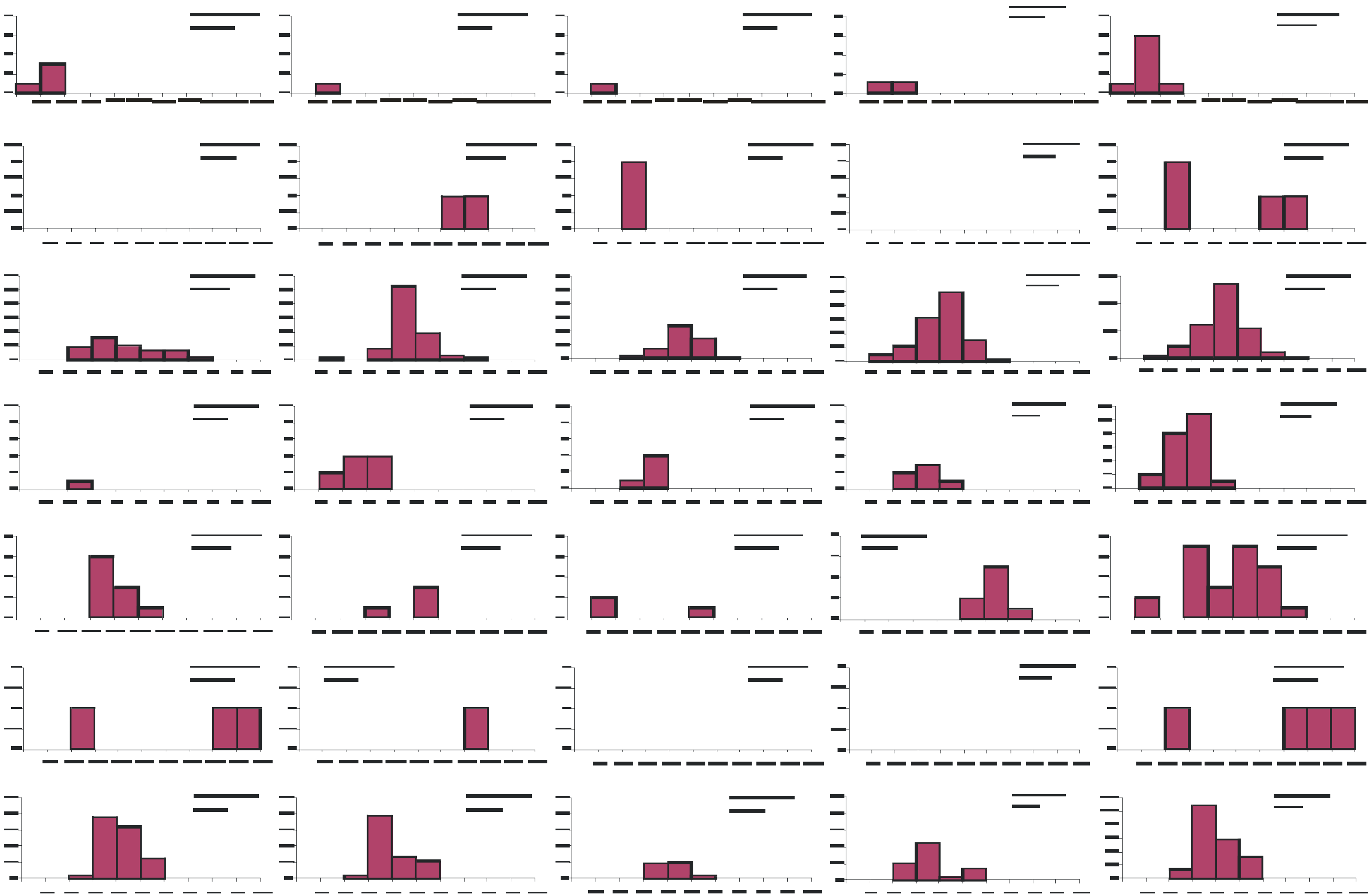


Figure 25: Length frequency distributions for fish sampled at site 14, Beehive Point, Lake Yarrunga. X axis = size classes (mm) Y axis = number of fish per class.

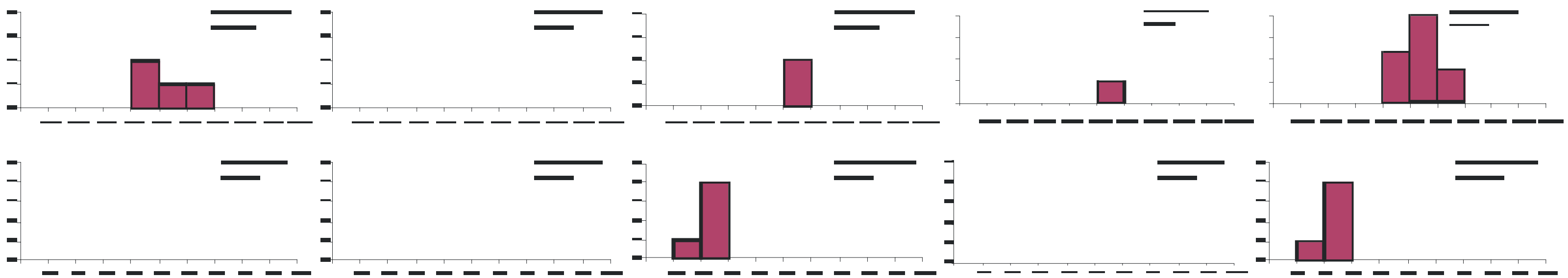


Figure 25 (cont.): Length frequency distributions for fish sampled at site 14, Beehive Point, Lake Yarrunga. X axis = size classes (mm) Y axis number of fish per class.

APPENDIX 4: FLOW DATA

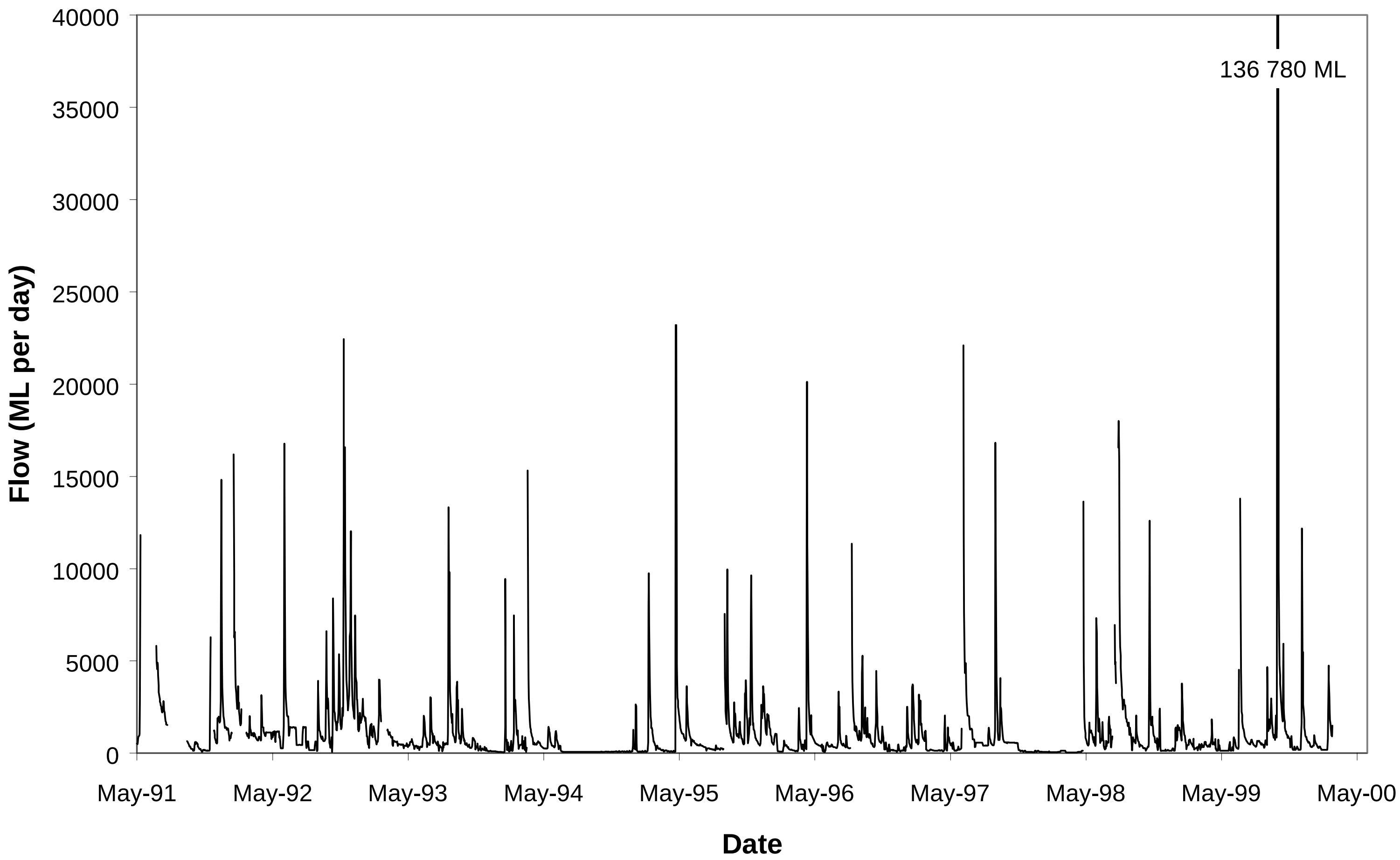


Figure 26. River flow (Megalitres day^{-1}) measured 500m downstream of Tallowa Dam from 30th May, 1991 – 21st March, 2000. Data supplied by the *Sydney Catchment Authority*.

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No. 17 Ogburn, D. and Ruello, N., 1999. Waterproof labelling and identification systems suitable for shellfish and other seafood and aquaculture products. Whose oyster is that? Final Report to Fisheries Research and Development Corporation. Project no. 95/360.

No. 18 Gray, C.A., Pease, B.C., Stringfellow, S.L., Raines, L.P. and Walford, T.R., 2000. Sampling estuarine fish species for stock assessment. Includes appendices by D.J. Ferrell, B.C. Pease, T.R. Walford, G.N.G. Gordon, C.A. Gray and G.W. Liggins. Final Report to Fisheries Research and Development Corporation. Project no. 94/042.

No. 19 Otway, N.M. and Parker, P.C., 2000. The biology, ecology, distribution, abundance and identification of marine protected areas for the conservation of threatened Grey Nurse Sharks in south east Australian waters. Final Report to Environment Australia.

No. 20 Allan, G.L. and Rowland, S.J., 2000. Consumer sensory evaluation of silver perch cultured in ponds on meat meal based diets. Final Report to Meat & Livestock Australia. Project no. PRCOP.009.

No. 21 Kennelly, S.J. and Scandol, J. P., 2000. Relative abundances of spanner crabs and the development of a population model for managing the NSW spanner crab fishery. Final Report to Fisheries Research and Development Corporation. Project no. 96/135.

No. 22 Williams, R.J., Watford, F.A. and Balashov, V., 2000. Kooragang Wetland Rehabilitation Project: History of changes to estuarine wetlands of the lower Hunter River. Final Report to Kooragang Wetland Rehabilitation Project Steering Committee.

No. 23 Survey Development Working Group, 2000. Development of the National Recreational and Indigenous Fishing Survey. Final Report to Fisheries Research and Development Corporation. Project no. 98/169. (Volume 1 – main report, Volume 2 – attachments).

No.24 Rowling, K.R and Raines, L.P., 2000. Description of the biology and an assessment of the fishery of Silver Trevally *Pseudocaranx dentex* off New South Wales. Final Report to Fisheries Research and Development Corporation. Project no. 97/125.

No. 25 Allan, G.L., Jantrarotai, W., Rowland, S., Kosuturak, P. and Booth, M., 2000. Replacing fishmeal in aquaculture diets. Final report to the Australian Centre for International Agricultural Research. Project no. 9207.

No. 26 Gehrke, P.C., Gilligan, D.M., Barwick, M., 2001. Fish communities and mig ation in the Shoalhaven River – Before construction of a fishway. Final report to Sydney Catchment Authority.