Monitoring changes in Crawford River fish community following replacement of an ineffective fishway with a vertical-slot fishway design:
Results of an eight year monitoring program

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NON-TECHNICAL SUMMARY

Monitoring changes in the fish community of the Crawford River following replacement of an ineffective fishway with a vertical slot design: results of an eight year monitoring program.

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OBJECTIVE:

Document the response of the fish community of the Crawford River to the reconstruction of the Buladelah Fishway.

NON TECHNICAL SUMMARY:

Artificial barriers on rivers, such as dams, weirs and culverts, impede fish passage. NSW Fisheries has recognised the importance of fish passage for freshwater fish communities since construction of fishways began in New South Wales in 1913. To date, fishways have been constructed on 76 barriers within NSW. However, none of the 44 constructed prior to 1985 were designed to cater for Australian native species, having been developed in the Northern Hemisphere for strong swimming salmon. As a result, most, if not all of these fishways are ineffective at providing fish passage in Australia. One of these, the original Buladelah fishway was constructed in 1964 at Buladelah.

Buladelah Weir is located in the lower freshwater reaches of the Myall-Crawford catchment. The fishway is important for the migration of adult and juvenile migratory fish. Fish passage is a necessity for 83% of the freshwater fish species known to currently exist within the Myall-Crawford system. Fifty-six percent require the ability to migrate between freshwaters and the sea to fulfil their life-cycles. As a result of the ineffectiveness of the original fishway and the migratory requirements of the fish species in the catchment, the fish community of the Crawford River was considered to be severely degraded by 1992. After 28 years of obstructed fish passage, the Crawford River, which once supported a diverse and productive fishery, was described by local residents as resembling a “stagnant pond”. The depleted fishery was the subject of angling club complaints and several ministerial representations. Great Lakes Shire Council and the Department of Public Works provided funding to reconstruct the fishway with a more appropriate vertical-slot design. Reconstruction was completed by February 1993.

In contrast to the Crawford River, the adjacent Myall River has always maintained continuous fish passage, resulting in maintenance of an abundant and diverse fish community. It was believed that the depauperate Crawford River fish community would be readily rehabilitated by the migration of fish from the adjacent Myall River following the redesign of the fishway on the Buladelah Weir.

Fish communities in the Myall and Crawford Rivers (upstream of the weir) were sampled by electrofishing for one year before fishway reconstruction to assess the existing differences in the fish communities and population structures of each river. Sampling continued following reconstruction and was undertaken for seven years. In addition to these electrofishing surveys, fish using the fishway were trapped to document the species and size classes of fish migrating through the fishway.

Prior to fishway renovation, significant differences were observed between the fish communities of the Myall and Crawford Rivers. Nine species were collected from the Crawford River compared with 15 species from the Myall River.

When sampling was discontinued in 2000, seven years after reconstruction of the fishway, the fish community of the Crawford River had not recovered to a state where it is comparable to the fish community of the Myall River. The fish communities of the two rivers were still significantly different. The fish community of the Myall River had remained unchanged over the corresponding period of time.

Although no significant improvement of the fish community of the Crawford River was detected as a whole, detectable changes in the abundance of some species have occurred. The abundance of two migratory species (striped gudgeon and empire gudgeon) have increased substantially within the Crawford River, while remaining stable within the Myall River. A further improvement was detected for striped mullet. Prior to fishway renovation, no juvenile mullet were sampled from the Crawford River. After addition of the vertical-slot fishway, juveniles occurred in the Crawford River in similar proportions to those in the Myall River.

Despite the recovery of these three species, the abundance of other species remains consistently lower in the Crawford River than in the Myall River. Potential explanations for the lower abundance of these species may be weir-pool effects in the Crawford River, or the saline-intrusion effects that occasionally affect the Myall River during periods of low rainfall. These could create differences in fish communities within each river regardless of the provision of free fish passage. Comparison of fish communities within the Crawford River weir-pool and the Crawford River upstream did not show evidence of a degraded fish community in the weir pool. Salt intrusion effects during periods of low rainfall did significantly affect the fish community of the Myall River. However as salt intrusion occur infrequently, this factor is considered unlikely to contribute significantly to the observed significant difference between the Myall and Crawford Rivers. To overcome any potential confounding effects, a comparison was made between fish communities in the upper reaches of each river. Regardless of salt intrusion or weir pool effects in the lower catchments, fish communities of the upper Myall and Crawford Rivers were still significantly different.

Although the fish community of the Crawford River remains different, analysis of the fish communities over time demonstrates clearly that fish communities of the Myall and Crawford Rivers are gradually becoming more similar over time since construction of the vertical-slot fishway. Although recovery was not as rapid as anticipated, and full recovery had still not occurred within seven years of upgrading the fishway, full recovery may be expected at some point in the future.

To demonstrate that fish were capable of ascending the fishway, the fishway was trapped for 117 hours. Individuals of 7 species were observed to successfully ascend the fishway. The average size of the fish trapped at the exit of the fishway was 78 ± 10mm (n = 71, range = 24mm – 660mm). Video surveillance of the fishway for a period of 24 hours revealed that striped gudgeons were able to ascend the fishway in less than 2.5 hours. Other species were capable of ascending within at least 4 hours. Trapping and filming fish passage through the fishway has established that the design and internal hydrology of the renovated vertical-slot fishway are likely to be capable of providing fish passage for the full range of species and size classes of fish within the Myall – Crawford river systems.

As the fishway is capable of providing fish passage, the lack of significant rapid recovery must result from either: 1) fish being incapable of finding the fishway entrance, 2) flow through the fishway being insufficient to allow fish passage during critical migration periods, or 3) fish preferentially migrating up the Myall River during upstream migrations. These are discussed further below:

1. Attracting fish to the fishway entrance is a critical feature of fishway design. Poor entrance conditions and location have been identified as a common failing of unsuccessful fishways. The three most important factors determining the success of entrance design are water temperature, attraction flow and location. As the depth of water in the Crawford River weir pool is insufficient to lead to thermal stratification, and the fishways flow is drawn from the surface of the weir pool, the temperature of the entrance flows is unlikely to lead to fish avoiding the fishway entrance. Attraction flow from the fishway entrance should be the most obvious flow in the area downstream from the weir and the jet of attraction flow should be aligned at 45 – 90^0 to the stream flow. These conditions are met at Buladelah with the entrance being aligned at 90^0 to the flow. Lastly, although the fishway entrance is located approximately 4 m downstream of the weir face, characteristics of the entrance of the Buladelah Fishway should allow it to meet the requirements for upstream fish passage.

2. Due to water extraction from the weir-pool, the Buladelah fishway is occasionally dry for extended periods. As a result, and despite the existence of a fishway, fish passage is not consistently available at Buladelah.

3. Comparison of water quality between the two rivers demonstrates that salinity and temperature differ significantly between rivers. Salinity (electrical conductivity) of the Crawford River remained relatively constant throughout the eight years of sampling. In contrast conductivity of the Myall River showed much greater variability, with periods of high conductivity. The temperature of the two rivers ranged from 10^oC (July) to 28^oC (February). Seasonal temperature fluctuations within the two rivers were similar. However, the Crawford River was consistently cooler than the Myall by a mean of $2.05 \pm 0.64\ ^0C$. Migrating fish are influenced by water temperature, with native fish preferentially moving towards warm flows. Therefore, natural temperature differences in the waters flowing from the Crawford and Myall Rivers at their confluence, may result in fish preferentially migrating up the Myall River rather than the 2^0C cooler Crawford. This scenario could explain the consistently lower abundance of fish in the Crawford River.

Conclusions

Renovation of the pre-existing submerged orifice fishway on the Buladelah Weir, with a vertical slot design, did not result in a rapid recovery of the fish community of the Crawford River. Despite this, a gradual improvement in the Crawford River fish community has been observed.

Although some aspects of fishway design and operation could be improved, such as: modification of the trash-rack and ensuring that sufficient water passes through the fishway, the provision of fish passage past the Buladelah Weir has been achieved by reconstruction of the pre-existing fishway. The fact that fish were sampled moving through the fishway has established that the vertical slot fishway at Buladelah is likely to be capable of providing fish passage to all species present within the Myall – Crawford River system and all size classes of fish.

The lack of a large and immediate response to construction of the fishway is most likely a result of natural temperature differences between the Myall and Crawford Rivers, with migrating fish preferentially moving up the Myall River.

1. INTRODUCTION

Artificial barriers on rivers, such as dams, weirs and culverts obstruct the free passage of fish. It has been well established, both in Australia and overseas, that the existence of fish passage obstructions results in detrimental effects to both upstream and downstream fish communities (Bishop and Bell 1978; Cadwallader 1978; Pollard *et al.* 1980; Kowarsky and Ross, 1981; Harris, 1983; Harris, 1984*a*; Harris, 1984*b*; Harris, 1988; Axford 1991; Russell 1991; Moring, 1993; Orth and White 1993; Harris & Mallen-Cooper, 1994; Gehrke, *et al.* 1995; Ribeiro *et al.* 1995; Lucas and Frear 1997; Holmquist *et al.* 1998; Peter 1998; Allibone 1999; Almodóvar and Nicola 1999; Thorncraft and Harris, 2000; Gehrke and Harris 2001; Harris, 2001; Gehrke *et al.* 2002).

NSW Fisheries has recognised the importance of fish passage for freshwater fish communities since construction of fishways began in New South Wales in 1913 (Mallen-Cooper 2000; Thorncraft and Harris, 2000). To date, fishways have been constructed on 76 fish passage obstructions within NSW (Cameron Lay, pers. comm.). However, of the 44 fishways constructed prior to 1985, none were designed to specifically cater for Australian native species. As a result, most, if not all of these fishways were found to be ineffective at providing fish passage. One of these ineffective fishways was the original Buladelah fishway in the Myall-Crawford River system.

1.1. Catchment

Located in the Myall Lakes catchment area of New South Wales, the Myall-Crawford drainage basin covers an area of 540 km^2. The catchment is composed of predominantly undisturbed vegetation with limited residential development (Atkinson *et al.* 1981). The majority of cleared land is in the vicinity of the Myall river system. The Crawford River joins the Myall River at Buladelah, 280km north of Sydney. The Myall River continues to the Bombah Broadwater, part of the Myall Lakes system, and drains into Port Stephens via the Lower Myall River (Figure 1).

1.2. Fish passage

Fish passage is essential for most of the fish species within the Myall-Crawford River system. Eighty-three percent of the freshwater fish species known to exist within the system depend on regular migrations within freshwater or between freshwater and the sea to fulfil their life cycles (Table 1). Several forms of migratory behaviour exist. These are:

Small scale migrations	Irregular localised movements of individual fish within their home range.
Potamodromous	Large or small scale migrations between freshwater habitats.
Diadromous	Migrations between fresh and salt water.
Anadromous	Spend most of their life in the sea and migrate to fresh water to breed.
Amphidromous	Migrate between the sea and freshwater but not for the purpose of breeding.
Catadromous	Spend most of their life in freshwater and migrate to the sea to breed.

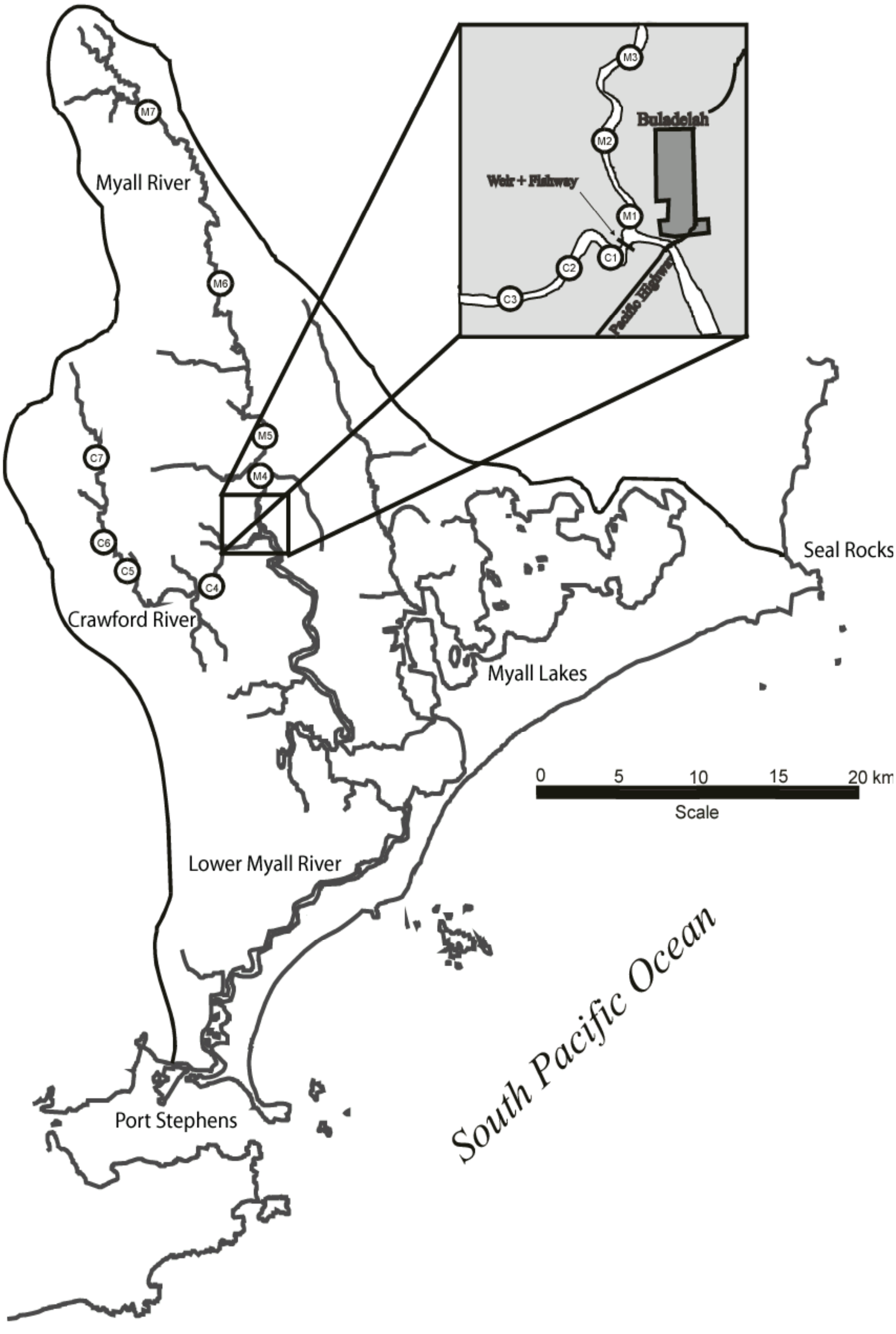

Figure 1. The Myall – Crawford catchment (indicated by solid line) showing the location of the sites sampled. Paired sites were sampled in both the Myall River ('M' sites) and Crawford River ('C' sites) to assess the rehabilitation of the Crawford River fish community as a result of retrofitting a vertical-slot fishway on the weir at Buladelah.

Table 1. Current knowledge of migratory status of fish species known or presumed to occur in the Myall - Crawford river system.

Migratory status	Scientific name
Undefined	*Gambusia holbrooki*
	Philypnodon grandiceps
	Philypnodon sp1.
	*Pseudomugil signifer**
	Tandanus tandanus
Potamodromous	*Gobiomorphus coxii*
	Hypseleotris galii
	Retropinna semoni
Amphidromous	*Gobiomorphus australis*
	Hypseleotris compressa[#]
Catadromous	*Anguilla australis*
	Anguilla reinhardtii
	Galaxias maculatus
	Macquaria novemaculeata
	Mugil cephalus[3]
	Myxus petardi
	Notesthes robusta
Estuarine / marine	*Acanthopagrus australis*
	Ambassis marianus
	Herklotsichthys castelnaui
	Liza argentea
	Myxus elongatus
	Selenetoca multifasciata

* The migratory behaviour of *Pseudomugil signifer* has previously been classified as amphidromous (Thorncraft and Harris, 2000) or unknown (Harris, 2001). Its migratory status was re-classified as undefined as a diadromous migration is not an essential requirement of the species. Rather, the species is characteristic of the estuarine-freshwater interface.

[#] The migratory behaviour of *Hypseleotris compressa* was previously unknown (Thorncraft and Harris, 2000; Harris, 2001). The species was included in the amphidromous category as: i) it becomes extinct above total fish passage obstructions (Gehrke *et al.* 2001), 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 are observed in estuaries and migrate upstream from estuaries in large numbers (Herbert *et al,* 1995; Gilligan *et al.* unpublished data), and v) Genetic analyses indicate little population sub-structuring between river systems (McGlashan and Hughes, 2001), suggesting an estuarine or marine migration phase.

[3] The migratory behaviour of *Mugil cephalus* was previously classified as amphidromous (Thorncraft and Harris, 2000) or catadromous (Harris, 2001). Its migratory behaviour was classified as catadromous as the seaward migration is an essential requirement for spawning in this species.

1.3. The Crawford River

1.3.1. Weir and original fishway

A weir and fishway were built on the Crawford River 75 m upstream from its junction with the Myall River in 1964, as part of the water supply scheme for the township of Buladelah. The weir is a simple sheet pile structure reinforced with rock-fill and steel bracing (Figure 2). At full capacity, the weir creates a headloss of up to 0.7 m, depending on fluctuations in tailwater level. In an effort to maintain fish passage, a submerged orifice fishway was built into the weir at construction.

The original fishway at Buladelah (Figures 3 and 4) contained only two baffles, each with a submerged orifice, and had a slope of 1:5 as opposed to current fishway standards of 1:18 to 1:30. Submerged orifice fishways were designed for bottom swimming species and some species of Australian native fish are unlikely to pass through submerged orifices, e.g. bony herring (*Nematalosa erebi*) at both the Euston and Torrumbarry fishways (Mallen-Cooper 1996). The headloss between cells was 300 mm, producing water velocities within the fishway of 2.41 m/s and substantial turbulence within the fishway cells. Lastly, the fishway exit at Buladelah was a submerged 3 m length of pipe with an internal diameter of 300 mm (Figures 3 and 5). This was likely to represent a significant behavioural barrier to any fish that were otherwise capable of ascending the original fishway.

Submerged orifice and pool-and-weir fishway designs were developed in the Northern Hemisphere to provide fish passage for anadromous species such as steelhead trout and salmon which migrate upstream as large, powerful adults and are capable of leaping to overcome barriers (Mallen-Cooper and Harris 1990; Thorncraft and Harris 2000). Prior to 1985, Northern Hemisphere fishway designs were constructed in New South Wales, without knowledge of the swimming ability of native fish or the migratory requirements of each species (Mallen-Cooper 1992*a*; Mallen-Cooper 2000).

In contrast to salmonids, Australian native diadromous fish require upstream fish passage at both adult and juvenile life stages. As juveniles are smaller and weaker swimmers, maximum headlosses, flow velocities and turbulence within fishways constructed in Australian coastal streams must take into account the swimming abilities of juvenile fish. It has been demonstrated that juvenile *Macquaria novemaculeata* (Australian bass) are prevented from ascending fishways with flow velocities greater than 1.4 m/s (Mallen-Cooper 1992*b*). With a flow velocity of at least 2.41 ms^{-1}, the original submerged orifice fishway constructed on the Buladelah Weir was clearly inappropriate for passage of juvenile and even adult Australian native fish.

1.3.2. Upstream effects of migration barriers

Diadromous species are incapable of sustaining healthy populations above weirs or dams. Populations of diadromous fish above total obstructions to fish passage will inevitably become extinct through their inability to complete their lifecycle when confined to freshwater habitats (Bishop and Bell 1978; Harris and Mallen-Cooper 1994; Holmquist *et al.* 1998; Allibone 1999; Gehrke *et al.* 2002). At low level weirs the effects are often more subdued with fish populations declining rather than disappearing completely (Harris, 2001). However, the end results can be severe for even very low level weirs, with Australian bass suffering a severe decline upstream of a 0.5 m barrier on the Clyde River (Harris, 1988) and populations of fish in Europe disappearing above a barrier only 0.4 m high (Peter, 1998). Clearly, barriers can modify previously continuous fish communities and result in changes in the faunal community structure in that river system (Thorncraft and Harris, 2000).

Figure 2. The Buladelah Weir located on the Crawford River about 75 m upstream from its junction with the Myall River, Buladelah, NSW, Australia.

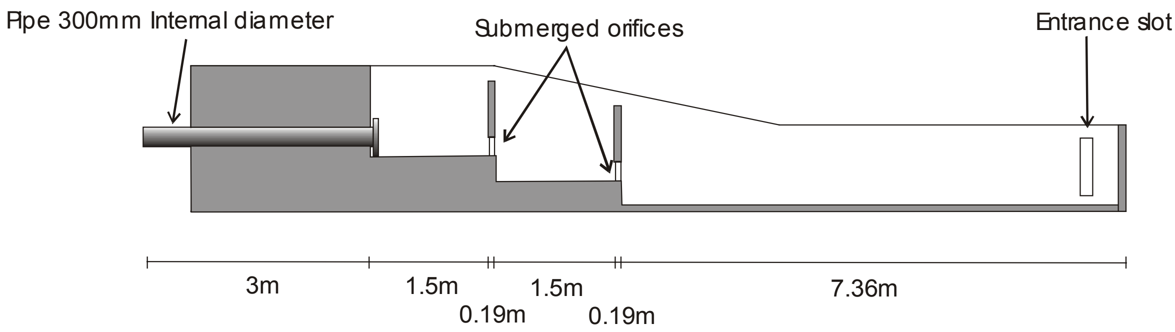

Figure 3. Longitudinal view and dimensions of the original (1964) Buladelah fishway. The channel width was 1.38m.

Figure 4. The original (1964) Buladelah fishway. This photo was taken under low flow conditions with the cover grids removed.

Figure 5. Exit pipe of original Buladelah Fishway. The pipe was 3 m long and had an internal diameter of 300 mm.

Within the Myall-Crawford system, 56% of all species present are diadromous and require fish passage to allow migration between freshwater and the sea. As the Buladelah weir is a low-level structure, drown-out flows (where the weir is inundated during a flood or high flow) may be sufficient to allow some fish to migrate past the weir. However, to be effective, drown-out flows must correspond with periods of peak fish migration (Thorncraft and Harris, 2000). Further, the weir must remain drowned-out for a sufficient period of time to allow movement of a sufficient proportion of the population (Thorncraft and Harris, 2000). Although temporally variable, drown-out flows have the potential to provide 'bursts' of fish migration that may enable the persistence of upstream fish communities. As a result, drown-out flows have been incorporated as a component of environmental-flow regimes in parts of the Murray-Darling Basin (Thoms *et al.* 1996; Harris 2001).

1.3.3. Downstream effects of migration barriers

In addition to the degradation of fish communities above obstructions, accumulations of fish regularly occur below weirs during upstream movement. Accumulations can lead to disease epizootics (Welcomme 1985; Moring 1993) and starvation, resulting in increased mortality within the entire river system. Further, high densities of fish below migration barriers are associated with increased predation (Elson, 1962; Kowarsky, 1980; Barlow and Bock, 1984; Kennedy and Greer, 1988; Feltham and Maclean, 1996), particularly of juvenile life stages. As a result of these density-dependent effects, in addition to altered flow regimes downstream of barriers (Almodóvar and Nicola 1999; Gehrke, *et al.* 1995; Gehrke and Harris 2001; Harris, 2001), fish communities downstream of weirs are also degraded by the existence of fish passage obstructions.

1.3.4. The Crawford River: (1964 – 1992) - before fishway renovation

By 1992 the fish community in the Crawford River was considered to be severely degraded as a result of the ineffectiveness of the original fishway. The Crawford River, which once supported a diverse and productive fishery, was subsequently described by local residents as resembling a "stagnant pond". The depleted fishery was the subject of angling club complaints and several ministerial representations. Following representations from NSW Fisheries, Great Lakes Shire Council and the Department of Public Works provided funding to reconstruct the fishway as a vertical-slot design. Reconstruction was completed by February 1993.

1.3.5. The new vertical slot fishway

Vertical slot fishways where developed in the 1940's to cope with widely fluctuating river levels in the Fraser River, Canada (Mallen-Cooper 2000). This fishway design is one of the most widely used, and has been used successfully in a number of countries (Mallen-Cooper 2000). In Australia, nine vertical slot fishways have been constructed in NSW, ten in Queensland and 10 - 15 in Victoria (Thorncraft and Harris, 2000; Marsden and McGill, 2001).

Vertical slot fishways are considered ideal for Australian conditions as (Mallen-Cooper, 2000):

- They enable fish passage of both bottom and surface dwelling species.
- They have a high capacity to pass a large number of fish.
- The flow patterns within the fishway promote self-cleaning and reduce ongoing maintenance requirements.
- They maximise water depth and operate at low flows.
- They operate over widely fluctuating river levels.
- The internal hydraulics are consistent and predictable so that specific design criteria can be easily achieved.

The new Buladelah vertical slot fishway was built within the existing channel of the original fishway, with lengthening of the upstream end of the original channel (Figure 6). The two original submerged orifice baffles were removed and replaced with seven vertical slot baffles spaced equi-distant through the length of the fishway. The headloss between cells is 80 mm and produced a water velocity of 1.2m/s within the fishway. This is slightly greater than the 50 mm headloss currently recommended for vertical slot fishways at tidal sites based on the laboratory experiments of Mallen-Cooper (1992). The exit pipe was removed and replaced with a large open exit with a trash-rack attached. The original entrance, a 150mm wide slot facing instream at 90^0 to the flow, was left in place.

1.4. The Myall River

In contrast to the Crawford River, the adjacent Myall River has always maintained continuous fish passage, a dominant factor contributing to it supporting an abundant and diverse fish community. As a result, the Myall River provides an ideal source of migrants for the recolonisation of the Crawford River. As historical information on the fish of the Crawford River does not exist, the fish community of the Myall River provides the best available reference against which to assess recovery. There has however been an unexplained decline in the population of *M. novemaculeata* within the catchment over the last decade.

1.5. Aims and objectives

The objective of this study was to document the response of the fish community of the Crawford River to the reconstruction of the Buladelah Fishway. To assess the rehabilitation of the Crawford River, it was necessary to determine;

i. Whether the Crawford River fish community differed from that in the Myall River before fishway reconstruction.
ii. Whether the Crawford River fish community has become more similar to that in the Myall River since the fishway was renovated.
iii. Whether the fish community of the Myall River has changed over the corresponding period of time.

It was believed that the depauperate community of the Crawford River would be readily rejuvenated by the abundant and diverse fish community of the adjacent Myall River. However, when significant recovery did not occur, secondary objectives were developed to determine why. The limited recovery could be attributed to three possible causes;

i. Fish are incapable of locating the fishway entrance.
ii. Fish are incapable of ascending the fishway.
iii. Fish preferentially move up the Myall River during upstream migrations.

Investigations of each of these issues, and the level of recovery achieved, are documented in this report.

Figure 6. The new vertical slot Buladelah fishway.

2. METHODS

2.1. Sites

Three paired sites were selected on each of the Myall and Crawford Rivers (M1-M3 & C1-C3; Figure 1). Each pair of sites was matched for distance upstream from the junction of the two rivers and for similarities of habitat characteristics (Appendix 1). As the Myall River contained no obstructions to fish passage, sites within the Myall River were used as reference sites for the equivalent sites on the Crawford River.

For the first sample, only one site (C1 & M1) was sampled in each river. For the final two surveys, four additional paired sites were selected on each of the Myall and Crawford Rivers (M4-M7 & C4-C7) upstream of the saline limit and weir pool respectively (Figure 1). This was initiated in an attempt to assess the fish communities of the two rivers above the potential influences of the frequent saline water intrusions affecting sites in the Myall (M1-M3) and the weir pool effects in the Crawford (C1-C3). As with the previous design, each pair of sites was matched for distance upstream from the junction of the two rivers and was similar in habitat characteristics (Appendix 1). Although matched as closely as possible, differences in altitude existed between the headwaters of the two catchments.

2.2. Sampling

2.2.1. Fish community assessment

Sites were sampled quarterly for a period of 12 months before and after fishway reconstruction. Subsequently, sites were sampled on an irregular basis for a period of 6 years. Regular quarterly sampling recommenced in January 1999 for a further 12 months (Table 2). Sites 4 – 7 on both rivers were sampled only in July and October 1999.

Fish were sampled using *FRV Electricus*, a 5 m aluminium electrofishing boat fitted with a Smith-Root Model GPP 7.5 electrofishing unit. Electrofishing settings ranged from 340 - 1000 V DC, 3 – 15 amps pulsed at 120 Hz and a 50 – 90% duty cycle depending on water conductivity. Sampling was conducted during daylight hours and each site was sampled with four electrofishing ‘shots’, each of 5 minutes duration. *FRV Electricus* required a crew of one senior operator and two dip-netters. Immobilised fish were netted and placed in an aerated live well for recovery. At the end of each shot all fish were identified to species, a sub-sample of the first 20 specimens was measured (total length or fork length as appropriate), and returned to the water. Individuals observed and identified, but not netted were recorded in the catch. Lengths of eel species were estimated because of the difficulty in restraining live eels for measurement.

As the water bodies and access points of sites 4 - 7 were more restrictive than in sites 1 - 3, *FRV Polevolt*, a 3.6 m aluminium boat fitted with a Smith-Root Model GPP 2.5 electrofishing unit was used. Electrofishing settings and sampling design were similar to those used on *FRV Electricus*, although due to its smaller size *FRV Polevolt* required only a single dip-netter. At sites that were too small to complete four 5 minute shots with the boat, wading with a 400W Smith-Root model 12 backpack electrofisher was used to sample the balance of the site. Electrofishing settings for the backpack electrofisher were 500 – 800 V DC at 120Hz.

Table 2. Sampling schedule for sites on the Myall (M) and Crawford Rivers (C) before and after reconstruction of the vertical-slot fishway on the Buladelah Weir. Site numbers started at 1 in the lower reaches and increased to 7 in the upper drainage of each river.

Date	Season	Sites		
May-92	Autumn	C1	M1	
June-92	Winter	C1-C3	M1-M3	***Before fishway construction***
November-92	Spring	C1-C3	M1-M3	
February-93	Summer	C1-C3	M1-M3	
May-93	Autumn	C1-C3	M1-M3	
July-93	Winter	C1-C3	M1-M3	
October-93	Spring	C1-C3	M1-M3	
February-94	Summer	C1-C3	M1-M3	
March-94	Autumn	C1-C3	M1-M3	
July-94	Winter	C1-C3	M1-M3	
	Spring			
	Summer			
	Autumn			
August-95	Winter	C1-C3	M1-M3	
November-95	Spring	C1-C3	M1-M3	
	Summer			
May-96	Autumn	C1-C3	M1-M3	
	Winter			***After fishway construction***
September-96	Spring	C1-C3	M1-M3	
February-97	Summer	C1-C3	M1-M3	
	Autumn			
	Winter			
	Spring			
December-97	Summer	C1-C3	M1-M3	
	Autumn			
	Winter			
	Spring			
January-99	Summer	C1-C3	M1-M3	
April-99	Autumn	C1-C3	M1-M3	
July-99	Winter	C1-C7	M1-M7	
October-99	Spring	C1-C7	M1-M7	

2.2.2. Environmental variables

A 'HORIBA U10' water quality meter was used to measure temperature, pH, turbidity, electrical conductivity and dissolved oxygen at 1 m depth intervals from surface to riverbed. Habitat variables including characteristics of substratum, littoral and instream vegetation and river flow were also recorded.

2.2.3. Fishway sampling

The fishway was trapped continually for a period of 24 hours starting at 14:30pm on 6 October 1999 and again for a period of 93 hours starting at 11:30am on 11 October 1999. The trap consisted of a 10 mm mesh fyke net with the wings arranged to totally enclose the exit to the fishway. The trap was emptied and reset at 4 hourly intervals on the 6th and at dusk and dawn from the 11th onwards.

A submersible black-and-white video surveillance camera (Ocean Graphics Australia) was used for the continuous 24 hour sampling period on 6 October. The camera was positioned 50-60 cm from the fishway entrance to gain maximum field-of-view given turbidity and weed-bed obstructions. At this distance the camera provided a field-of-view of around 10 cm either side of the fishway entrance and a 30 – 40 cm depth profile of the entrance slot. The depth of water at the fishway entrance was 60 cm. The camera was positioned just above the debris on the riverbed. At night, lighting was provided by a single lamp mounted on the camera bracket and fitted with an infra-red filter. The images were relayed to a 34 cm television screen for observation and recorded continuously on a VHS video recorder.

2.2.4. Flow records

River height records from the Pacific Highway Bridge gauging station on the Myall River were obtained from the Manly Hydraulics Laboratory. River height was measured against the AHD and collected on an hourly basis. Data obtained were from 1/7/1992 to 21/12/1999 and included almost the entire monitoring period of this study.

2.3. Data analyses

Bray-Curtis similarities (Bray and Curtis, 1957) between fish communities at different sites were calculated based on 4th-root transformed catch data using PRIMER 5.1.2 (Plymouth Marine Laboratory). Multi-dimensional scaling (MDS) ordinations of similarities between sites were used to demonstrate the affinities of fish assemblages among samples and to observe patterns in fish communities. Differences between the fish communities within each of the rivers before and after fishway reconstruction (sites 1 – 3 pooled), differences between the fish communities in the upstream reaches (sites 4-7), between the upstream reaches and within the weir-pool / saline limit in each of the rivers (sites 1-3 versus 4-7) and differences between samples collected during high conductivity versus normal conductivity within the Myall River (M1-M3) were examined using one-way ANOSIM (ANalysis Of SIMmilarities) analyses (Clarke, 1993). Permutation tests to estimate the probability of the observed results used 999 randomisations. SIMPER (similarity percentages) analyses were used to identify species most responsible for the observed relationships between communities. All analyses were repeated with estuarine species omitted from the data set. The results of these analyses were consistent with those of the entire data set and are not reported. All individual species comparisons were analysed using one-way ANOVA.

A regression analysis of Bray-Curtis similarities between paired sites on time since fishway upgrade was used to determine if similarity between the Myall and Crawford rivers had increased as a result of the fishway upgrade. Only samples collected after upgrade were used in this analysis.

Water quality variables were correlated between rivers using Pearson product moment correlation. Differences in water quality between paired sites were examined using paired t-tests.

3. RESULTS AND DISCUSSION

3.1. Fish community comparisons

3.1.1. Catch and species

A total of 10,108 individuals from 23 species were sampled from the Myall and Crawford Rivers (Table 3). Six of the species sampled, *Herklotsichthys castelnaui* (southern herring), *Ambassis marianus* (estuary perchlet), *Acanthopagrus australis* (yellow-finned bream), *Selenetoca multifasciata* (striped butterfish), *Myxus elongatus* (sand mullet) and *Liza argentea* (flat-tail mullet) are largely estuarine species and do not spend a significant part of their life above the tidal limit within rivers (Harris and Gehrke, 1997) (Table 3).

3.1.2. Species differences between rivers

Seventeen species of freshwater fishes were sampled within the two catchments. All 17 freshwater species were sampled in the Crawford River but only 15 species in the Myall River. The species not sampled in the Myall River were *Galaxias maculatus* (common jollytail) and *Tandanus tandanus* (freshwater catfish). Both were sampled in the Crawford River as single specimens only. Although not collected, it is likely that these locally rare species also occur within the Myall River.

3.1.3. Fish communities before fishway renovation

Before the fishway was renovated, significant differences were observed between fish communities of the Myall and Crawford Rivers (Table 4; Figure 7). Nine species were collected from the Crawford River compared with 15 species from the Myall.

Despite obstructed fish passage, the Crawford River supported six diadromous species before fishway renovation; *Anguilla reinhardtii* (long-finned eel), *Gobiomorphus australis* (striped gudgeon), *Hypseleotris compressa* (empire gudgeon), *Maquaria novemaculeata* (Australian bass), *Mugil cephalus* (striped mullet) and *Myxus petardi* (freshwater mullet). However, all but *M. novemaculeata* and *G. australis* and *Retropinna semoni* (Australian smelt) exhibited substantially higher abundance in the Myall River prior to fishway renovation (Table 5). *M. novemaculeata* was uncommon in both rivers and *G. australis* was sampled regularly but in similar abundance in both rivers (Table 5). The potamodromous *R.. semoni* was the only species consistently more abundant in the isolated Crawford River than in the Myall River (Table 5).

3.1.4. Fish communities after fishway renovation

The renovation of the Buladelah fishway with a vertical-slot design has not yet resulted in the recovery of the fish community of the Crawford River. The fish community of the Crawford River did not change significantly following fishway renovation (Table 4). Further, fish community data over a period of 7 years after renovation of the fishway show that the fish communities of the Myall and Crawford Rivers are still significantly different (Table 4, Figure 7).

The fish community of the Myall River has remained unchanged through the whole sampling period (Table 4).

Table 3. Fish species observed within the freshwater reaches of the Myall-Crawford River catchment. ● represent fish sampled from the Crawford River before (Pre) and after (Post) the construction of the vertical-slot fishway and those from the Myall River (over the entire sampling period).

Scientific name	**Common name**	**Crawford** *Pre*	*Post*	**Myall**	
Anguilla australis	Short-finned eel		●	●	
Anguilla reinhardtii	Long-finned eel	●	●	●	
Herklotsichthys castelnaui	Southern herring			●	Estuarine / marine
Galaxias maculatus	Common jollytail		●		
Retropinna semoni	Australian smelt	●	●	●	
Tandanus tandanus	Freshwater catfish		●		Possibly translocated
Gambusia holbrooki	Gambusia		●	●	Alien
Pseudomugil signifer	Southern blue-eye		●	●	
Notesthes robusta	Bullrout			●	
Ambassis marianus	Estuary perchlet			●	Estuarine / marine
Macquaria novemaculeata	Australian bass	●	●	●	
Acanthopagrus australis	Yellow-finned bream			●	Estuarine / marine
Selenetoca multifasciata	Striped butterfish			●	Estuarine / marine
Myxus petardi	Freshwater mullet	●	●	●	
Myxus elongatus	Sand mullet			●	Estuarine / marine
Mugil cephalus	Striped mullet	●	●	●	
Liza argentea	Flat-tail mullet			●	Estuarine / marine
Philypnodon grandiceps	Flat-headed gudgeon	●	●	●	
Philypnodon sp.	Dwarf flat-headed gudgeon	●	●	●	
Gobiomorphus coxii	Cox's gudgeon		●	●	
Gobiomorphus australis	Striped gudgeon	●	●	●	
Hypseleotris compressa	Empire gudgeon	●	●	●	
Hypseleotris galii	Fire-tailed gudgeon		●	●	

Table 4. Summary of one-way analysis of similarity comparisons between fish communities in the Crawford and Myall rivers before and after construction of a vertical-slot fishway.

Comparison	R – value	Probability* > R
Crawford and Myall Rivers before fishway construction	0.646	0.029
Myall River before and after fishway construction	-0.051	0.572
Crawford River before and after fishway construction	-0.021	0.501
Crawford and Myall Rivers after fishway construction	0.197	0.001

* Probability values less than 0.05 indicate that the fish communities being compared are significantly different.

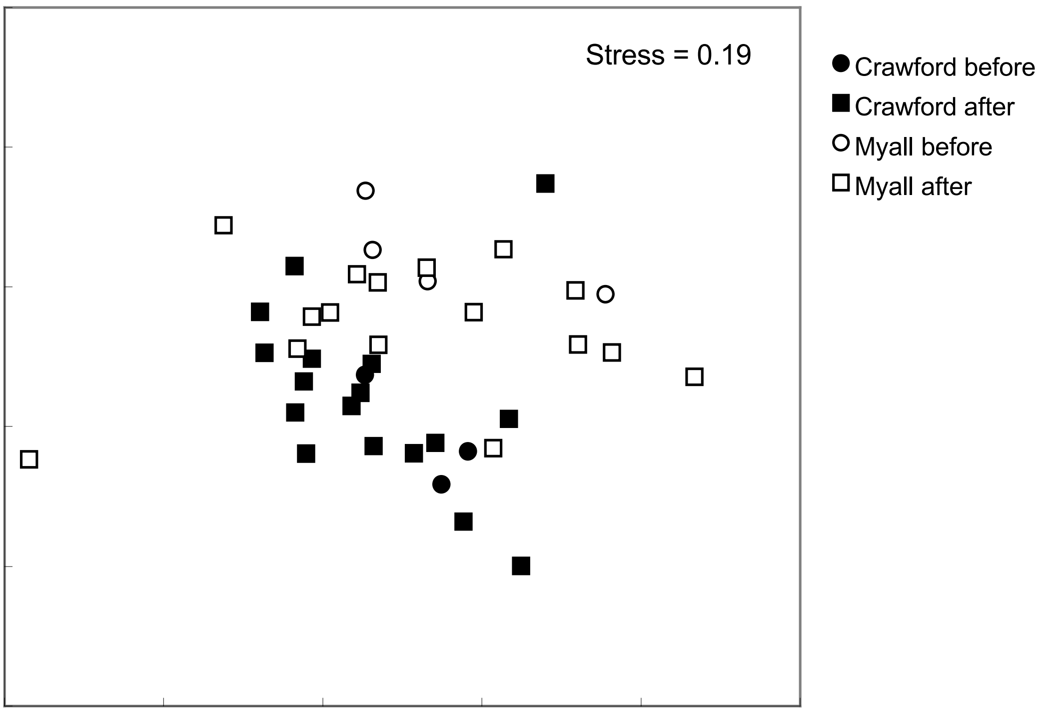

Figure 7. Two-dimensional multi-dimensional scaling ordination of fish communities of the Myall and Crawford Rivers before and after the construction of a vertical-slot fishway on the Buladelah Weir. Sites were pooled prior to analysis.

Table 5. Contributions of individual species to the dissimilarity between fish communities of the Myall and Crawford Rivers before and after fishway renovation. Mean abundances are for each of the 4 x 5 minute electrofishing 'shots' pooled. The abundance ratio is the abundance of each species in the Crawford River as a proportion of its abundance in the Myall River. The consistency ratio indicates the consistency of each species at discriminating between communities in each river. % is the percentage of total dissimilarity between fish communities that is contributed by each species individually. D% is the dissimilarity of the fish communities being compared.

Species	**Mean abundance**		**Abundance ratio**	**Consistency ratio**	**%**	**D%**
	Crawford	**Myall**				
Before fishway construction						46.65
Retropinna semoni	18.25	0.25	73	1.06	10.07	
Mugil cephalus	5.25	44.5	0.12	3.00	9.71	
Hypseleotris compressa	0.25	5.25	0.05	1.34	8.64	
Philypnodon grandiceps	1.25	8.00	0.16	1.35	8.34	
Myxus petardi	5.75	31.25	0.18	2.28	7.67	
Anguilla reinhardtii	16.25	33.5	0.49	1.28	5.93	
Gobiomorphus australis	6.00	5.50	1.09	0.95	6.05	
Gambusia holbrooki	Was not sampled prior to fishway renovation					
After fishway construction						47.15
Retropinna semoni	35.75	25.69	1.39	1.20	12.16	
Mugil cephalus	14.44	110.75	0.13	1.74	9.57	
Hypseleotris compressa	14.00	5.19	2.70	1.20	8.46	
Philypnodon grandiceps	4.25	30.00	0.49	1.02	5.79	
Myxus petardi	3.69	17.00	0.22	1.13	7.93	
Anguilla reinhardtii	14.63	30.00	0.49	1.02	5.79	

3.1.5. Individual species comparisons

Although no significant changes in the community structure of the Crawford River were detected, changes in the abundance of some species have occurred. The abundance of two diadromous species, *G. australis* and *H. compressa* have increased substantially within the Crawford River, while remaining stable within the Myall River. This increase is significant for *G. australis* based on a oneway analysis of variance of catch rates before and after fishway renovation (Mean = 5.50 before versus 15.94 after, $F_{1,58} = 3.08$, one-tailed $p = 0.04$). These responses are likely to be the result of these species successfully utilising the vertical-slot fishway. The abundance of no other fish species increased significantly following the installation of the fishway on the Crawford River.

The abundance ratios (abundance in the Crawford/Myall) of three other relatively abundant diadromous species; *M. cephalus*, *M. petardi* and *A. reinhardtii* and their contribution to the dissimilarity between rivers have remained stable over the period before and after fishway renovation (Table 5). This suggests that the renovation of the fishway has not impacted on the relationship between the abundance of these species in each river. This suggests two alternatives: 1) These species were capable of passage through the previous fishway, or 2) these species are incapable of using either fishway design and only migrate into the Crawford River during infrequent drown-out flows. Both *M. cephalus* and *M. petardi* are strong swimmers, while *A. reinhardtii* is known to climb large barriers during upstream migrations (McDowall, 1996). Both *M. cephalus* and *A. reinhardtii* have been shown to successfully pass through pool-and-weir design fishways with water velocities of 2.1 ms^{-1} (Burnett River: Russell, 1991; Stuart and Berghuis, 1999) and 0.87 ms^{-1} (Fitzroy River: Kowarsky and Ross, 1981). Therefore, these species have been documented ascending pool-and-weir fishways, although with lower water velocities than the pre-existing Buladelah Fishway. These species did not exhibit any additional upstream migration into the Crawford River as a result of the more effective vertical-slot design. Therefore, it appears either that the previous fishway design was capable of providing fish passage for these species, or, that these species move upstream in drown-out conditions.

However, comparisons of length-frequency distributions of *M. cephalus* before and after fishway renovation suggest that only adult specimens were capable of utilising the original fishway or passing over the weir (Figure 8). Prior to fishway renovation, no juvenile mullet were sampled from the Crawford River. After the vertical-slot fishway was built, juvenile *M. cephalus* occurred in the Crawford River in similar proportions to those in the Myall River (Figure 8). The renovated fishway has enabled juvenile mullet to enter the Crawford River and contribute to a more natural fish community structure. For all other species, either no length-frequency difference was apparent between rivers or sample sizes were too small for comparisons to be meaningful.

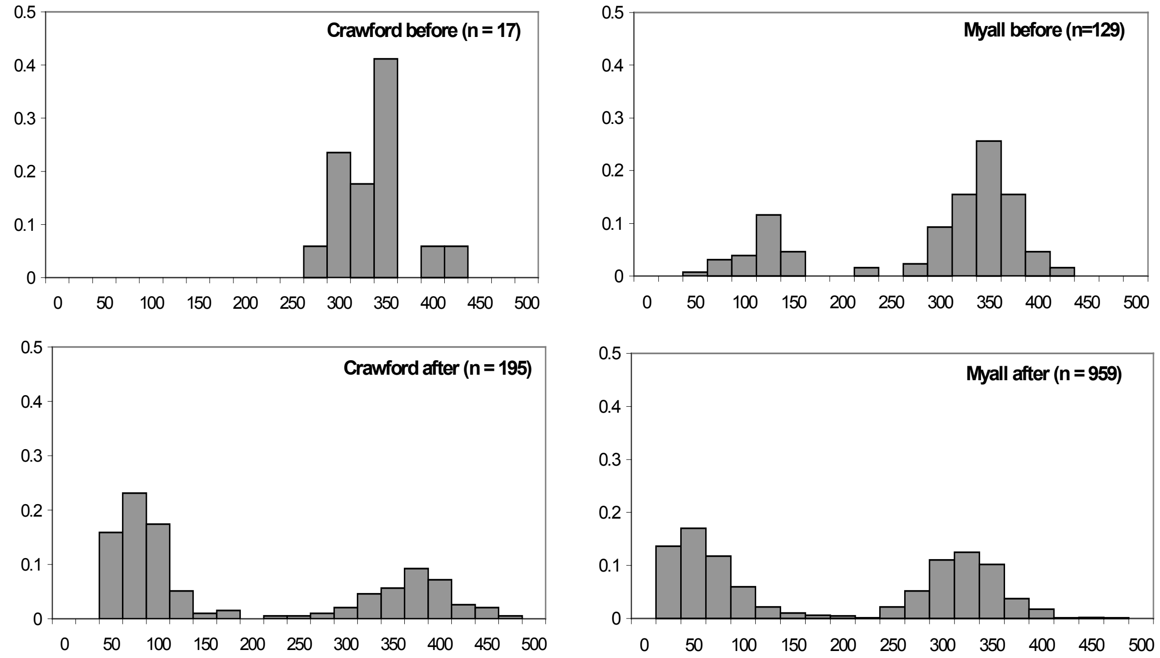

Figure 8. Changes in the length-frequency distribution of *Mugil cephalus* in the Crawford River as a result of renovation of an existing pool-orifice-pipe fishway with a vertical-slot design. Before fishway renovation, only large individuals occurred in the Crawford River. After renovation, both adults and juveniles occur with a similar length frequency distribution as the Myall River. Note the strongly bimodal distribution of size/age classes within the freshwater reaches of the rivers.

3.2. Environmental effects

3.2.1. Weir pool and salt intrusion effects

The analyses above demonstrate improvements in abundance for only a few species, and that the fish community of the Crawford River has not yet improved to a point where it is similar to the fish community of the Myall River. Despite construction of the vertical slot fishway, the abundance of a majority of species remains consistently lower in the Crawford River than in the Myall River (Table 5). These species include *M. cephalus*, *Gambusia holbrooki*, *M. petardi*, *P. grandiceps* and *A. reinhardtii*. As suggested above, three of these species, *M. cephalus*, *M. petardi* and *A. reinhardtii* are efficient migrators and were likely to be capable of ascending the previous fishway, or passing over the weir. Further, *G. holbrooki* and *P. grandiceps* are both capable of sustaining populations without access to estuarine waters. Therefore, effectiveness of either the original or new fishway at the Buladelah Weir is unlikely to have affected the abundance of these species within the Crawford River. Potential explanations for the lower abundance of these species may be weir-pool effects in the Crawford River, or the saline-intrusion effects that occasionally affect the Myall River during periods of low rainfall. Weir-pool effects are caused by altered flow regimes, habitat characteristics and water quality variables, and have significant impacts on fish communities (Brizga, 2001; Koehn, 2001; Leadbitter, 2001). Weir pools often develop divergent biological communities from those that occur in the original riverine environment (Welcomme 1985; Walker *et al.* 1992; Sheldon and Walker 1997; Gehrke *et al.* 2002). Similarly, occasional intrusion of estuarine waters from the brackish Myall Lakes could significantly alter the fish community composition of the Myall River. These events are characterised by elevated conductivity within the Myall River while the conductivity of the Crawford River remains low (Figure 9). Atkinson *et al.* (1981) also reported irregular occurrences of high salinity within the Myall River during water quality assessments of the two rivers for a period between 1972 – 1978 and correlated these events with periods of low rainfall.

Salt intrusion into the Crawford River is prevented by Buladelah Weir. Either of these effects could result in persistent differences in the fish populations of the Crawford and Myall Rivers irrespective of the availability of fish passage at Buladelah Weir. However, if the observed differences in the rivers are due to effects associated with the weir pool or saline intrusion, the rivers should become more similar further up the catchment.

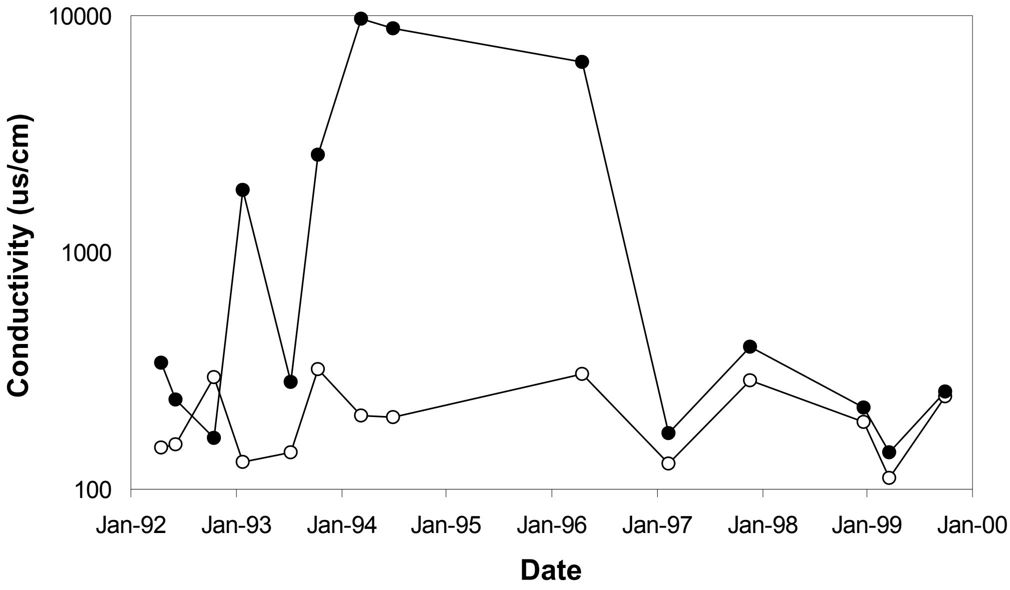

Figure 9. Conductivity measured at sites 1 – 3 in both the Myall River (●) and Crawford River (O) during sampling sessions. Each value is the mean of measurements made at 1 m depth intervals from each of the three survey sites within each river.

3.2.1.1. Salt intrusion effects

No significant differences were detected between the lower reaches of the Myall River (potentially affected by salt intrusion) and its upper reaches (Table 6; Figure 10). This result was anticipated, as the effects of salt intrusion on fish communities are likely to be temporally variable and only apparent during periods of low rainfall. These conditions did not occur in July- October 1999 when the samples used in this comparison were collected. Therefore, further sampling during low rainfall periods would be required to make an effective assessment.

Comparison of fish communities within the lower reaches (sites 1 –3) of the Myall River (sampled during either periods of high salinity (conductivity > 1000 us/cm) or low conductivity levels, Figure 9), suggests that during periods of salt intrusion, the fish community observed in the lower reaches of the Myall River changes significantly (ANOSIM: $R = 0.071$, $p = 0.009$). During periods of high salinity, the abundance of the freshwater species *M. cephalus*, *M. petardi*, *G. australis* and *H. compressa* all decline, while the abundance of estuarine species increases. However, due to the temporal variation of salt intrusion events, the irregularity with which estuarine fish were sampled resulted in them contributing relatively little to the percentage dissimilarity between rivers, which was driven primarily by the freshwater species mentioned above. This suggests that a salt-intrusion effect between the upper and lower reaches of the Myall River could be expected.

Table 6. Summary of one-way analysis of similarity comparisons between fish communities in the Crawford River within and upstream of the weir pool, sites of the Myall River within and upstream of the salt intrusion zone and a comparison of upstream sites in each of the rivers.

Comparison	R – value	Probability > R
Crawford River within and upstream of weir pool	0.665	0.001
Myall River within and upstream of saline limit	0.113	0.126 n.s.
Upstream sites of the Crawford and Myall Rivers	0.205	0.028

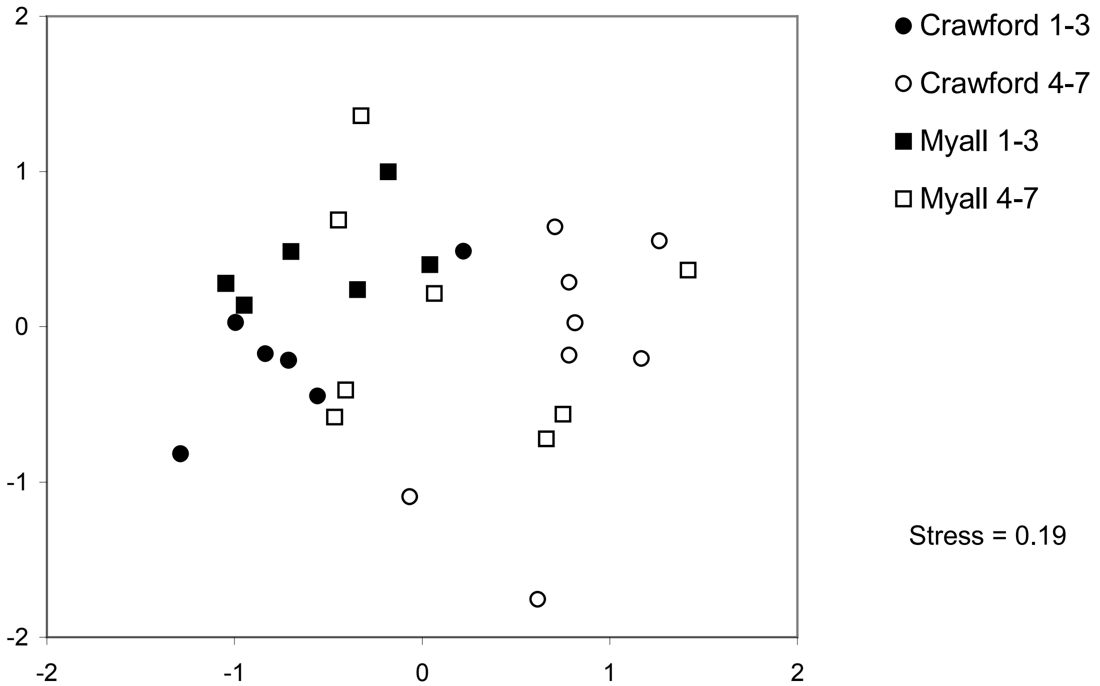

Figure 10. Two-dimensional multi-dimensional scaling ordination of fish communities of Myall - Crawford River in the upstream reaches (sites M4 – 7 and C4 - 7), in the weir pool of the Crawford (C1 - 3) and the salt intrusion zone of the Myall River (M1 - 3) in July and October 1999.

3.2.1.2. *Weir pool effects*

Within the Crawford River, significant differences were detected between fish communities within the weir pool and those further up the catchment (Table 6; Figure 10). Both *M. cephalus* and *A. reinhardtii* were slightly more abundant within the weir pool while *H. compressa* and *G. holbrooki* were only found in the weir pool and not at all in the upper reaches (Table 7). These differences are not likely to be a result of what are considered typical weir-pool effects, such as degraded flows, habitat and water quality. Weir-pool effects would be expected to result in reduced abundance and diversity within the weir-pool instead of increases as was observed in this case. Therefore, differences between the fish communities within the weir-pool and upstream reaches of the Crawford River are likely to be largely influenced by habitat preferences of the species involved.

Table 7. Contributions of individual species to the dissimilarity between fish communities of the Crawford River within and upstream of the weir pool created by the Buladelah Weir.

Species	**Mean abundance Weir pool**	**Upstream**	**Consistency ratio**	**%**	**D%**
Hypseleotris compressa	2.33	0.00	3.44	17.61	63.88
Retropinna semoni	2.17	18.5	1.68	17.58	
Mugil cephalus	3.50	2.13	1.72	16.03	
Anguilla reinhardtii	4.33	3.50	1.05	9.51	
Gambusia holbrooki	0.83	0.00	1.28	9.05	

Both factors (i.e. occasional salt-intrusion within the Myall River and the preference for weir-pool versus riverine environments in the Crawford River) could potentially lead to confounded comparisons between the fish communities, as the previous analyses were based on data collected from sites 1-3 and therefore were susceptible to these effects. These effects could lead to persistent differences between the fish communities observed, despite the provision of effective fish passage at the weir.

3.2.2. *Comparison of upstream riverine environments*

To overcome these confounding effects, a comparison was made between the fish communities in the upper reaches of each of the rivers. Regardless of the occurrence of salt intrusion or weir pool effects in the catchments of each river, comparison of the fish communities upstream of the influences of the saline intrusion zone and the weir pool suggest that the fish communities of the Myall and Crawford Rivers are still significantly different (Table 6). The abundance of *R. semoni*, *M. petardi* and *G. australis* are greater in the upstream reaches of the Myall River than they are in similar environments within the Crawford (Table 8). Further, no trend of increasing similarity between rivers with distance upstream was observed ($r = 0.13$, $p = 0.33$) (Figure 11).

Table 8. Contributions of individual species to the dissimilarity of the fish communities within upstream areas of the Myall and Crawford Rivers.

Species	**Mean abundance**		**Consistency**	**%**	**D%**
	Myall	**Crawford**	**ratio**		
					55.40
Retropinna semoni	94.25	18.50	1.50	24.63	
Myxus petardi	3.50	0.00	1.19	14.16	
Gobiomorphus australis	6.13	2.38	1.08	12.28	

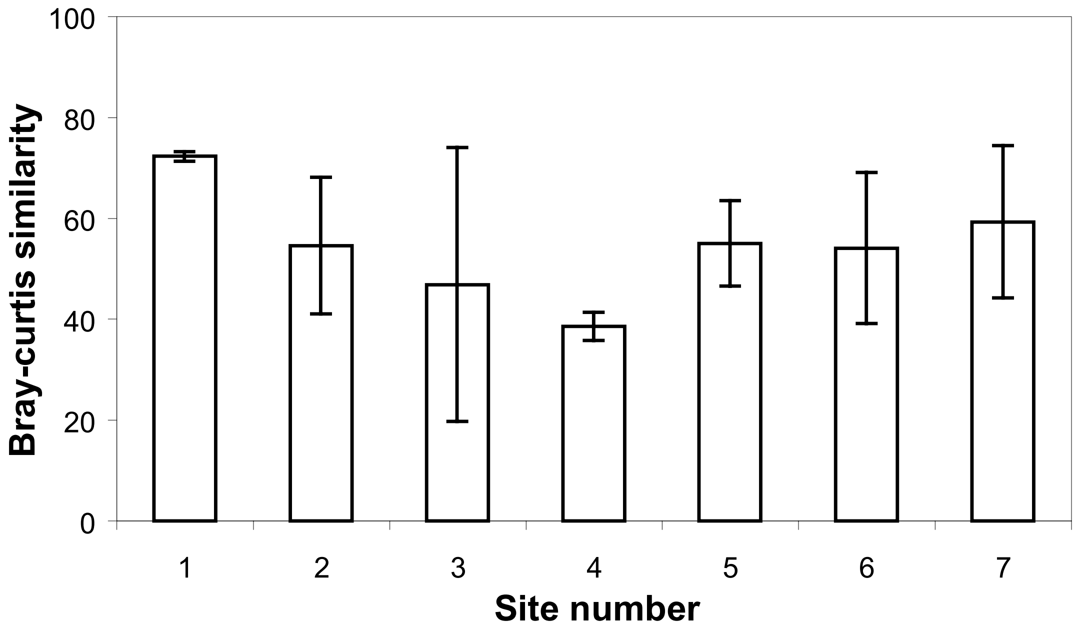

Figure 11. Bray–Curtis similarities between paired sites on the Myall and Crawford Rivers from the lower reaches to the upper drainages (C1-C7 & M1-M7) for samples collected in July and October 1999. There is no significant relationship between distance upstream and similarity between rivers. Higher Bray-Curtis similarity indicates greater similarity between fish communities.

3.3. Rate of recovery

Improvements have been demonstrated for only a few species, and the analyses above suggest that the fish community of the Crawford River has not yet improved to a point where it is comparable with the fish community of the Myall River in either the upper or lower reaches of the rivers. However, regression of similarity of paired sites within the two rivers on time since fishway renovation demonstrates clearly that the fish communities of the Myall and Crawford Rivers are gradually becoming more similar over time since construction of the vertical-slot fishway ($F_{1, 44}$ = 11.92697, p = 0.0012, r^2 = 0.213: Figure 12). Although recovery of the fish community of the Crawford River was not as rapid as was anticipated over the study period, further improvement could be expected in the future.

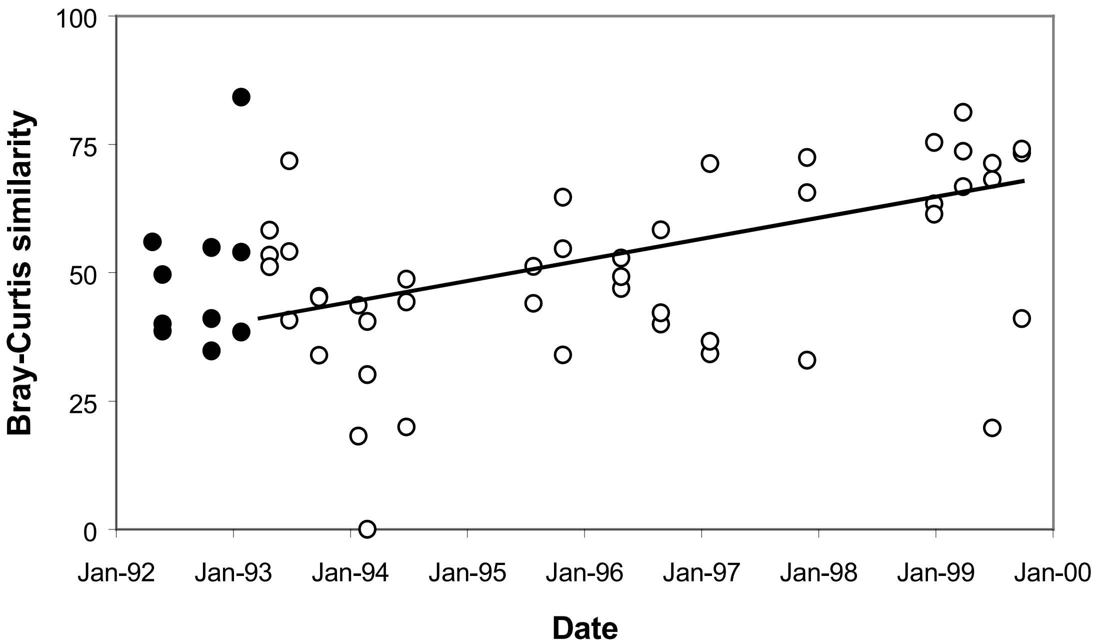

Figure 12. Bray – Curtis similarities between paired sites on the Myall and Crawford Rivers before (●) and after (O) renovation of the pre-existing submerged orifice fishway with a vertical-slot design. The regression line shows a significant (p = 0.001) increase in similarity between the two rivers after renovations of the fishway.

3.4. Investigation of fish passage

3.4.1. Drown-out flows

The existence of diadromous fish upstream of the weir could be a result of migration during periods of high flows. If drown-out flows occur with sufficient frequency, occur during periods of fish migration, and last for a sufficient period of time to allow a sufficient proportion of the population to migrate upstream, a representation of the natural upstream fish community could occur despite a lack of fish passage through the fishway.

Drown-out flows, where the tail-water level equalled the height of the Buladelah Weir, occurred with a frequency of 2.3% of days from 1/7/1992 to 21/12/99 (Figure 13). Drown-out occurred 15 times during 11 separate flood events over the 8 years of sampling. The mean length of time that the weir was submerged during any one drown-out event was 4.5 ± 1.3 days with a minimum of 1 day and a maximum of 20 days. The monthly occurrence of drown-out events over the 8 years of sampling was not uniform, but there was no marked seasonality of events (Figure 14). This frequency of drown-out events is considered unlikely to result in sufficient fish passage into the Crawford River. As the Crawford River fish community was incapable of sustaining itself upstream of the weir prior to construction of the vertical slot fishway, it is unlikely that drown-out flows are responsible for the gradual improvement of the current fish community afterwards (assuming that the occurrence of drown-out events has remained stable before and after fishway renovation). Further, the temporal variability of drown-out events suggests that they are unlikely to be correlated with periods of peak fish migration. Therefore they are unlikely to contribute to long term fish community changes in the Crawford River.

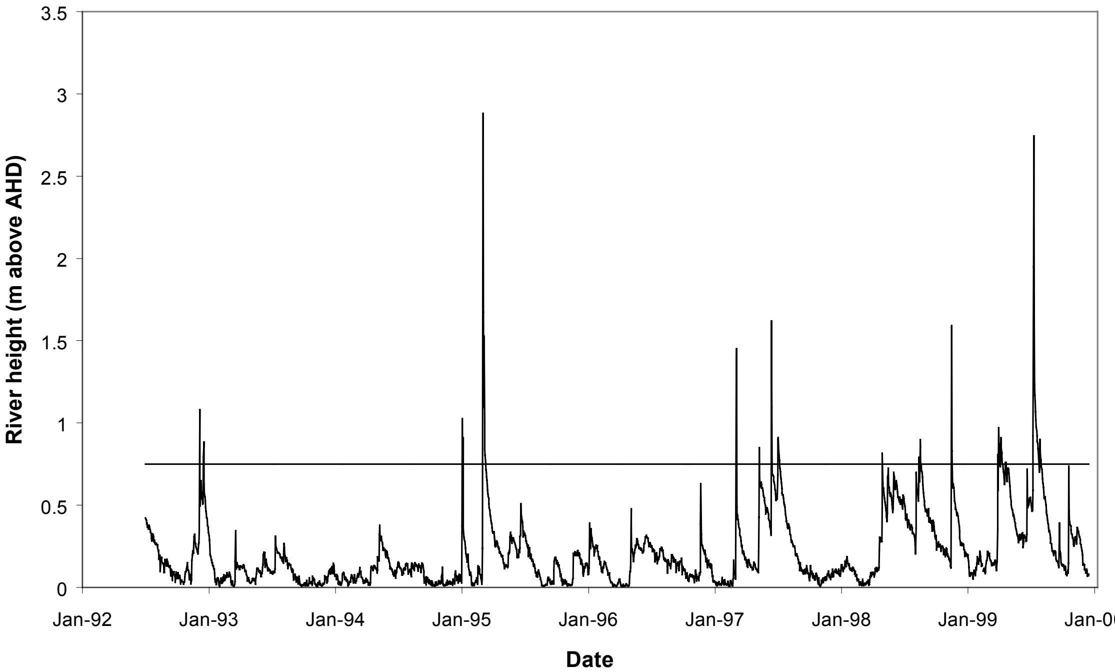

Figure 13. Daily river height above 'Australian Height Datum' under the Pacific Highway Bridge, Buladelah during the period sampled. The horizontal line across the figure represents the height of the Buladelah Weir.

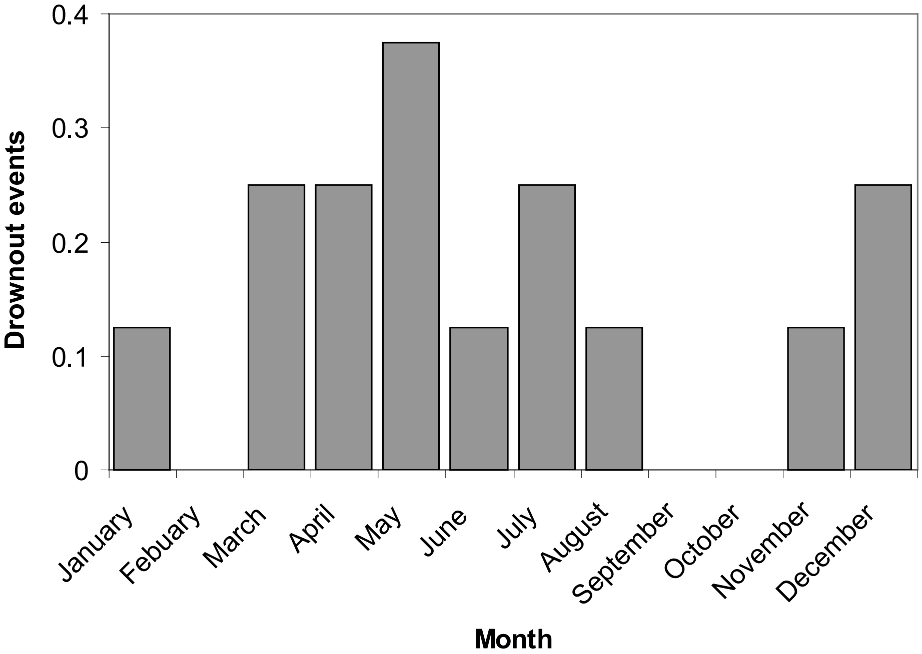

Figure 14. Frequency of drown-out events (events per year) in each month from 1/7/1992 to 21/12/99.

3.4.2. Fish passage through the fishway

During 117 hours of trapping the fishway, individuals of 7 species successfully ascended the fishway (Table 9). Of these species, five are recognised as migratory fish and four of these were diadromous. The average size of the fish trapped at the exit of the fishway was 78 ± 10mm. The range was from a single large *A. reinhardtii* (660 mm long) to small individuals of *R. semoni* (24 mm), *H. compressa* (25 mm), *Philypnodon sp.1* (28 mm) and *G. australis* (29 mm).

Over the 117 hour period of trapping, only 71 individuals were recorded successfully ascending the fishway. This rate of fish passage is very low when compared with reported rates of fish passage through vertical-slot fishways on coastal streams. On the Fitzroy River in Queensland, *M. cephalus* ascended a pool and weir fishway at a rate of 1.2 – 46.3 fish hr^{-1} (Kowarsky and Ross, 1981). After renovation with a vertical-slot design, this fishway passed 8.5 fish hr^{-1} (all species) (Stuart, 1997). On the Burnett River, also in Queensland, a pool and weir fishway showed low numbers of 0.66 fish hr^{-1} ascending the fishway (Russell, 1991). After renovation of the fishway with a vertical-slot design, fish passage increased to 18.3 fish hr^{-1} (Stuart and Berghuis, 1999). The rate of fish passage through the Torrumbarry fishway on the Murray River, New South Wales, was even greater than at these coastal streams, with an average of 222.1 fish hr^{-1} reaching the top of the vertical-slot fishway (Mallen-Cooper 1996). These reports of fish passage at a rate of 8.5 to 222.1 fish hr^{-1} in vertical-slot fishways are all greater than the 0.62 fish hr^{-1} recorded successfully negotiating the fishway on the Buladelah Weir.

A potential explanation for this low rate of fishway use may be that the restricted period of sampling was not be a peak upstream migration period for species within the Myall – Crawford river system. The objective of this sampling was to assess whether fish were capable of ascending the fishway, not the rate at which they did so. The studies of Mallen-Cooper (1996), Stuart and

Berghuis (1999) and Stuart and Mallen-Cooper (1999) all used much more intensive sampling over a much greater period of time.

All the relatively abundant migratory species, excluding *M. petardi*, were observed to successfully pass the fishway (Table 9). Interestingly, the species most frequently recorded in the fishway, *R. semoni*, was the species most responsible for dissimilarities between the fish communities of the Myall and Crawford Rivers (Table 5 and Table 8). Although it contributes substantially to the dissimilarity between the rivers, it did show a significant increase in abundance following renovation of the fishway (Table 5). The next three most common species to use the fishway were *H. compressa*, *M. cephalus* and *G. australis*, the species identified as benefiting most from the renovation.

Video surveillance of the fishway for a period of 24 hours (6 October) revealed that fish observed entering the fishway were capable of ascending its full length. Individuals of *G. australis* were observed to ascend the fishway in less than 2.5 hours. Other species were capable of ascending within 4 hours or less. These times are based on the time the fish was observed entering the fishway and when the net at the exit of the fishway was cleared. Therefore, these are maximum estimates of ascent time. The actual time taken for passage through the fishway may be much less.

We observed diel patterns in use of the fishway by the various species of fish trapped at the fishway exit (Figure 15). *A. reinhardtii* and *G. australis* only utilised the fishway at night.

However, only a single individual of *A. reinhardtii* was sampled in the fishway, and a single sample cannot give an indication of diel behaviour, although this species is recognised as being nocturnally active. In contrast, *M. cephalus* only used the fishway during the day. However, all individuals of *M. cephalus* recorded in the fishway as a school and therefore only represent a single sample of diel behaviour. All the remaining species ascended the fishway both day and nigh, with a greater tendency to use the fishway during the day. The difference was quite marked for *R. semoni* and *H. compressa* and less so for the other two species of *Philynodon*. Although these observations are quite distinct for three of the species, these data must be interpreted with caution, as the sample sizes were very small.

Table 9. Fish successfully passing through the vertical-slot fishway on the Buladelah Weir over a 117 hour period.

Migratory status	Scientific name	Number of individuals successfully ascending the fishway
Undefined	*Philypnodon grandiceps*	5
	Philypnodon sp1.	6
Potamodromous	*Retropinna semoni*	24
Amphidromous	*Gobiomorphus australis*	9
	Hypseleotris compressa	14
Catadromous	*Anguilla reinhardtii*	1
	Mugil cephalus	12

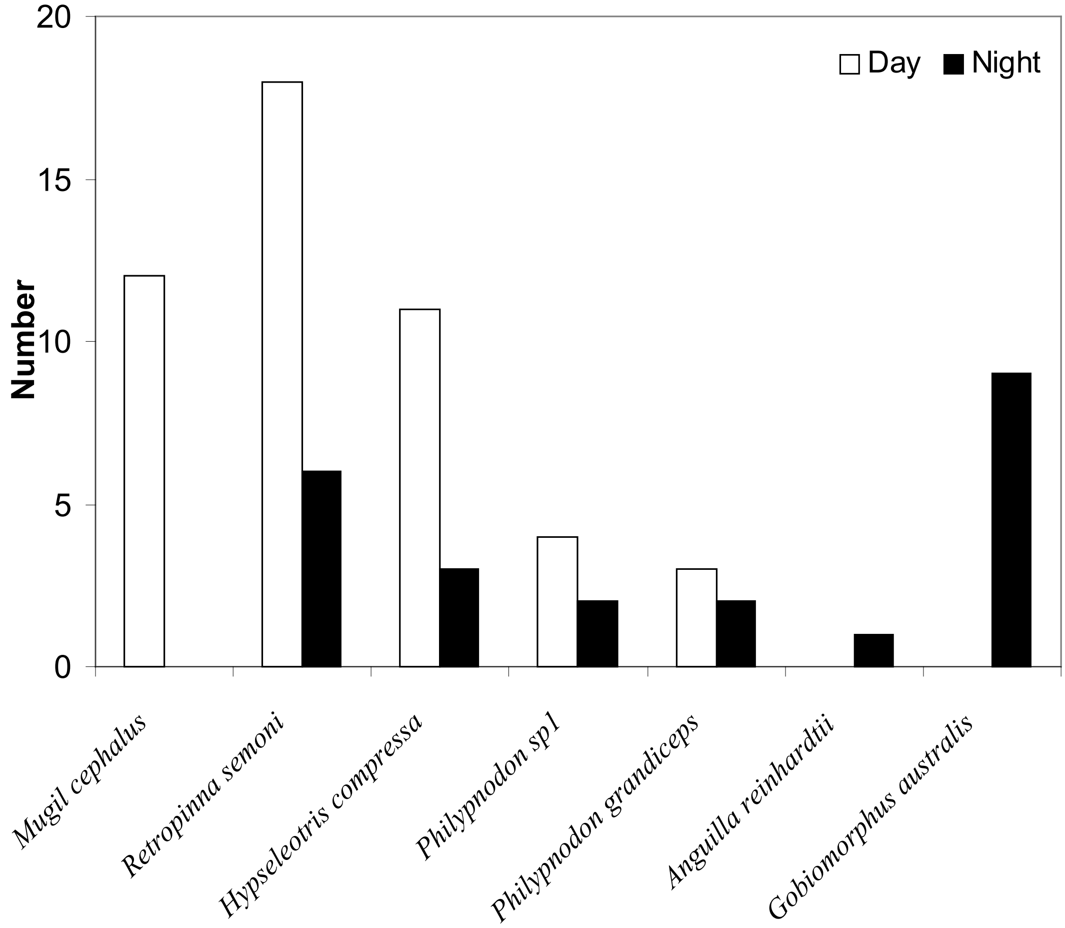

Figure 15. Diel differences in ascent of fish species through the Buladelah Fishway.

3.5. Assessment for reasons of slow recovery

Trapping and filming of fish passage through the fishway has established that the design and internal hydrology of the renovated vertical-slot fishway are capable of providing fish passage for fish within the Myall – Crawford River systems. As the fishway is capable of providing fish passage, the lack of significant recovery must result from either; 1) fish being incapable of finding the fishway entrance, 2) flow through the fishway being insufficient to allow fish passage, or 3) fish preferentially migrate up the Myall River during upstream migrations.

3.5.1. Fishway design problems

Attracting fish to the fishway entrance is a critical feature of fishway design (Clay, 1995; Katopodis, 2001; White *et al.* 2001) and poor entrance conditions and location have been identified as a common failing of unsuccessful fishways (Mallen-Cooper and Harris 1990; Northcote 1998; Travade *et al.* 1998; Williams 1998; Marsden and McGill, 2001). The three most important factors determining the success of entrance design are water temperature, flow and location (Clay 1995). The water temperature flowing from the fishway entrance must be equivalent to (or warmer) than the water flowing through or over the weir. The depth of water in the Crawford River weir pool is unlikely to be sufficient to lead to thermal stratification, and the fishway flows are drawn from the surface of the weir pool. Therefore, the temperatures of the entrance flow are unlikely to lead to fish avoiding the fishway entrance.

The flow from the fishway entrance should be the most obvious flow in the area downstream from the weir and the jet of attraction flow should be aligned at 45 – 90^0 to the stream flow (Mallen-Cooper and Harris, 1990). The fishway flow is often the dominant flow downstream of the Buladelah Weir and is aligned at 90^o to the flow (Figure 16).

Lastly, the entrance should be located close to the weir wall (Mallen-Cooper and Harris, 1990). The fishway entrance of the Buladelah fishway is located approximately 4 m downstream of the weir face (Figure 16). Although the entrance is not located at the upstream limit of migration, characteristics of the entrance of the Buladelah Fishway should allow it to meet the requirements for upstream fish passage.

A further design problem was observed during an earlier fishway assessment (reported in Mallen-Cooper (2000)). Mallen-Cooper suggested that the trash rack at the upstream exit of the Buladelah fishway has a surface area that is too small, resulting in the rapid accumulation of debris and restricted flow within the fishway. Trash racks with at least three times the cross-sectional area of the fishway channel have been recommended as adequate (Mallen-Cooper, 2000).

Figure 16. The vertical-slot fishway on the Buladelah Weir. The attracting flow is aligned 900 to the weir face but is approximately 4m downstream. During periods of low flow, the fishway entrance provides the greatest attracting flow although some flow does pass directly through the weir.

3.5.2. Insufficient fishway flow

Mallen-Cooper (2000) observed that following water abstraction from the Crawford River weir pool, sufficient water remains to operate the fishway over only a few weeks of the year. This was confirmed by several Buladelah residents who stated on several occasions that the fishway was often dry. As fishways are only functional when operating under sufficient flow, the operating conditions at Buladelah Weir contribute to the low rate of recovery of the Crawford River fish community.

3.5.3. Attraction flow - River confluence

Comparisons of water quality between rivers indicate that they differ significantly in two water quality variables, electrical conductivity and temperature. pH was not significantly different between rivers ($t_5 = 1.709$, $p = 0.15$) (Figure 17). Similarly, dissolved oxygen concentration (D.O.) did not differ significantly between rivers ($t_8 = -0.28$, $p = 0.79$), however it was not highly correlated ($r = 0.23$).

3.5.3.1. Dissolved oxygen

The mean D.O. of the Myall and Crawford Rivers was low (D.O = 3.24mg/l and 3.48mg/l respectively) in comparison with other rivers within the same region (Williams River (Dungog) = 6.37mg/l; Gloucester River (Gloucester) = 8.22mg/l; Karuah River (Stroud) = 8.12mg/l (NSW Rivers survey: data report)). With the exception of periods of high flow, surface D.O. was low in both Myall and Crawford Rivers (mean D.O = 5.80mg/l and 5.18mg/l respectively) and was lost rapidly with depth (Figure 17).

As both rivers exhibit low D.O. levels, this is not likely to be responsible for low abundance of fish in the Crawford River. Low D.O. could be a response to high turbidity, leading to restricted photosynthesis among aquatic vegetation (Atkinson *et al.* 1981). Without sufficient photosynthesis, aquatic plants place a significant drain of the oxygen content of the water. However, the waters of both rivers generally show low turbidities.

Alternatively, leaching of water soluble phenolic compounds such as tannins and lignins from surrounding swamps and decaying litter, can significantly reduce available D.O by oxidative polymerisation (Gehrke, Revell and Philbey, 1993). The resulting reduced D.O. retards further polymerisation of these toxic compounds and results in high concentrations of toxins in the water. Due to the nature of the vegetation surrounding the lower reaches of the Myall and Crawford Rivers, and the generally sluggish flows due to their low gradient, the lower reaches of both rivers do exhibit 'dark water' associated with high concentrations of phenolic compounds.

3.5.3.2. Conductivity

Electrical conductivity of the Crawford River remained relatively constant throughout eight years of sampling (Figure 9). In contrast, conductivity of the Myall River showed much greater variability, with periods of extremely high conductivity (Figure 9). This led to a significant difference between the conductivity of the rivers ($t_{13} = -2.25$, $p = 0.04$) with the mean conductivity of the Myall River being an order of magnitude greater than the Crawford (mean = 2256 v 205 µs/cm).

3.5.3.3. Temperature

The temperature of the two rivers ranged from 10°C (July) to 28°C (February). Seasonal temperature fluctuations within the rivers were significantly correlated ($r = 0.88$ $p < 0.01$), however, the Crawford River (mean = 18.75°C) was consistently cooler than the Myall (mean = 20.80°C)($t_{12} = 3.22$, $p < 0.01$) by a mean of 2.05 ± 0.64 ^{0}C (Figure 17).

Migrating fish are influenced by water temperature (Lake 1967; Koehn *et al.* 1997; Northcote, 1998). Under laboratory conditions it has been demonstrated that a warm water species, *Bidyanus bidyanus,* preferentially moves towards warm flows in preference to flows 10°C cooler (Astles *et al.* 2000). Further, examination of the spatial distribution of fish accumulations below Tallowa Dam demonstrated that localised temperature differences between competing attraction flows, resulted in a partitioning of the fish community, with some species showing a significant preference for warmer waters (Gehrke *et al.* 2001). Therefore, temperature differences in the waters flowing from the Crawford and Myall Rivers at the confluence may result in fish preferentially migrating up the Myall River rather than the 2^0C cooler Crawford.

Fish migrating upstream would naturally progress through gradual gradients of salinity, pH, and other water quality variables. While fish can make natural adjustments in behaviour and physiology while moving through water quality gradients in the Myall River, the transition of water quality is abrupt across the Buladelah Weir interface. This rapid change may be physiologically challenging to migrating fish at various developmental stages, seasons and flow cycles.

This scenario could explain the consistently lower abundance of fish in the Crawford River. This temperature difference is presumably a natural feature driven by the higher elevation of the Crawford River catchment.

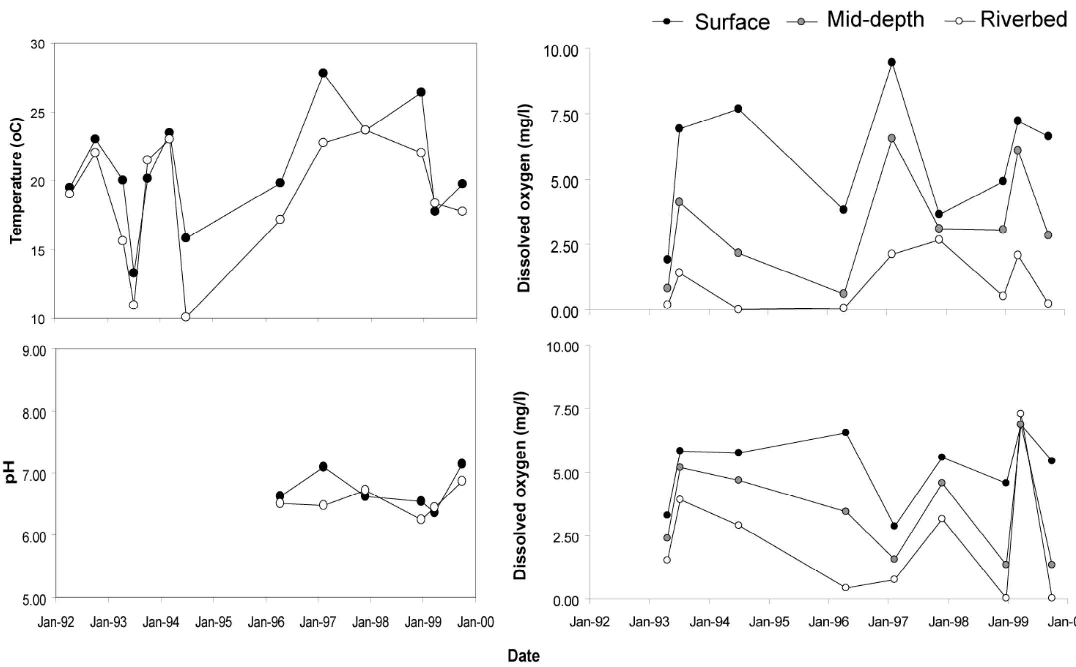

Figure 17. Water quality variables measured at sites 1 – 3 in both the Myall River (●) and Crawford Rivers (O). For temperature and pH, each value is the mean of measurements made at 1 m depth intervals from each of the three survey sites within each river. Dissolved oxygen is figured separately for each river with values for surface, mean and riverbed.

4. CONCLUSIONS

Renovation of the pre-existing submerged orifice fishway on the Buladelah Weir, using a vertical-slot design, did not result in rapid rehabilitation of the fish community of the Crawford River. Although a gradual improvement in the fish community of the Crawford River was observed.

Although some aspects of fishway design and operation could be improved, such as enlargement of the trash-rack and ensuring that sufficient water passes through the fishway, fish passage past the Buladelah Weir has been achieved by renovation of the pre-existing fishway.

The lack of a large and immediate response to renovation of the fishway may be at least partially due to natural temperature differences between the Myall and Crawford Rivers, with migrating fish preferentially moving up the Myall River.

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APPENDIX 1: SITE DETAILS

Site Number	C1	**Stream Name**	Crawford River
		Easting	424876
Site Name	Crawford weir pool (downstream)	**Northing**	6413714
		Altitude	<10m

Substrate	**Grade**
Bedrock	
Boulder	
Cobble	
Gravel	
Sand	
Mud/Silt	A
Clay	
Unknown	

Plants	**Grade**
Native trees	F
Exotic trees	
Shrubs	O
Terrestrial grass	O
Rushes, Sedges	A
Littoral grass	F
Floating macrophytes	F
Submerged macrophytes	F
Algae	O

Cover	**Grade**
Rock	
Timber	O
Undercuts	O
Plant litter	O

Pool	A
Run	
Riffle	
Rapid	

Grades
Abundant
Frequent
Occasional
Rare

Depth (m)
4.7

Date	Temp (^oC)	D.O. (mg/l)	pH	Conductivity (us/cm)	Turbidity	Flow	Velocity
7/5/92	19			170			
25/6/92	11			154			
3/11/92	22			297			
28/7/93	11.6	4.45		144	High	Low	Slow
28/10/93	21.5			301			
26/7/94	10.6	4.9					
1/5/96	17.2	2.71	6.45	280			
5/9/96	14.1	5.11	7.41	170			
10/12/97	24.0	6.14	7.03	284			
7/1/99	20.0	0.27	6.20	167	9 (Low)	Low	Slow
7/4/99	18.6	6.46	6.39	109	High	Low	Slow
29/7/99						Low	Slow
15/10/99	17.4	0.95	6.77	225			
22/12/99	20.7	1.96	7.29	303	Mod.	Low	Slow
25/1/00	20.7	7.92	7.17	179	Mod.	Low	Slow

Figure 18. Habitat details for site C1, Crawford weir pool (downstream).

Site Number	C2	**Stream Name**	Crawford River
		Easting	4245525
Site Name	Crawford (middle)	**Northing**	6414138
		Altitude	<10m

Substrate	**Grade**
Bedrock	
Boulder	
Cobble	
Gravel	
Sand	
Mud/Silt	A
Clay	
Unknown	F

Plants	**Grade**
Native trees	F
Exotic trees	R
Shrubs	O
Terrestrial grass	F
Rushes, Sedges	F
Littoral grass	F
Floating macrophytes	F
Submerged macrophytes	F
Algae	F

Cover	**Grade**
Rock	
Timber	O
Undercuts	O
Plant litter	O

Pool	A
Riffle	
Run	
Rapid	

Grades
Abundant
Frequent
Occasional
Rare

Depth (m)
3

Date	Temp (^{o}C)	D.O. (mg/l)	pH	Conductivity (us/cm)	Turbidity	Flow	Velocity
9/2/93				130			
13/5/93	15.6	2.16		203		Low	Slow
28/7/93	11.1	5.35		157		Low	Slow
28/10/93	21.5			328			
9/2/94	27			400			
29/3/94	23.0			206			
20/7/94	10.1	4.34		200	Mod.	Low	Slow
1/5/96	17.6	3.14	6.50	305			
5/9/96	12.8	5.76	7.3	177			
10/12/97	23.3	3.40	6.46	296			
7/1/99	22.8	1.26	6.19	194	7.7 (Low)	Low	Slow
7/4/99	18.3	6.91	6.62	112	High	Low	Slow
29/7/99						Low	Slow
15/10/99	19.28	2.50	7.29	256			

Figure 19. Habitat details for site C2, Crawford weir pool (middle).

Site Number	C3	**Stream Name**	Crawford River
		Easting	424740
Site Name	Crawford weir pool (upstream)	**Northing**	6415442
		Altitude	<10m

Substrate	Grade
Bedrock	
Boulder	
Cobble	
Gravel	
Sand	
Mud/Silt	A
Clay	O
Unknown	

Plants	Grade
Native trees	A
Exotic trees	R
Shrubs	F
Terrestrial grass	F
Rushes, Sedges	F
Littoral grass	F
Floating macrophytes	O
Submerged macrophytes	F
Algae	F

Cover	Grade
Rock	
Timber	F
Undercuts	F
Plant litter	A

Pool	A
Run	
Riffle	
Rapid	

Grades
Abundant
Frequent
Occasional
Rare

Depth (m)
3.3

Date	Temp (^oC)	D.O. (mg/l)	pH	Conductivity (us/cm)	Turbidity	Flow	Velocity
28/7/93	10.1	6.36		172	High	Low	Slow
28/10/93	21.5			339			
20/7/94	9.5	4.78		200	High	Low	Slow
1/5/96	16.5	3.79	6.53	320			
5/9/96	12.3	6.48	6.69	170			
25/2/97	22.8	1.55	6.48	128	7.75		
10/12/97	23.8	4.09	6.66	308			
7/1/99	24.9	2.52	6.41	202	4.3 (Low)	Low	Slow
7/4/99	18.24	6.98	6.34	113	High	Low	Slow
29/7/99						Low	Slow
15/10/99	18.0	2.06	6.91	266			

Figure 20. Habitat details for site C3, Crawford weir pool (upstream).

Site Number C4

Site Name Crawford (below 1st riffle)

Stream Name Crawford River
Easting 424460
Northing 6416530

Altitude <10m

Substrate	Grade
Bedrock	
Boulder	
Cobble	
Gravel	
Sand	
Mud/Silt	A
Clay	
Unknown	

Plants	Grade
Native trees	A
Exotic trees	
Shrubs	O
Terrestrial grass	F
Rushes, Sedges	R
Littoral grass	A
Floating macrophytes	
Submerged macrophytes	R
Algae	

Cover	Grade
Rock	
Timber	F
Undercuts	A
Plant litter	F

Pool	A
Run	R
Riffle	
Rapid	

Grades
Abundant
Frequent
Occasional
Rare

Depth (m)
2

Date	Temp (^oC)	D.O. (mg/l)	pH	Conductivity (us/cm)	Turbidity	Flow	Velocity
8./7/99					Mod.	Mod.	Slow

Figure 21. Habitat details for site C4, Crawford (below 1st riffle).

Site Number	C5	**Stream Name**	Crawford River
		Easting	425182
Site Name	Gooch's Road	**Northing**	6418569
		Altitude	40m

Substrate	Grade
Bedrock	O
Boulder	R
Cobble	R
Gravel	R
Sand	R
Mud/Silt	A
Clay	
Unknown	

Plants	Grade
Native trees	A
Exotic trees	
Shrubs	A
Terrestrial grass	
Rushes, Sedges	R
Littoral grass	A
Floating macrophytes	
Submerged macrophytes	O
Algae	R

Cover	Grade
Rock	O
Timber	F
Undercuts	A
Plant litter	

Pool	A
Run	R
Riffle	
Rapid	

Grades
Abundant
Frequent
Occasional
Rare

Depth (m)
3.7

Date	Temp (^{o}C)	D.O. (mg/l)	pH	Conductivity (us/cm)	Turbidity	Flow	Velocity
8/7/99	10.1	9.62	6.31	138	15.5 (Mod.)	Mod.	Slow
13/10/99	15.0	3.16	6.78	293			

Figure 22. Habitat details for site C5, Gooch's Road.

Site Number	C6	**Stream Name**	Crawford River
		Easting	423434
Site Name	Mason's Bend	**Northing**	6424065
		Altitude	50m

Substrate	Grade
Bedrock	A
Boulder	F
Cobble	
Gravel	
Sand	
Mud/Silt	A
Clay	
Unknown	

Plants	Grade
Native trees	A
Exotic trees	
Shrubs	A
Terrestrial grass	
Rushes, Sedges	
Littoral grass	A
Floating macrophytes	
Submerged macrophytes	R
Algae	

Cover	Grade
Rock	A
Timber	F
Undercuts	A
Plant litter	F

Pool	A
Run	O
Riffle	O
Rapid	O

Grades
Abundant
Frequent
Occasional
Rare

Depth (m)
1.5

Date	Temp (^{o}C)	D.O. (mg/l)	pH	Conductivity (us/cm)	Turbidity	Flow	Velocity
8/7/99	10.0	10.56	5.99	137	16.5 (Mod.)	Mod.	Slow
13/10/99	16.6	7.86	7.39	206		Low	

Figure 23. Habitat details for site C6, Mason's Bend.

Site Number	C7	**Stream Name**	Crawford River
		Easting	422362
Site Name	Upper Crawford	**Northing**	6430289
		Altitude	120m

Substrate	Grade
Bedrock	
Boulder	
Cobble	F
Gravel	A
Sand	
Mud/Silt	A
Clay	
Unknown	

Plants	Grade
Native trees	A
Exotic trees	
Shrubs	A
Terrestrial grass	
Rushes, Sedges	R
Littoral grass	F
Floating macrophytes	
Submerged macrophytes	O
Algae	

Cover	Grade
Rock	
Timber	F
Undercuts	F
Plant litter	A

Pool	A
Run	R
Riffle	
Rapid	

Grades
Abundant
Frequent
Occasional
Rare

Depth (m)
1

Date	Temp (^{o}C)	D.O. (mg/l)	pH	Conductivity (us/cm)	Turbidity	Flow	Velocity
8/7/99	11.1	9.55	6.38	129	15.5 (Mod.)	Mod.	Slow
13/10/99	16.9	7.73	7.53	217		Low	

Figure 24. Habitat details for site C7, Upper Crawford River.

Site Number	M1	**Stream Name**	Myall River
		Easting	424624
Site Name	Lower Myall (downstream)	**Northing**	6413150
		Altitude	<10m

Substrate	Grade
Bedrock	
Boulder	
Cobble	
Gravel	
Sand	
Mud/Silt	A
Clay	
Unknown	

Plants	Grade
Native trees	O
Exotic trees	R
Shrubs	R
Terrestrial grass	A
Rushes, Sedges	A
Littoral grass	O
Floating macrophytes	O
Submerged macrophytes	A
Algae	F

Cover	Grade
Rock	
Timber	O
Undercuts	O
Plant litter	O

Pool	A
Run	
Riffle	
Rapid	

Grades
Abundant
Frequent
Occasional
Rare

Depth (m)
3.4

Date	Temp (^oC)	D.O. (mg/l)	pH	Conductivity (us/cm)	Turbidity	Flow	Velocity
7/5/92	19.5			340			
24/6/92	15			240			
2/11/92	23			178			
27/7/93	13.7	3.31		292	High	Low	Slow
28/10/93	20.1			3330			
10/2/94	27.4	1.87		1400			
30/3/94				11500			
2/5/96	19.9	1.00	6.63	6753			
4/9/96	14.4	5.86	7.41	227			
24/2/97	27.2	5.90	7.1	164			
11/12/97	23.6	3.95	6.54	475	2.7 (Low)	Low	Slow
6/1/99	27.8	3.81	6.70	200	45 (Low)	Low	Slow
8/4/99	18.3	6.84	6.42	139	High	Mod.	Slow
29/7/99						Low	Slow
14/10/99	20.0	3.23	7.30	223			
22/12/99	22.0	4.20	7.81	350	Low	Low	Slow
25/1/00	22.9	5.06	7.28	224	Mod.	Low	Slow

Figure 25. Habitat details for site M1, Lower Myall (downstream).

Site Number	M2	**Stream Name**	Myall River
		Easting	423984
Site Name	Lower Myall (middle)	**Northing**	6412854
		Altitude	<10m

Substrate	Grade
Bedrock	R
Boulder	R
Cobble	R
Gravel	R
Sand	R
Mud/Silt	A
Clay	
Unknown	F

Plants	Grade
Native trees	F
Exotic trees	R
Shrubs	F
Terrestrial grass	A
Rushes, Sedges	A
Littoral grass	F
Floating macrophytes	F
Submerged macrophytes	F
Algae	R

Cover	Grade
Rock	R
Timber	F
Undercuts	O
Plant litter	F

Pool	
Run	A
Riffle	
Rapid	

Grades
Abundant
Frequent
Occasional
Rare

Depth (m)
2.5

Date	Temp (^{o}C)	D.O. (mg/l)	pH	Conductivity (us/cm)	Turbidity	Flow	Velocity
2/11/92	23			170			
12/5/93	20.2	0.575		3940	High	Mod	Slow
27/7/93	13.6	3.56		274	High	Low	Slow
28/10/93	20.1			3130			
10/2/94	27.4	1.82		1200			
30/3/94				11000			
2/5/96	19.9	0.59	6.62	6486			
4/9/96	14.6	6.06	7.1	227			
24/2/97	28.5	7.15	7.08	184			
11/12/97	23.8	3.53	6.68	448	2	Low	Slow
6/1/99	26.6	3.52	6.37	208	15 (Low)	Low	Slow
8/4/99	17.9	6.09	6.32	142	High	Mod.	Slow
29/7/99						Low	Slow
14/10/99	20.5	3.48	7.12	258			

Figure 26. Habitat details for site M2, Lower Myall (Middle).

Site Number	M3	**Stream Name**	Myall River
		Easting	423136
Site Name	Lower Myall (upstream)	**Northing**	6412630
		Altitude	<10m

Substrate	Grade
Bedrock	
Boulder	
Cobble	
Gravel	
Sand	
Mud/Silt	A
Clay	R
Unknown	

Plants	Grade
Native trees	A
Exotic trees	R
Shrubs	O
Terrestrial grass	A
Rushes, Sedges	F
Littoral grass	O
Floating macrophytes	O
Submerged macrophytes	A
Algae	F

Cover	Grade
Rock	
Timber	F
Undercuts	O
Plant litter	F

Pool	A
Run	
Riffle	
Rapid	

Grades
Abundant
Frequent
Occasional
Rare

Depth (m)
3.75

Date	Temp (°C)	D.O. (mg/l)	pH	Conductivity (us/cm)	Turbidity	Flow	Velocity
2/11/92	23			160			
8/2/93				370		Low	
12/5/93	19.8	1.0		1193			
28/10/93	20.1			1834			
10/2/94				1100			
30/3/94	23.5			8000			
2/5/96	19.3	0.51	6.68	4348			
4/9/96	14.1	7.21	7.05	200			
11/12/97	23.7	1.74	6.64	527	1.3 (Low)	Low	Slow
6/1/99	24.7	1.78	6.53	232	15 (Low)	Low	Slow
8/4/92	17.3	6.97	6.29	145	High	Mod.	Slow
29/7/99						Low	Slow
14/10/99	19.3	2.38	7.06	297			

Figure 27. Habitat details for site M3, Lower Myall (upstream).

Site Number M4

Site Name Markwell

Stream Name Myall River
Easting 422184
Northing 6410758
Altitude <10m

Substrate	Grade
Bedrock	
Boulder	
Cobble	
Gravel	
Sand	
Mud/Silt	A
Clay	
Unknown	

Plants	Grade
Native trees	F
Exotic trees	
Shrubs	F
Terrestrial grass	A
Rushes, Sedges	F
Littoral grass	F
Floating macrophytes	O
Submerged macrophytes	O
Algae	

Cover	Grade
Rock	R
Timber	O
Undercuts	A
Plant litter	F

Pool	A
Run	O
Riffle	R
Rapid	

Grades
Abundant
Frequent
Occasional
Rare

Depth (m)
1.8

Date	Temp (^{o}C)	D.O. (mg/l)	pH	Conductivity (us/cm)	Turbidity	Flow	Velocity
8/7/99	12.3	8.53	6.59	187	36 (Mod.)	Mod.	Slow
12/10/99	19.4	2.92	6.86	275			

Figure 28. Habitat details for site M4, Markwell.

Site Number	M5	**Stream Name**	Myall River
		Latitude	417136
Site Name	Rosenthal	**Longitude**	6411446
		Altitude	<10

Substrate	Grade
Bedrock	R
Boulder	O
Cobble	O
Gravel	O
Sand	
Mud/Silt	A
Clay	A
Unknown	

Plants	Grade
Native trees	A
Exotic trees	R
Shrubs	O
Terrestrial grass	
Rushes, Sedges	
Littoral grass	A
Floating macrophytes	
Submerged macrophytes	
Algae	

Cover	Grade
Rock	O
Timber	A
Undercuts	A
Plant litter	A

Pool	F
Run	O
Riffle	A
Rapid	R

Grades
Abundant
Frequent
Occasional
Rare

Depth (m)
2.5

Date	Temp (^{o}C)	D.O. (mg/l)	pH	Conductivity (us/cm)	Turbidity	Flow	Velocity
7/7/99	12.45	8.35	6.44	145	107 (High)	High	Mod.
12/10/99	19.6	3.82	6.54	242		Low	

Figure 29. Habitat details for site M5, Rosenthal.

Site Number	M6	**Stream Name**	Myall River
		Easting	415676
Site Name	Strawberry Hill	**Northing**	6412890
		Altitude	20m

Substrate	Grade
Bedrock	
Boulder	
Cobble	R
Gravel	O
Sand	R
Mud/Silt	A
Clay	
Unknown	

Plants	Grade
Native trees	F
Exotic trees	F
Shrubs	O
Terrestrial grass	A
Rushes, Sedges	O
Littoral grass	A
Floating macrophytes	O
Submerged macrophytes	O
Algae	O

Cover	Grade
Rock	F
Timber	O
Undercuts	A
Plant litter	F

Pool	A
Run	
Riffle	
Rapid	

Grades
Abundant
Frequent
Occasional
Rare

Depth (m)
1.8

Date	Temp (^{o}C)	D.O. (mg/l)	pH	Conductivity (us/cm)	Turbidity	Flow	Velocity
3/6/99	15.2	7.1	7.32	285	Clear	Low	Slow
12/10/99	18.4	3.24	6.7	222		Low	

Figure 30. Habitat details for site M6, Strawberry Hill.

Site Number	M7	**Stream Name**	Myall River
		Easting	415254
Site Name	Warranulla	**Northing**	6419197
		Altitude	50m

Substrate	Grade
Bedrock	R
Boulder	R
Cobble	A
Gravel	A
Sand	
Mud/Silt	O
Clay	
Unknown	

Plants	Grade
Native trees	A
Exotic trees	
Shrubs	
Terrestrial grass	F
Rushes, Sedges	O
Littoral grass	R
Floating macrophytes	
Submerged macrophytes	F
Algae	R

Cover	Grade
Rock	A
Timber	O
Undercuts	O
Plant litter	R

Pool	O
Run	F
Riffle	F
Rapid	

Grades
Abundant
Frequent
Occasional
Rare

Depth (m)
0.5

Date	Temp (^oC)	D.O. (mg/l)	pH	Conductivity (us/cm)	Turbidity	Flow	Velocity
8/5/92				164		Mod.	Slow
7/7/99	13.4	8.43	6.3	163	17.5 (Low)	High	Mod.
11/10/99	20.3	6.11	5.88	201	Clear	Low	Slow

Figure 31. Habitat details for site M7, Warranulla.

APPENDIX 2: CATCH DETAILS

Table 10. List of fish species recorded in the Myall – Crawford River system: 1992 - 1999.

Family	Scientific name	Common name
Anguillidae	*Anguilla australis*	Short-finned eel
	Anguilla reinhardtii	Long-finned eel
Clupeidae	*Herklotsichthys castelnaui*	Southern herring
Galaxiidae	*Galaxias maculatus*	Common jollytail
Retropinnidae	*Retropinna semoni*	Australian smelt
Plotosidae	*Tandanus tandanus*	Freshwater catfish
Poeciliidae	*Gambusia holbrooki*	Eastern gambusia
Pseudomugilidae	*Pseudomugil signifer*	Pacific blue-eye
Scorpaenidae	*Notesthes robusta*	Bullrout
Chandidae	*Ambassis marianus*	Estuary perchlet
Percichthyidae	*Macquaria novemaculeata*	Australian bass
Sparidae	*Acanthopagrus australis*	Yellow-finned bream
Scatophagidae	*Selenetoca multifasciata*	Striped butterfish
Mugilidae	*Liza argentea*	Flat-tail mullet
	Mugil cephalus	Striped mullet
	Myxus elongatus	Sand mullet
	Myxus petardi	Freshwater mullet
Gobiidae	*Gobiomorphus australis*	Striped gudgeon
	Gobiomorphus coxii	Cox's gudgeon
	Hypseleotris compressa	Empire gudgeon
	Hypseleotris galii	Fire-tailed gudgeon
	Philypnodon grandiceps	Flat-headed gudgeon
	Philypnodon sp1.	Dwarf flat-headed gudgeon

Table 11. Mean ± SE of each species sampled during four x 5 minute electrofishing shots in the Myall and Crawford River and total number of individuals sampled over the life of the project (1992 – 1999). Species are ranked according to abundance in the entire Myall - Crawford river system.

Species	**Catch per sample**		**Total**
	Crawford (Mean ±SE)	**Myall (Mean ±SE)**	
Mugil cephalus	4.10 ± 0.91	33.84 ± 7.66	2648
Retropinna semoni	11.66 ± 3.07	16.7 ± 8.70	1962
Gambusia holbrooki	4.94 ± 2.22	19.66 ± 8.40	1712
Anguilla reinhardtii	4.97 ± 0.54	10.3 ± 1.24	1059
Hypseleotris compressa	3.44 ± 1.23	6.31 ± 3.79	676
Myxus petardi	1.24 ± 0.26	6.24 ± 1.18	521
Gobiomorphus australis	4.53 ± 0.64	2.2 ± 0.40	462
Pseudomugil signifer	0.09 ± 0.07	3.47 ± 1.88	249
Philypnodon grandiceps	1.07 ± 0.32	2.29 ± 0.80	233
Myxus elongatus	0	3.23 ± 3.23	226
Herklotsichthys castelnaui	0	2.04 ± 0.88	143
Philypnodon sp1.	0.59 ± 0.24	0.79 ± 0.52	95
Liza argentea	0	0.67 ± 0.24	47
Macquaria novemaculeata	0.24 ± 0.08	0.19 ± 0.07	29
Gobiomorphus coxii	0.16 ± 0.13	0.01 ± 0.01	12
Anguilla australis	0.12 ± 0.10	0.03 ± 0.03	10
Hypseleotris galii	0.04 ± 0.03	0.07 ± 0.03	8
Acanthopagrus australis	0	0.09 ± 0.06	6
Notesthes robusta	0	0.07 ± 0.04	5
Galaxias maculatus	0.03 ± 0.02	0	2
Tandanus tandanus	0.01 ± 0.01	0	1
Ambassis marianus	0	0.01 ± 0.01	1
Selenetoca multifasciata	0	0.01 ± 0.01	1

Table 12. Sampling data from site C1, Crawford weir pool (downstream).

	Sample																					
	Before				After																	
	May	Jun	Nov	Feb	May	Jul	Octt	Feb	Mar	Jul	Aug	Nov	May	Sep	Feb	Dec	Jan	Apr	Jul	Oct	Dec	Jan
Acanthopagrus australis																						
Ambassis marianus																						
Anguilla australis																			1			
Anguilla reinhardtii	3	1	16	5	2	3	1	5		6	4	13	4	3	1	6	5	2	1	8	6	5
Galaxias maculatus																						
Gambusia holbrooki									22								25	127	1	1	13	14
Gobiomorphus australis	4			2			15	1	19	1		10	2			4	13	1	6	9	8	4
Gobiomorphus coxii																1						
Herklotsichthys castelnaui																				3		
Hypseleotris compressa							1		75	2		1	1			1	25	20	3		7	2
Hypseleotris galii												1										
Liza argentea																						
Macquaria novemaculeata	2								1	1												
Mugil cephalus	3	3		1	1	1	4	1		1	15	7	1	5	7		45	6	2	13	1	9
Myxus elongatus																						
Myxus petardi	5	1		3			2			2		1		1		2	2	2	2			2
Notesthes robusta																						
Philypnodon grandiceps	1		1						18			4				2	2	3	1			
Philypnodon sp1.									4			3						2				
Pseudomugil signifer																						
Retropinna semoni		17					8	100	3	76	5	60		85		2		2				
Selenetoca multifasciata																						
Tandanus tandanus													1									
Total number of fish	18	22	17	11	3	4	31	107	142	89	24	100	9	94	8	18	117	165	17	34	35	36
Total number of species	6	4	2	4	2	2	6	4	7	7	3	9	5	4	2	7	7	9	8	5	5	6

Table 13. Sampling data from site C2, Crawford weir pool (middle).

	Sample																					
	Before				After																	
	May	Jun	Nov	Feb	May	Jul	Octt	Feb	Mar	Jul	Aug	Nov	May	Sep	Feb	Dec	Jan	Apr	Jul	Oct	Dec	Jan
Acanthopagrus australis																						
Ambassis marianus																						
Anguilla australis																						
Anguilla reinhardtii		3	17	4	3	4	5	9	2	3	3	12	6	1		14	13	3	1	8		
Galaxias maculatus							1								1							
Gambusia holbrooki								2				2					23	75	2			
Gobiomorphus australis		1	6		2	1	20	11	14	1	1	11	1	2		2	3	7	2	7		
Gobiomorphus coxii															9							
Herklotsichthys castelnaui																						
Hypseleotris compressa			1						6	2		3		2	6	1	8	19	1	4		
Hypseleotris galii												1					1					
Liza argentea																						
Macquaria novemaculeata				2			1						4									
Mugil cephalus		2	2		3		2	3	4		1		2	1	6	2	13	6	1	4		
Myxus elongatus																						
Myxus petardi				2	1							2					4	1	1			
Notesthes robusta																						
Philypnodon grandiceps			1				3	2	3	1		1				1	10	2				
Philypnodon sp1.			1							1		2						4				
Pseudomugil signifer																						
Retropinna semoni			51		8		13	7	1	14			1			11						
Selenetoca multifasciata																						
Tandanus tandanus																						
Total number of fish		6	79	8	17	5	45	34	30	22	5	34	14	6	22	31	75	117	8	23		
Total number of species		3	7	3	5	2	7	6	6	6	3	8	5	4	4	6	8	8	6	4		

Table 14. Sampling data from site C3, Crawford weir pool (upstream).

	Sample																					
	Before				After																	
	May	**Jun**	**Nov**	**Feb**	**May**	**Jul**	**Octt**	**Feb**	**Mar**	**Jul**	**Aug**	**Nov**	**May**	**Sep**	**Feb**	**Dec**	**Jan**	**Apr**	**Jul**	**Oct**	**Dec**	**Jan**
Acanthopagrus australis																						
Ambassis marianus																						
Anguilla australis																						
Anguilla reinhardtii		2	7	7	7		6	8	7	3		9	3		1	18	12	1	1	7		
Galaxias maculatus																						
Gambusia holbrooki																	16	12		1		
Gobiomorphus australis			6	3		4	15	8	21	2		12	10	1		2	7	5		2		
Gobiomorphus coxii															1							
Herklotsichthys castelnaui																						
Hypseleotris compressa							1		11					1	1	5	2	16	1	2		
Hypseleotris galii																						
Liza argentea																						
Macquaria novemaculeata				1	1								2									
Mugil cephalus		1	2	7				6	2	2		2	3		7	9	36	6	1			
Myxus elongatus																						
Myxus petardi			9	3	3		4		5			1	1	2	12	4		4				
Notesthes robusta																						
Philypnodon grandiceps			2				1		5							3	1	3		2		
Philypnodon sp1.					1							1						1		1		
Pseudomugil signifer																	4	2				
Retropinna semoni		1	4		3		4	21	40			14		49		31		1		13		
Selenetoca multifasciata																						
Tandanus tandanus																						
Total number of fish		4	30	21	15	4	31	43	91	7	0	39	19	53	22	72	78	51	3	28		
Total number of species		3	6	5	5	1	6	4	7	3	0	6	5	4	5	7	7	10	3	7		

Table 15. Sampling data from site C4, Crawford (below 1st riffle).

	Sample																					
	Before				After																	
	May	Jun	Nov	Feb	May	Jul	Octt	Feb	Mar	Jul	Aug	Nov	May	Sep	Feb	Dec	Jan	Apr	Jul	Oct	Dec	Jan
Acanthopagrus australis																						
Ambassis marianus																						
Anguilla australis																						
Anguilla reinhardtii																						
Galaxias maculatus																						
Gambusia holbrooki																						
Gobiomorphus australis																			3	3		
Gobiomorphus coxii																						
Herklotsichthys castelnaui																						
Hypseleotris compressa																						
Hypseleotris galii																						
Liza argentea																						
Macquaria novemaculeata																						
Mugil cephalus																				17		
Myxus elongatus																						
Myxus petardi																						
Notesthes robusta																						
Philypnodon grandiceps																						
Philypnodon sp1.																						
Pseudomugil signifer																						
Retropinna semoni																				2		
Selenetoca multifasciata																						
Tandanus tandanus																						
Total number of fish																			3	22		
Total number of species																			1	3		

Table 16. Sampling data from site C5, Gooch's Road.

	Sample																					
	Before				**After**																	
	May	**Jun**	**Nov**	**Feb**	**May**	**Jul**	**Octt**	**Feb**	**Mar**	**Jul**	**Aug**	**Nov**	**May**	**Sep**	**Feb**	**Dec**	**Jan**	**Apr**	**Jul**	**Oct**	**Dec**	**Jan**
Acanthopagrus australis																						
Ambassis marianus																						
Anguilla australis																						
Anguilla reinhardtii																			2	13		
Galaxias maculatus																						
Gambusia holbrooki																						
Gobiomorphus australis																			2	1		
Gobiomorphus coxii																						
Herklotsichthys castelnaui																						
Hypseleotris compressa																						
Hypseleotris galii																						
Liza argentea																						
Macquaria novemaculeata																				1		
Mugil cephalus																						
Myxus elongatus																						
Myxus petardi																						
Notesthes robusta																						
Philypnodon grandiceps																						
Philypnodon sp1.																						
Pseudomugil signifer																						
Retropinna semoni																			1	11		
Selenetoca multifasciata																						
Tandanus tandanus																						
Total number of fish																			5	26		
Total number of species																			3	4		

Table 17. Sampling data from site C6, Mason's Bend.

	Sample																					
	Before				After																	
	May	Jun	Nov	Feb	May	Jul	Octt	Feb	Mar	Jul	Aug	Nov	May	Sep	Feb	Dec	Jan	Apr	Jul	Oct	Dec	Jan
Acanthopagrus australis																						
Ambassis marianus																						
Anguilla australis																						
Anguilla reinhardtii																			4	5		
Galaxias maculatus																						
Gambusia holbrooki																						
Gobiomorphus australis																			3	6		
Gobiomorphus coxii																						
Herklotsichthys castelnaui																						
Hypseleotris compressa																						
Hypseleotris galii																						
Liza argentea																						
Macquaria novemaculeata																						
Mugil cephalus																						
Myxus elongatus																						
Myxus petardi																						
Notesthes robusta																						
Philypnodon grandiceps																						
Philypnodon sp1.																			5	14		
Pseudomugil signifer																						
Retropinna semoni																			3	127		
Selenetoca multifasciata																						
Tandanus tandanus																						
Total number of fish																			15	152		
Total number of species																			4	4		

Table 18. Sampling data from site C7, Upper Crawford.

	Sample																					
	Before				After																	
	May	Jun	Nov	Feb	May	Jul	Octt	Feb	Mar	Jul	Aug	Nov	May	Sep	Feb	Dec	Jan	Apr	Jul	Oct	Dec	Jan
Acanthopagrus australis																						
Ambassis marianus																						
Anguilla australis																				7		
Anguilla reinhardtii																			3	1		
Galaxias maculatus																						
Gambusia holbrooki																						
Gobiomorphus australis																				1		
Gobiomorphus coxii																						
Herklotsichthys castelnaui																						
Hypseleotris compressa																						
Hypseleotris galii																						
Liza argentea																						
Macquaria novemaculeata																						
Mugil cephalus																						
Myxus elongatus																						
Myxus petardi																						
Notesthes robusta																						
Philypnodon grandiceps																						
Philypnodon sp1.																						
Pseudomugil signifer																						
Retropinna semoni																			2	2		
Selenetoca multifasciata																						
Tandanus tandanus																						
Total number of fish																			5	11		
Total number of species																			2	4		

Table 19. Sampling data from site M1, Lower Myall (downstream).

	Sample																					
	Before				After																	
	May	Jun	Nov	Feb	May	Jul	Octt	Feb	Mar	Jul	Aug	Nov	May	Sep	Feb	Dec	Jan	Apr	Jul	Oct	Dec	Jan
Acanthopagrus australis												4										
Ambassis marianus	1																					
Anguilla australis																						
Anguilla reinhardtii	10	18	11	12	11	11	15		7	21	23	14	25	12	11	27		3	8	6	10	14
Galaxias maculatus																						
Gambusia holbrooki															2		250	2	7	13	211	182
Gobiomorphus australis	11	2		6								1	2		2		6	3	1	7	5	2
Gobiomorphus coxii														1								
Herklotsichthys castelnaui							4					19	3		1	5	48					
Hypseleotris compressa	2			13							1	5		1	2		13	4	3	3	253	84
Hypseleotris galii		1																				
Liza argentea		1	4		2					1		3										
Macquaria novemaculeata	1						3				1						1					
Mugil cephalus	45	18	27	18	3	1	7	5	2	18	6	20	23	39	44	35	369	5	54	59	315	78
Myxus elongatus	226																					
Myxus petardi	45	10	15	7	8	3	3			1		12	11	1	10	15	5		2	3	7	5
Notesthes robusta	2																					1
Philypnodon grandiceps	23	4		3				1				2		2	1		2	1		19	16	19
Philypnodon sp1.													1	1	1		1				5	
Pseudomugil signifer		3		105				12			1						8					2
Retropinna semoni														10				2			3	
Selenetoca multifasciata														1								
Tandanus tandanus																						
Total number of fish	366	57	57	164	24	15	32	18	9	41	32	80	65	68	74	82	703	20	75	110	825	387
Total number of species	10	8	4	7	4	3	5	3	2	4	5	9	6	9	9	4	10	7	6	7	9	9

Table 20. Sampling data from site M2, Lower Myall (middle).

	Sample																					
	Before				After																	
	May	Jun	Nov	Feb	May	Jul	Octt	Feb	Mar	Jul	Aug	Nov	May	Sep	Feb	Dec	Jan	Apr	Jul	Oct	Dec	Jan
Acanthopagrus australis												1				1						
Ambassis marianus																						
Anguilla australis							2															
Anguilla reinhardtii		4	28	6	17	5	11		3	4	14	25	16	4	2	66		1	7	22		
Galaxias maculatus																						
Gambusia holbrooki					3			2							2		385	13	1			
Gobiomorphus australis				2			1					1		2		1	9	8		6		
Gobiomorphus coxii																						
Herklotsichthys castelnaui							19					30	1		2		2					
Hypseleotris compressa		4		2											2	3	13	25	1			
Hypseleotris galii													1				1	1				
Liza argentea		11							3	4			1									
Macquaria novemaculeata							2										1			1		
Mugil cephalus		8	9	19	7		10	4	11	7	91	51	13	240	82	45	39	18	7	97		
Myxus elongatus																						
Myxus petardi		8	2	25	1	3	8			3	1	11	2	4	4	15	12		7	12		
Notesthes robusta		1																				
Philypnodon grandiceps														1		2	43			7		
Philypnodon sp1.																	36			2		
Pseudomugil signifer				5							2						77					
Retropinna semoni												23	1	48		10		5	4	264		
Selenetoca multifasciata																						
Tandanus tandanus																						
Total number of fish		36	39	59	28	8	53	6	17	18	108	142	35	299	94	145	618	71	27	411		
Total number of species		6	3	6	4	2	7	2	3	4	4	7	7	6	6	8	11	7	6	8		

Table 21. Sampling data from site M3, Lower Myall (upstream).

	Sample																					
	Before				**After**																	
	May	**Jun**	**Nov**	**Feb**	**May**	**Jul**	**Octt**	**Feb**	**Mar**	**Jul**	**Aug**	**Nov**	**May**	**Sep**	**Feb**	**Dec**	**Jan**	**Apr**	**Jul**	**Oct**	**Dec**	**Jan**
Acanthopagrus australis																						
Ambassis marianus																						
Anguilla australis																						
Anguilla reinhardtii		14	12	8	11	3	3		5	2	18	10	3	4	2	9	6	1	3	9		
Galaxias maculatus																						
Gambusia holbrooki													1	2	10		281	5	1	1		
Gobiomorphus australis		2		1		3						3	3	3		1	5	2	3	1		
Gobiomorphus coxii																						
Herklotsichthys castelnaui			1									8										
Hypseleotris compressa															2		1	3		1		
Hypseleotris galii		1																				
Liza argentea							3		10		4											
Macquaria novemaculeata														2								
Mugil cephalus		7	22	4	2		45		26		18	50	28	25	38	18	83	6		21		
Myxus elongatus																						
Myxus petardi		9	3	1	1	4	2				1	21		63	7	7	3	3	2	1		
Notesthes robusta													1									
Philypnodon grandiceps		2									1					1	1	4	1			
Philypnodon sp1.																1				1		
Pseudomugil signifer																1	27					
Retropinna semoni		1				1						1	4	5			8	15	3	7		
Selenetoca multifasciata																						
Tandanus tandanus																						
Total number of fish		36	38	14	14	11	53	0	41	2	42	93	40	104	59	38	415	39	13	42		
Total number of species		7	4	4	3	4	4	0	3	1	5	6	6	7	5	7	9	8	6	8		

Table 22. Sampling data from site M4, Markwell.

	Sample																					
	Before				After																	
	May	Jun	Nov	Feb	May	Jul	Octt	Feb	Mar	Jul	Aug	Nov	May	Sep	Feb	Dec	Jan	Apr	Jul	Oct	Dec	Jan
Acanthopagrus australis																						
Ambassis marianus																						
Anguilla australis																						
Anguilla reinhardtii																			1	2		
Galaxias maculatus																						
Gambusia holbrooki																						
Gobiomorphus australis																			3			
Gobiomorphus coxii																						
Herklotsichthys castelnaui																						
Hypseleotris compressa																						
Hypseleotris galii																						
Liza argentea																						
Macquaria novemaculeata	1																					
Mugil cephalus	1																		4	2		
Myxus elongatus																						
Myxus petardi																			3	7		
Notesthes robusta																						
Philypnodon grandiceps																						
Philypnodon sp1.																						
Pseudomugil signifer																						
Retropinna semoni																				509		
Selenetoca multifasciata																						
Tandanus tandanus																						
Total number of fish	2																		11	520		
Total number of species	2																		4	4		

Table 23. Sampling data from site M5, Rosenthal.

	Sample																					
	Before				After																	
	May	Jun	Nov	Feb	May	Jul	Octt	Feb	Mar	Jul	Aug	Nov	May	Sep	Feb	Dec	Jan	Apr	Jul	Oct	Dec	Jan
Acanthopagrus australis																						
Ambassis marianus																						
Anguilla australis																						
Anguilla reinhardtii																			4	8		
Galaxias maculatus																						
Gambusia holbrooki																				2		
Gobiomorphus australis																			5	12		
Gobiomorphus coxii																						
Herklotsichthys castelnaui																						
Hypseleotris compressa																			1			
Hypseleotris galii																						
Liza argentea																						
Macquaria novemaculeata																						
Mugil cephalus																				16		
Myxus elongatus																						
Myxus petardi																			4	6		
Notesthes robusta																						
Philypnodon grandiceps																				4		
Philypnodon sp1.																						
Pseudomugil signifer																						
Retropinna semoni																			14	230		
Selenetoca multifasciata																						
Tandanus tandanus																						
Total number of fish																			28	278		
Total number of species																			5	7		

Table 24. Sampling data from site M6, Strawberry Hill.

	Sample																					
	Before				After																	
	May	Jun	Nov	Feb	May	Jul	Octt	Feb	Mar	Jul	Aug	Nov	May	Sep	Feb	Dec	Jan	Apr	Jul	Oct	Dec	Jan
Acanthopagrus australis																						
Ambassis marianus																						
Anguilla australis																						
Anguilla reinhardtii																			33	24		
Galaxias maculatus																						
Gambusia holbrooki																						
Gobiomorphus australis																			12	15		
Gobiomorphus coxii																						
Herklotsichthys castelnaui																						
Hypseleotris compressa																						
Hypseleotris galii																						
Liza argentea																						
Macquaria novemaculeata																						
Mugil cephalus																				4		
Myxus elongatus																						
Myxus petardi																				8		
Notesthes robusta																						
Philypnodon grandiceps																						
Philypnodon sp1.																			1			
Pseudomugil signifer																						
Retropinna semoni																						
Selenetoca multifasciata																						
Tandanus tandanus																						
Total number of fish																			46	51		
Total number of species																			3	4		

Table 25. Sampling data from site M7, Warranulla.

	Sample																					
	Before				After																	
	May	**Jun**	**Nov**	**Feb**	**May**	**Jul**	**Octt**	**Feb**	**Mar**	**Jul**	**Aug**	**Nov**	**May**	**Sep**	**Feb**	**Dec**	**Jan**	**Apr**	**Jul**	**Oct**	**Dec**	**Jan**
Acanthopagrus australis																						
Ambassis marianus																						
Anguilla australis																						
Anguilla reinhardtii	11																		2	9		
Galaxias maculatus																						
Gambusia holbrooki																						
Gobiomorphus australis																				2		
Gobiomorphus coxii																						
Herklotsichthys castelnaui																						
Hypseleotris compressa																						
Hypseleotris galii																						
Liza argentea																						
Macquaria novemaculeata																						
Mugil cephalus																						
Myxus elongatus																						
Myxus petardi																						
Notesthes robusta																						
Philypnodon grandiceps																						
Philypnodon sp1.																			2	3		
Pseudomugil signifer																						
Retropinna semoni																			1			
Selenetoca multifasciata																						
Tandanus tandanus																						
Total number of fish	11																		5	14		
Total number of species	1																		3	3		

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