Department of **Employment, Economic Development and Innovation**

Paradise Dam Downstream Fishway Monitoring Program

Final V1.1 Report

February 2012

for Burnett Water Pty Ltd, contract dated 5 September 2007

Toward Q2 Tomorrow's Queensland

Queensland Government

Paradise Dam Downstream Fishway Monitoring Program
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DEEDI Fisheries Queensland for Burnett Water Pty Ltd, contract dated 5 September 2007

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Glossary

Downstream exit chute pipe

the half pipe section of the downstream fishway where fish and water are delivered into the tailwater.

Environmental flow release intake tower

the intake tower located in the impoundment adjacent to the dam wall through which water is drawn into for environmental flow releases.

Environmental flow release outlet

the outlet located at the base of the dam adjacent to the hopper chamber. This outlet contains two hydraulically controlled gate valves where environmental flow releases of up to 240 cumecs can be made from.

Fishlock

a type of fishway that operates by controlling the operation of a moving gate and valves to fill and drain a chamber carrying fish and water over a barrier, usually a dam or high weir.

Fishlock chamber

part of the downstream fishway consisting of a concrete chamber that holds water and fish during the attraction phase.

Fishlock entrance slot (quad leaf gate)

the 500 mm wide, vertical slot opening in the fishlock chamber, located adjacent to the irrigation intake screen.

Fishlock entrance (spillway)

the 500 mm wide, channel opening adjacent to the dam crest on the right hand side. This opening allows fish to enter the fishlock by moving through the spillway flume channel and then into the 500 mm vertical slot opening in the fishlock chamber.

High flow

releases of water made from the environmental flow release outlet and/or from water overtopping the dam spillway.

Hopper

a component of the fishlift that holds and moves water and fish up and over the barrier.

Hopper chamber attraction flow valves

three valves located on the back wall of the hopper chamber. These provide attraction flows into the hopper chamber and out through the fishlift entrance slot. Water is delivered through three horizontally oriented perforated pipe diffusers at varying heights.

Irrigation release intake

the intakes for the irrigation outlets are located within the impoundment, adjacent to the dam wall and entrance to the downstream fishway.

Irrigation release outlets

two irrigation outlets valves located at the upstream extent of the outlet release channel. These can pass up to 9 cumecs of water into the outlet release channel. Water through one of these outlets can be diverted into a hydroelectric turbine for power production when possible.

Knife valve

a valve located within the fishway pipe that opens rapidly to release the water and fish into the downstream tailwater area during the fishlock drain phase.

Left bank

the bank on the left side of a river when looking downstream.

Low flow

releases of water made from the dam through the fishway valves only.

Main river channel

the original river channel downstream of the Paradise Dam including the bed and banks and water contained within.

Medium flow

releases of water made from the dam through the irrigation outlets. This type of release can also include releases made from the fishway valves.

Nappe flow

A type of flow characterised by a succession of free-fall jumps impinging on the steps of a spillway and creating a hydraulic jump.

Outlet release channel

the channel created to deliver water from the dam release valves to the main river channel.

Quad leaf gate

a mechanically operated gate that opens and closes access through the fishlock entrance slot adjacent to the irrigation intake screen.

Right bank

the bank on the right side of a river when looking downstream.

Skimming flow

A type of flow where the water forms a coherent stream across the steps of the spillway.

Spillway apron

the concrete area directly below the downstream side of the spillway wall that protects the dam wall from erosion.

Spillway flume

the open channel, 500 mm wide located along the dam abutment which allows water and fish to move from the right hand edge of the spillway to the fishlock chamber.

Stepped spillway

a type of dam spillway containing a series of steps on the downstream face for the purpose of dissipating energy.

Executive Summary

The 37 metre high Paradise Dam is located at 131.2km AMTD on the Burnett River and incorporates the first high lift fish passage facility in Australia. Construction of the dam was completed in November 2005 with fish passage required under the *Fisheries Act 1994*, Waterway Barrier Works approval. Two fishways were constructed, one to provide upstream fish passage and another for downstream fish passage. A condition of the Waterway Barrier Works Approval was the implementation of a monitoring program to evaluate the effectiveness of these fishways. The current document constitutes the final report detailing the results and recommendations for the downstream fishway monitoring program.

Fish captured migrating downstream of the dam during fishlock sampling demonstrated that 21 species, from 26 species identified within the dam impoundment, successfully utilised the fishway. Migrating fish were recorded utilising the fishway throughout the year and during all flow conditions. The most numerically abundant species within the dam impoundment were captured in the fishlock samples. Species captured within the dam impoundment but not identified in the fishlock during sampling were silver perch, Australian bass, Queensland lungfish, striped mullet and barramundi.

The greatest rate of fish migrating through the fishway was recorded in June 2010 with 1.39 (±0.456) fish per minute from 10 species captured using the fishway. The greatest number of species recorded using the fishway was in February 2010 with 20 species documented. Flow conditions had an influence on the downstream migration of fish through the Paradise Dam fishlock, some species were identified migrating in significantly greater numbers during periods when there was inflow into the dam impoundment, and other species mostly migrated during no inflow periods. The migration of some species was not influenced by either flow period.

The downstream fishway first became available for access by fish on the 5th February 2009 following an increase in the water level in the Paradise Dam to EL 62.0 m. During the period from the 5th February 2009 to 31st October 2010 the Paradise Dam downstream fishlock was operational for 88.5% of the time that water was being released from the dam. Non-operational periods were due to mechanical failures or unsuitable fishway entrance or exit flow conditions. The fishlock was not operated when the impoundment water level fell below EL 62.0 m (the minimum operating level of the fishway) or was above EL 67.9 m (the maximum operating level of the fishway).

Operating the fishway as per the design intent was found to be unsuitable due to excessive velocities and turbulence within the fishlock chamber. Modified operation of the fishlock determined that the fishway should be operated with a minimum of 300 mm water depth across the quad leaf gate entrance slot and a 900 mm headloss between the fishlock chamber and the impoundment water level. At these settings, hydraulic conditions in the fishlock chamber during the attraction phase were optimised but were still not ideal for small bodied fish as they must continually reorientate themselves in upwelling flow patterns.

An attraction time of 60 minutes per cycle was adopted to reduce the chance of fish being injured, whilst still maintaining a reasonable fishway attraction time. The capacity of the fishway would appear to be adequate for the numbers of fish encountered during the short cycle period. Tests to ascertain the success of fish exiting the downstream fishway determined that a 2 minute flushing time and flow was acceptable.

Spillway flow events occurred in March and September 2010. During the March 2010 spillway event an average of 60.8 (±30.31) small fish per minute were documented passing over the spillway during the rising hydrograph. Fish from the majority of the fish species that were identified within the dam impoundment were also collected and/or observed downstream of the dam either deceased or injured during spillway flows. The most abundant large bodied fish species to suffer mortality were bony herring, Queensland lungfish, long-finned eel, freshwater catfish and golden perch. Larger fish exhibited injuries consisting of abrasions, descaling and head damage including decapitation or loss of eyes.

During the design phase of the dam the greatest risk to fish survivorship over the spillway was considered to be during low flows over the spillway steps which produced a non-skimming or nappe flow up to 0.54m above the spillway crest. Visual observations of the flow over the spillway established that the flow appeared to be striking the steps under all flow conditions. Collection of injured and deceased fish that had passed over the dam wall during high flow periods indicated that the skimming flows did not occur as predicted.

Passage over the spillway wall is likely to be the major mode of passage for downstream migrating fish. Catadromous species in particular rely on flood flows for downstream migration. The impetus for the downstream migration of Queensland lungfish remains unknown but whether volitional or not, large numbers of lungfish move downstream during flood flows.

As found in the current study, fish that pass through the environmental flow tower are also injured and suffer mortality. Inflows into the dam impoundment attract fish downstream to the dam wall and large numbers of fish drift with the downstream flow. The operation of the environmental flow release tower on a rising hydrograph is therefore likely to incur large fish mortalities.

Fish mortalities are occurring during all flows over the Paradise Dam stepped spillway regardless of the flow condition. The cumulative affect of mortalities of fish passing over the spillway is likely to have a major impact on populations of fish over the longer term. The bypassing of downstream migrating fish at the Paradise Dam may provide a solution to the current issues of fish injury and mortality through the environmental release tower and over the stepped spillway.

As specified in the Scope (BD2 page 31) of the Accepted Proposal for the Burnett River Dam Fish Passage Monitoring Program contract. The results of the monitoring program were evaluated against the broad requirements of the Waterway Barrier Works Approval issued under the Fisheries Act 1994:

1. Operation of the fishway was achieved over the full range of design flows.
2. The fishway provided passage of most species of fish and a wide variety of size ranges. Modified operation and reduced attraction cycle times managed the risk of fish injury within the fishlock.
3. Fish utilised both fishlock entrances, but competing attraction flows during spillway and high release flows are likely to impact fish attraction. Fish that moved into the environmental flow tower and irrigation intakes were injured and killed.
4. Operation of the fishlock differed from the design intent for outlet release and spillway flows. Modification of the operation to reflect the design intent is recommended.
5. Fish mortalities and injuries occurred during all flow conditions over the Paradise Dam spillway. Releases through the environmental release tower to mitigate spillway flows were ineffective as fish mortalities also occurred under these flow releases.

Introduction

Paradise Dam, located at 131.2km AMTD on the Burnett River incorporates the first high lift fish passage facility in Australia. As part of requirements under the Waterway Barrier Works Approval, and associated fisheries directives under the *Fisheries Act 1994*, two fishways were constructed on Paradise Dam, one to provide upstream fish passage and another for downstream fish passage.

A condition of the Waterway Barrier Works Approval was the implementation of a monitoring program to evaluate the effectiveness of these fishways. A Monitoring Framework was developed for the Paradise Dam by the Burnett Dam Alliance in consultation with the Queensland Fisheries Service (as it was at the time). The monitoring framework identified that the following objectives were to be addressed:

- Establish the constructed design is operating to specification.
- Determine whether the fish passage facilities are effective in achieving the design aims.
- Provide data for the optimisation of operations and/or design over time.
- Provide information that may be of use in the mitigation of the impacts of future water infrastructure developments.

A number of key questions were established to address the above objectives. These questions are listed in the Downstream Fishlock Assessment and Investigative Program; Table BD5.5.1, in Schedule A of the Accepted Proposal for the Paradise Dam Downstream Fishway Monitoring Program (Appendix A).

The fishway monitoring program incorporated core (assessment) questions consistent with standard fishway assessment methodologies and non-core (investigative) questions unique to the Paradise Dam downstream fishway. Whilst both the core assessment and non-core investigative questions were to be undertaken from the outset of the monitoring program, the intent was to complete most of the core assessment components within the first three years of the program. The last two years of the program were to be used primarily to address the non-core investigative monitoring components and to complete any outstanding assessment components.

However, the monitoring program was impacted by a four year delay between the completion of the Paradise Dam in 2005 and the filling and overtopping of the dam in March 2010. As a result, some of the core assessment and non-core investigative components remain outstanding. In addition, the routine operation of the fishlock has been interrupted by an extended commissioning phase due to the low storage levels.

This report specifically addresses questions listed in the Downstream Fishlock Assessment and Investigative Program; Table BD5.5.1, in Schedule A of the Accepted Proposal for the Paradise Dam Downstream Fishway Monitoring Program. The report details the findings of the monitoring program for the Paradise Dam downstream fishway from commencement in July 2005 up to November 2010. The information presented in this document also draws upon previous annual monitoring reports completed in June 2007, September 2008 and September 2009.

Data sourced directly from the above mentioned reports is included within text where required, the three annual reports are provided in Appendix B.

Design and function of the downstream fishway

At Paradise Dam, passage for downstream migrating fish is provided by a dedicated fishlock. The design of the Paradise Dam fishlock differs from other Australian fishlocks in that it provides only downstream passage and is therefore somewhat less complex (Figure 1). The fishlock is operable between EL 62.0m, 5.6m below full supply level (FSL) and EL 67.9m, some 300mm above FSL.

The fishlock operates by attracting migrating fish to the entrance slot by a constant flow of water into the fishlock chamber. The volume and flow of water entering the fishlock chamber is controlled by an adjustable quad leaf gate in the fishway entrance slot (Figure 2). The water level in the fishlock chamber is controlled by a screened drain control valve. Adjustment of the quad leaf gate and the drain control valve can provide variation between the water level in the impoundment and in the fishlock chamber that can be used to retain fish in the fishlock chamber. After a pre-set time period, the drain control valve opens and water and fish are lowered down the standpipe. As the level reaches the base of the standpipe a quick release gate is opened and the water and fish are sluiced along the exit chute into the tailwater channel (Figure 3). A small release of water is then pulsed through the exit chute to ensure that all fish have exited and the cycle is repeated.

An additional fishway entrance slot and flume is located adjacent to the spillway (Figure 4). During overtopping flows less than 0.3 m above FSL a single leaf gate is opened in the fishlock chamber and fish have the opportunity to move away from the spillway through the flume and into the downstream fishway.

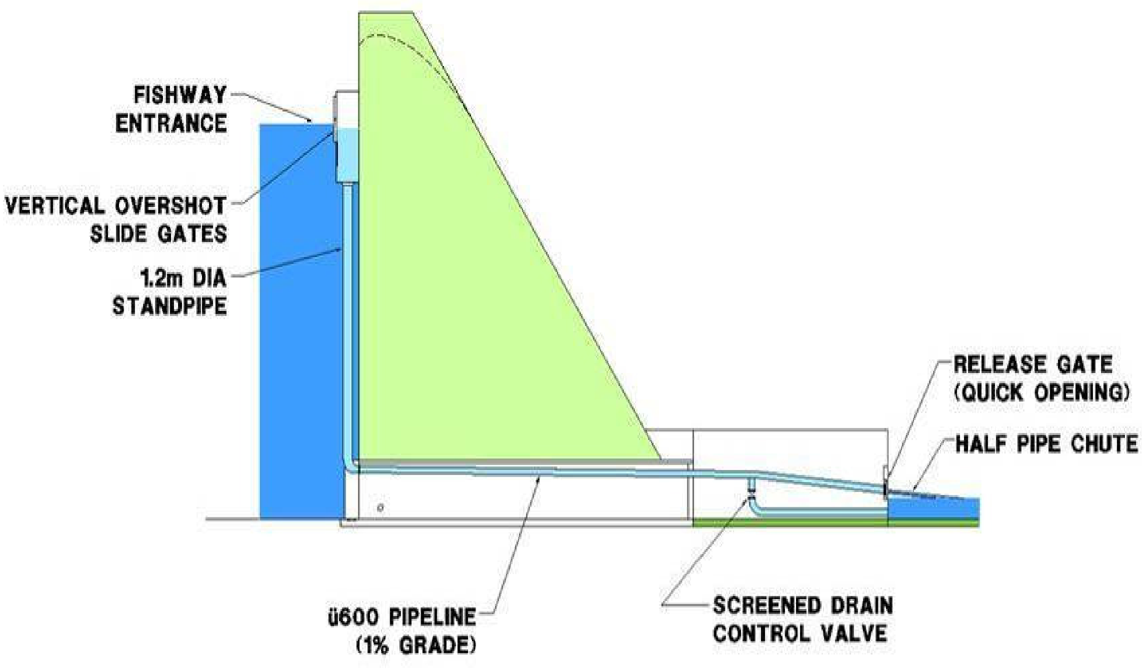


Figure 1 Schematic of the downstream fishway at Paradise Dam

Figure 2 The downstream fishway prior to filling of the dam showing the fishway entrance slot, the fishlock chamber and the standpipe. Note the adjustable quad leaf gate in the fishway entrance slot.

Figure 3 The exit chute of the downstream fishway at Paradise Dam

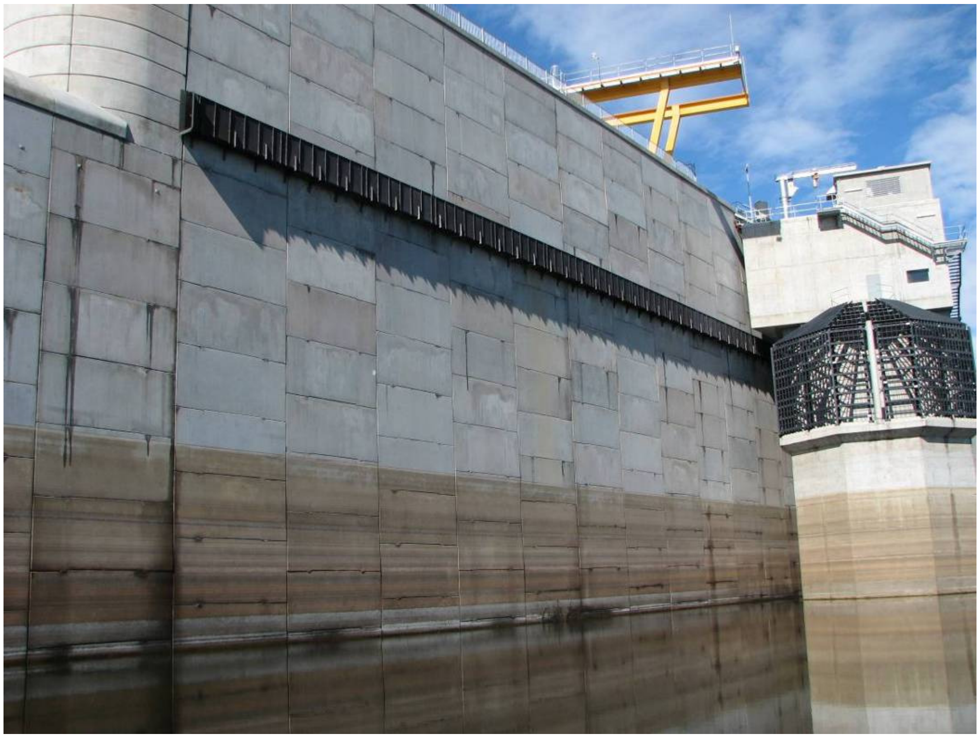


Figure 4 Spillway flume for directing fish from the spillway to the fishlock chamber during overtopping flows. The environmental release intake tower is shown in the centre right of the image.

Methods

A number of methods were employed throughout the monitoring program in order to collect information required to address the monitoring objectives. Information required to answer a specific monitoring question may have been derived from either a single method only or from a combination of methods.

Fishway Monitoring

Introduction

The fishlock at Paradise Dam was purpose built for providing downstream fish passage beyond the dam. Fishlocks are traditionally monitored in a similar way to other technical fishways such as vertical slot designs. This involves the direct trapping of the fishway entrances and exits. The numbers, size and species of fish captured in these traps are then compared to ascertain the effectiveness of the fishway. Previous studies in Queensland have assessed fishlock type design fishways at Ned Churchward Weir (Burnett River), Eden Bann Weir, Neville Hewitt Weir (Fitzroy River), Clare Weir (Burdekin River) and Dumbleton Weir (Pioneer River). Results from these studies have demonstrated their effectiveness in providing fish passage, however most of these studies (Berghuis, *et al*. 2000, Long and Meager, 2000, Stuart, 1997, Marsden, et al. 2005, Renfree and Marsden, 2006 and McGill and Marsden, 2000) focused on upstream fish passage. A dedicated investigation on downstream fish passage was undertaken by Berghuis, *et al* 2000 at the Ned Churchward Weir fishlock.

Direct trapping of the downstream fishway was employed at Paradise Dam with the entrance of the fishway defined as the fishlock chamber, and the exit of the fishway defined as the exit chute.

The main factor in determining the success of the fishway is that it is able to successfully provide passage for the entire migratory fish community. In order to provide comparative data for the fish identified using the Paradise Dam downstream fishway, a sample of the migratory community upstream of the dam wall was also collected using boat electrofishing. This method was used to assess the species composition of the fish community present in the headwater of the dam and where aggregations of these fish were occurring.

Methods

Two main methods were used to assess the effectiveness of the downstream fishway, including direct trapping and boat electrofishing.

Sampling the downstream fishway consisted of setting either; a trap in the fishlock chamber (Figure 5) or the exit chute sampling net (Figure 6) for a set period of time. The use of the trap in the fishlock chamber over a 24 hour period resulted in an unacceptable number of fish mortalities whilst sampling. For this reason, the use of the trap to monitor the fishway for any extended period of time was deemed unacceptable and not used. The exit chute sampling net was the preferred method to assess the downstream fishway. This net was used for both monitoring the fishway and experimental trials.

The exit chute sampling net consisted of three sections. The first section comprised of a 1000 mm long throated circular entrance designed to fit inside the exit chute pipe. This section was solid PVC and spread outwards to meet the next section. The second section consisted of a 5000 mm (length) x 1800 mm (width) x 1800 mm (height) rectangle chamber with solid PVC top and bottom panels and 3mm mesh side panels. Floats and weights were attached at all four corners of this section to maintain its shape prior to water entering. This section was designed so that water energy could be dissipated in a large area and through the sides of the rectangular chamber. This was to reduce the water velocity and potential impacts that would occur to fish as they were captured in the exit chute sampling net. The end of this section was solid PVC on all sides and narrowed to 1000 mm where the next section attached. The third section consisted of a cylinder of 4 mm knotless mesh, 5000 mm in length and 1000 mm in diameter. This narrowed at the end to a conical point where a drawstring was located for the removal of fish. A float and weight were attached at the end of the sampling net to hold its position and structure prior to water being released.

To monitor the downstream fishway, the fishlock was set in attraction mode for a predetermined time. The depth of water across the fishway entrance slot and headloss was set at the optimum level as determined during testing and initial operation of the fishway. The downstream exit chute sampling net was placed into position at the throat of the downstream exit chute and tethered. Once the attraction phase had ended, the drain cycle commenced and water was lowered in the standpipe. After a short period, the quick release gate valve opened and water flowed down the pipe and into the exit chute sampling net. This occurred for a period of two minutes. As soon as the flow ceased the net was lifted from the throated opening, raised vertically and shaken to ensure fish were trapped into the mesh cod end. Fish were then removed through the drawstring opening and placed into a live well. Fish were then sorted, measured and released into the main irrigation release channel.

Figure 5 The sampling trap in the downstream fishlock chamber.

Figure 6 The exit chute sampling net at the downstream fishway exit chute.

Initial trapping trials showed that all fish that had entered the fishlock chamber were captured in the exit chute sampling net at the exit of the fishway. For this reason a paired top and bottom sample was not considered necessary as fish could not escape out of the fishlock chamber due to the 900 mm headloss across the quad leaf gate entrance slot. For all sample methods, the first 100 individuals of each fish species were measured, with the remainder counted. Data was entered into a purpose built Microsoft Access database and cross checked for validity.

Zones of aggregation

Introduction

In order to provide comparative data for fish identified using the Paradise Dam downstream fishway, a sample of the migratory community immediately upstream of the dam embankment was collected using boat electrofishing. This method was used to assess if any downstream migrating fish were present in the headwater of the dam and where aggregations of these fish were occurring.

Methods

Boat electrofishing was conducted using a 5.3 m boat fitted with a 7.5 kW Smith–Root electrofisher that produced a pulsed DC waveform. Two operators at the bow of the boat collected stunned fish with dip nets and placed them into an aerated tank of water until processed; a third person operated the boat and the electrofisher controls. A number of areas above the dam wall were specifically targeted to determine zones of fish aggregations, descriptions are provided below in Figure 15.

Boat electrofishing was conducted using a 5.3 m boat fitted with a 7.5 kW Smith–Root electrofisher that produced a pulsed DC waveform. Two operators at the bow of the boat collected stunned fish with dip nets and placed them into an aerated tank of water until processed; a third person operated the boat and the electrofisher controls. A number of areas above the dam wall were specifically targeted to determine zones of fish aggregations, descriptions are provided below in Figure 7. Comparisons with fish species and numbers collected by other methods were also made. Boat electrofishing sampling began in July 2007 after repairs were made to equipment.

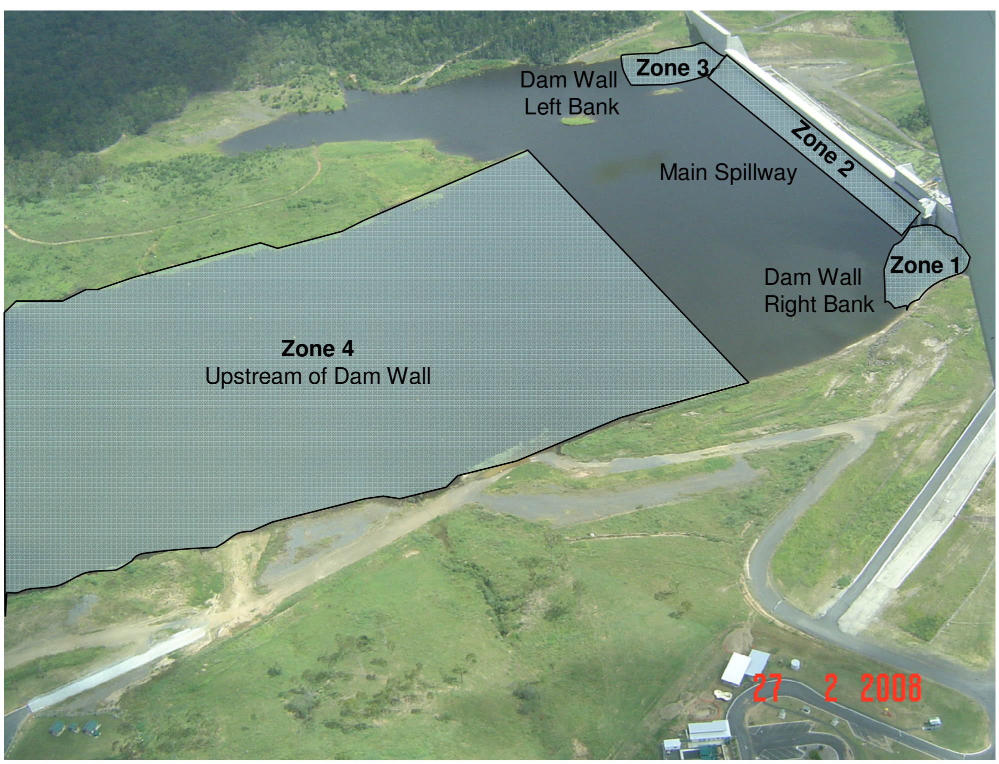


Figure 7 Areas boat electrofished to determine zones of fish aggregation.

In order to provide a rate of fish migration for different sample times and periods a value for Catch per Unit Effort (CPUE) was calculated. The CPUE value is the number of fish sampled on each event divided by period of sampling to provide of value of the number fish per unit of time. A standard error (±SE) is provided for each CPUE value. Where required for comparative analysis, data collected over different time frames was rescaled to a common CPUE. For example when comparing the rates of migration through the fishlock, the number of fish captured in a given time was rescaled to the number of fish per minute.

PIT tagging program

Introduction

The use of PIT tags with fixed readers is an established method of recording fish passage through fishways (Castro-Santos et al, 1996; Nunnalee et al, 1998). This technique does not require surgery, further handling, or interception of fish during migratory runs. The PIT tags themselves weigh less than 0.6g and are therefore suitable for relatively small fish. The tags are injected under the skin of the fish or within the gut cavity and have no obvious effect on behaviour (Ombredane, et. al, 1997; Braennaes et. al, 1994; Prentice and Flagg, 1987).

A PIT tag reader system has the potential to provide continuous automatic data of fish usage of the fishway. The detection of a tagged individual at the fishway entrance slot and the exit chute indicates that the fish has passed downstream through the dam wall. Alternately if a fish is not detected at the exit chute then it has not been provided passage downstream through the dam wall. In both cases report parameters can be analysed to determine the conditions most conducive to successful fish passage. Continuous data from detected PIT tagged fish can also be reviewed and analysed to determine the timing of migrations and factors that may influence these migrations.

Methods

The system installed within Paradise Dam incorporated Texas Instruments low frequency (134 kHz) RFID half-duplex technology. Each reader/antenna station comprised of a control module (RI-CTL-MB6A), remote antenna radio frequency modulator (RI-RFM-008B), an antenna-tuning module (RI-ACC-008B) and a double-wire loop antenna. On the downstream fishway, PIT tag reader antennae have been installed in the entrance slots of the fishway and on the fishway exit chute. Any PIT tagged fish detected, are recorded and stored on the programmable logic controller (PLC) of the fishway. Fish tag reports from the PLC provide the tag number, location, fishway operational phase and ambient water quality parameters at the date and time of detection.

In order to obtain quality data from the PIT tag reader system, a large number of fish must be implanted with PIT tags. Access to up to 33 potential tagging sites both upstream and within the dam have been established at both public areas and from within private landholdings. In these areas, fish were collected using a 5.3 m boat fitted with a 7.5 kW Smith–Root electrofisher that produced a pulsed DC waveform. Two operators at the bow of each boat collected stunned fish with dip nets and placed them into an aerated tank of water containing a dilute solution of the anaesthetic, AQUI-S (20 mg/L) for light sedation; a third person operated the boat and the electrofisher controls. All fish captured were measured and scanned to ascertain whether they had been previously tagged.

Untagged fish above 100 mm in total length were then tagged in the gut cavity and Queensland lungfish tagged in the dorsal muscle. The 23mm Eco-line glass transponders (RI-TRP-REHP) weighing 0.6 grams were implanted using a sterile needle and Henke-ject™ applicator gun. All tagged native fish were marked with an external plastic t-tag bearing an identification code, the project name and a contact phone number for reporting of re-captures by the public. Brochures have been distributed to stakeholders and signs erected at public boat ramps detailing what to look for and how to handle and report a tagged fish.

Fish morphometrics and capture information were immediately recorded in an electronic database alongside the unique PIT identification number. Occasionally, fish that had been tagged during previous surveys were recaptured in subsequent surveys. The tag details of recaptured fish were recorded, the fish re-measured and released at the capture point.

The details of PIT tag detections and their timing was analysed and interpreted against inflows into the dam (SunWater, 2010), upstream riverine flow and water temperature at the Mt Lawless gauging station (Department of Environment and Resource Management, 2010). This data was used to determine the timing of migrations, factors that may influence these migrations, and conditions most conducive to successful fish passage.

Assessment of fish health in the downstream fishway

Introduction

One of the investigative components of the Paradise Dam downstream fishway monitoring program was to ensure that the safety of fish using the fishway was not compromised. This fishway is the first of its type to use a relatively long section of large diameter pipe to transfer fish from the fishlock chamber to the downstream side of the dam. Most other fishlock design fishways incorporate a vertical concrete open tower to move fish upstream or downstream of the dam or weir. When the fishway is operating and the attraction time has elapsed, the quad leaf gate is raised and the water within the fishlock chamber is lowered in the standpipe at 0.5 m/sec down to the invert of the transfer pipe. The standpipe is 1200 mm in diameter and designed to cater for large bodied fish, including the Queensland Lungfish (Burnett Dam Alliance, 2002). As the water level reaches the invert of the standpipe, a quick release gate (knife valve) is opened and the water and fish are sluiced along the transfer pipe into the tailwater channel (Figure 3). The horizontal transfer pipe is 750 mm in diameter and sloped on a 1% fall. Water is also released through a valve at the most upstream position of the pipe to ensure fish are flushed out.

The potential for fish injury within the Paradise Dam downstream fishway was considered low however a number of areas were considered to be a greater risk. This included the chance that fish could be injured against the sides of the transfer pipe as they were flushed out; the trapping of fish against valve screens; the stranding of fish within the transfer pipe after flushing has ceased; the potential impact of fish into the tailwater as they exited the downstream exit chute pipe and the potential effects of hydraulic conditions on fish within the fishlock chamber and transfer pipe. In order to assess the risks on fish using the fishway, a number of trials were performed throughout the monitoring period.

Methods

Fish were collected from a number of sources to use in the trials to assess fish health. Most fish used in the trials were collected from the upstream fishway (hopper) when it was emptied as part of the upstream fishway assessment. At times when there weren't sufficient fish in the hopper, fish were collected by scoop netting from downstream of the dam. Only fish observed to have normal swimming behaviour and no external marks or parasites were used in the trials. The number of fish used for each trial ranged between 9 and 421 fish (mean 90.1 fish per trial) depending on what was available at the time. Once collected, fish were placed into the fishlock chamber where the start of the trial commenced. An investigation into the effects of the exit chute sampling net was also undertaken. In this case fish were placed into the exit chute sampling net before water was flushed through. Fish were subjected to the following experiments based on two variables; the time they were in the fishway and the location they were collected from (Table 1).

Table 1 Experimental treatments on fish to determine potential effects of the fishway.

Entry location	Collection method	Attraction time treatment (minutes)		
Fish placed into fishlock chamber	Fishlock chamber trap	0	60	>60
	Exit chute sampling net	0	60	>60
Fish placed into exit chute sampling net	Exit chute sampling net	0		

After each treatment had been performed, fish were collected, measured and assessed for injuries before being released back into the water. Injured fish were determined as fish which were observed to be either dead, unable to maintain a normal upright swimming position or had evidence of physical damage. Counts of injured and healthy fish were totalled and the rate of fish injury was calculated by dividing the total number of injured fish by the total number of fish for each treatment. Summary statistics were used to determine effects of varying treatments.

Radio telemetry study

Introduction

Objective DI-4 in the monitoring program was to quantify the survival of and injuries to fish over the dam wall (Table BD 5.5.1 Appendix A). As fish pass over the stepped spillway during overtopping flows the potential exists for injury to be sustained. Methodologies to assess the impact of downstream passage over the dam spillway were developed within the monitoring program. Radio telemetry was to be used to monitor the passage of radio-tagged fish over the dam spillway. Fish that moved over the dam wall during river flows were also collected with fixed nets placed in the river channel downstream of the dam.

Radio telemetry involves the implantation of a radio transmitter into a suitably sized fish. A fixed station, data logging radio receiver station with directional antenna can be used to autonomously monitor the movement of tagged fish within a set area. Mobile radio receivers can also be used to manually locate and track individual fish in a given area. Radio transmitters have relatively long battery lives and fish can be tagged before predicted flow events and monitored over the life of the radio transmitter. Subsequently they can be very useful for tracking the migrations of catadromous fish species in rivers with highly variable flow regimes. Adult catadromous species such as striped mullet, barramundi and Australian bass, as well as the potamodromous Queensland lungfish, were radio tagged to monitor their behaviour and downstream migration patterns.

Methods

A sample population of radio-tagged fish was established at sites within and upstream of Paradise Dam. Fish were collected utilising a 7.5-kVA, boat-mounted electrofisher, from several locations on the Burnett River and released at one of six locations listed in Table 2.

Table 2 Details of Radio-tagged fish release sites.

Site Name	AMTD (km)	Latitude	Longitude	Relationship to Dam
Paradise Dam Headwater	131.9	25.35775	151.91231	Within
Old Kalliwa Camping Ground	135.7	25.35953	151.88200	Within
Mingo Gorge	157.8	25.39352	151.75923	Within
Grey's Waterhole	182.8	25.53570	151.66045	Upstream
Ideraway Upper	191.2	25.58965	151.64737	Upstream
Sunday Creek	165.0	25.39504	151.68972	Within

Fish were dip netted and placed into an aerated holding tank until an adequate number of fish had been collected. Fish that were to be radio tagged were taken to a holding tank at the tagging station, all other fish were PIT tagged, measured and capture details recorded. These fish were released immediately within the capture area.

Fish were selected for radio tag implantation based on their species, condition and size. A guideline ratio of 2% or lower for tag weight to fish weight was adopted for all radio-tagged fish. The methods utilised have been performed extensively on Australian native freshwater fish (O'Connor, 2003) as well as in studies of fish migration overseas. Several overseas studies have documented the effects of radio tagging on fish behaviour (Adams, 1998; Thoreau, 1997). All studies reported short-term changes in behaviour extending up to two weeks but no long-term changes in growth, daily behaviour or gonadal development.

Two types of radio tags were employed:

- a standard coded radio tag; and
- a combined acoustic/radio tag (CART).

The standard coded radio tag (Lotek MCFT-3A) was 16 x 46 mm in size, weighed 16 g in air and had a battery life of 641 days at a 5 second code transmission interval. Two RF frequencies (channels) 149.460 MHz and 149.800 MHz were used, with each channel having thirty-five codes within the band, giving a total of 70 unique code sets. Coded radio-tags have an advantage over standard radio-tags in that each tag transmits a unique identifying signal that permits multiple tags to use the same frequency. The use of coded tags decreases the scanning time required and therefore increases the chances of successfully detecting a fish.

The CART tag (CART 16_2) used for implantation into Queensland Lungfish was 16 x 85 mm, weighed 36 g in air and had a battery life of 1446 days at a 5 second code transmission interval. The acoustic signal generated by CART tags can be detected using a dedicated hydrophone from considerable depths of water. Queensland lungfish are known to utilise deep water habitats (Brooks and Kind, 2002) and the use of these tags addressed the problem of detecting radio signals in impounded waters. Thirty CART tags were used on an acoustic up-converted RF frequency of 150.077MHz, whilst maintaining a standard RF frequency of 149.680 MHz.

Prior to surgery, fish were placed into an anaesthetic solution of AQUI-S at 60 mg/L concentration for a period of time to render them unconscious. Once unconscious, fish were placed into custom made surgical boards ensuring that their gills were submerged (Figure 8). Aeration of the surgery tank was supplied to maintain adequate oxygenation of the water. All equipment including the radio transmitters and surgical instruments used in the surgical procedure were sterilised with ethanol.

Figure 8 Radio-tag implantation of barramundi showing surgical mounting boards and aeration tanks.

Coded microprocessor radio transmitters were surgically implanted into the body cavity of anaesthetised fish via a small incision through the ventral cavity wall using an established methodology (Koehn and Nicol, 1998). The incision was closed with surgical sutures and fish injected with oxytetracycline as a broad-spectrum antibiotic to aid in the healing process. Figure 9 shows the tag site of a barramundi after suturing. All radio-tagged fish were also implanted with a PIT tag and external plastic t-tag. Fish were then placed within a holding cage until they recovered from the anaesthetic and were released into the river once normal respiration and swimming behaviour was observed. Figures 10 and 11 show adult catadromous fish after surgery prior to release.

Queensland lungfish were collected from two separate sites to study their behaviour with regards to downstream migration. Fifteen lungfish were captured 4 to 8 km upstream of the dam wall and after radio tagging were released at the Old Kalliwa Camping Ground, 4.5 kilometres upstream of the dam wall. The other 15 lungfish were captured approximately 9 to 13 km downstream of Paradise Dam at Cherelly Orchard and after radio tagging were translocated to within the dam impoundment. These translocated lungfish were released at the temporary boat ramp 700 metres upstream of the dam wall. This group of lungfish was translocated within the dam to observe if they displayed home ranging behaviour by trying to return downstream. Figure 12 shows a post operative lungfish prior to release.

Figure 9 Radio-tag implantation site showing sutures in an adult barramundi. Note the radio-tag aerial on the right side.

Figure 10 A post operative adult striped mullet before being released into the holding cages for recovery.

Figure 11 A post operative barramundi before being released into the holding cages for recovery.

Figure 12 A post operative lungfish prior to being released into the impoundment.

A Lotek DRX-600 radio receiver logger was installed on the dam abutment to detect radio-tagged fish approaching the dam. Four directional antennae were mounted on the abutment wall to scan radio-tagged fish:

1. As they approach the dam wall from upstream.
2. As they pass over the dam wall during overtopping flows.
3. Following passage over the dam wall and/or attempt to return upstream.
4. As they attempt to return upstream via the fishway channel.

The direction and location of the directional antennae are detailed in Figure 13 and antennae 1 to 3 are shown in Figure 14.

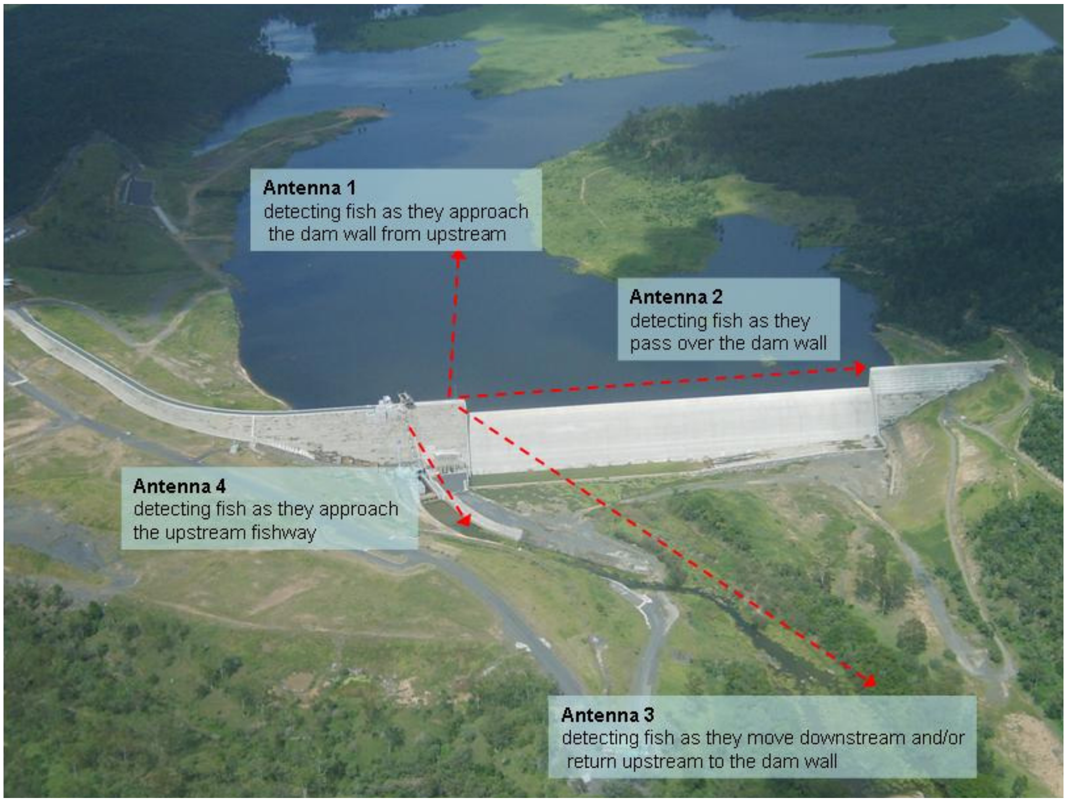


Figure 13 Aerial view of the Paradise Dam indicating the location and scanning area of the directional antennae.

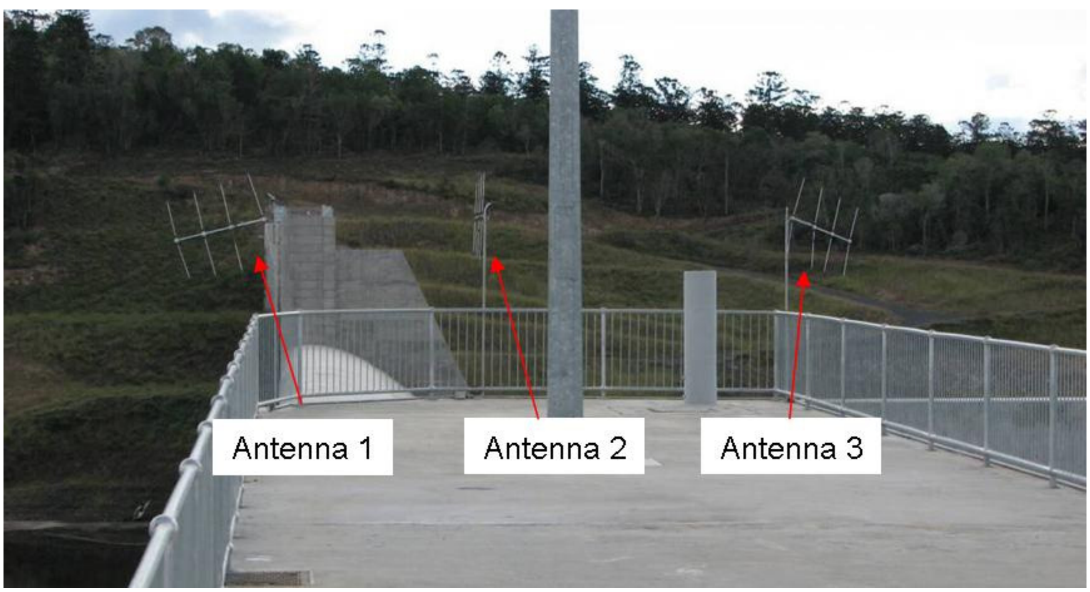


Figure 14 Directional antennae 1 to 3 on the right abutment of Paradise Dam.

Manual tracking was performed using a Lotek SRX 400 radio receiver and a hand-held directional yagi antenna or hydrophone (CART tags). Fish were located by boat along the length of the river between Gayndah and the Paradise Dam wall. Location surveys were concentrated around the release locations, excluding two occasions where tracking was done along the entire sample area. The directional antenna or hydrophone was oriented to obtain the strongest signal possible providing an indication of the location of the fish. A GPS location was recorded for the frequency and code detected and tracking continued until all fish were identified or the entire area had been completely scanned. Fish location was referenced to the dam wall by measuring the AMTD (Adopted Middle Thread Distance) of the fish location within the water course with the AMTD of the dam wall (131.2 km).

Following confirmed passage of a radio-tagged fish over the Paradise Dam wall, intensive manual tracking downstream of the dam was to commence. Fish that were located downstream were to be tracked to determine if they were displaying normal behaviour (moving between habitats, upstream movements). If possible, fish that are located were to be recaptured to determine whether physical injury had been sustained.

Due to the lack of flows into the dam and no spill events, the second radio receiver logger system was relocated from downstream of the dam at Ned Churchward Weir to upstream of the dam at Sunday Creek (AMTD 165.2 km). The purpose of this receiver was to determine if fish were moving in or out of the impounded waters during various flow conditions. The receiver was not returned to the Ned Churchward Weir.

Paradise Dam storage inflow data (SunWater, 2010) and riverine flow data from the Mt Lawless Gauging Station (Department of Environment and Resource Management, 2010) was used in the analysis of downstream movements of radio tagged fish. The Mt Lawless Gauging Station is 7.8 km upstream of the full inundation level of Paradise Dam. Riverine flow data from the Mt Lawless Gauging station does not include any inflows into Paradise Dam from tributaries downstream of the gauging station or from rain events on the impoundment itself. Any significant inflow differences can be observed by comparing storage level and flow graphs.

Manual tracking of radio-tagged fish downstream of the dam was performed from the dam to River Road approximately 3 km downstream on the 10th March 2010. A further manual tracking survey was performed from the dam downstream to Booyal Crossing approximately 22 km downstream on the 20th April 2010. In both surveys no signals from radio-tagged fish were detected. Manual tracking of radio-tagged fish upstream of the dam ceased after a survey performed on the 6th May 2010 detected no valid signals.

Hydroacoustic monitoring

Introduction

Hydroacoustic monitoring has the potential to provide capture independent behavioural data of downstream migrating fish as they approach the Paradise Dam wall. Hydroacoustics utilises an echo sounding system that detects and records the return signals of transmitted pulses of ultrasound waves. The processed acoustic signals provide an integrated picture of many signal types known as an echogram, and from this, information pertaining to the target objects in the water column can be obtained.

Hydroacoustics has been widely used in the deep-water marine environment for many years with pulses beamed vertically through the water column. In shallow riverine environments a vertically beamed signal received may not travel the distance longer than the near field zone (area immediately in front) of the transducer, making analysis of fish echoes impossible.

The intention for the downstream fishway assessment was to quantify fish behaviour near the fishway entrance by placing the transducer in an upward looking position to detect fish swimming at or just below the water surface. The advantage of this methodology is that the conical shaped acoustic beam is transmitted vertically through the water column with the largest beam area near the water surface.

Methods

Testing and calibration of the hydroacoustic system was completed in August 2008 within the impounded waters of the dam using a Biosonics DTX split-beam system with a 200 kHz transducer. Calibration of the system was performed in a side looking aspect across the river channel. A tungsten carbide calibration ball with a theoretical target strength of -39.6 dB was suspended 7 metres away from the transducer. The hydroacoustic system was operated and an echogram of 30 minute duration was collected. Analysis of the echogram with Echoview acoustic software determined that the average recorded target strength of the calibration ball was -39.68 dB indicating that the system was calibrated and could be used effectively.

Operation of the hydroacoustic system was instigated in May 2009 after testing and initial operation of the downstream fishway was completed in early February 2009. The transducer was mounted to a float and weighted so that it was submerged 16.9m below the water surface. Adjustments were made to the location of the transducer so that it was aimed directly towards the water surface in the vicinity of the fishway entrance. A schematic in Figure 15 indicates the ensonified area of the hydroacoustic beam which is represented by the yellow shaded cone.

Scientific hydroacoustic systems develop echograms that plot the location in the water column of returned acoustic signals over time was used to perform the analysis of echograms associated with system calibration and fish counting trials. In the detection of single targets the Biosonics beam compensation model was utilised with a maximum beam compensation of 12 dB and a maximum standard deviation of 0.6° for both minor and major axis angles. The minimum target strength threshold was set at -50 dB to reduce the detection of targets that were not fish. The pulse length determination level was set at 6 dB and the accepted minimum and maximum normalised pulse lengths were 0.5 and 1.5 respectively.

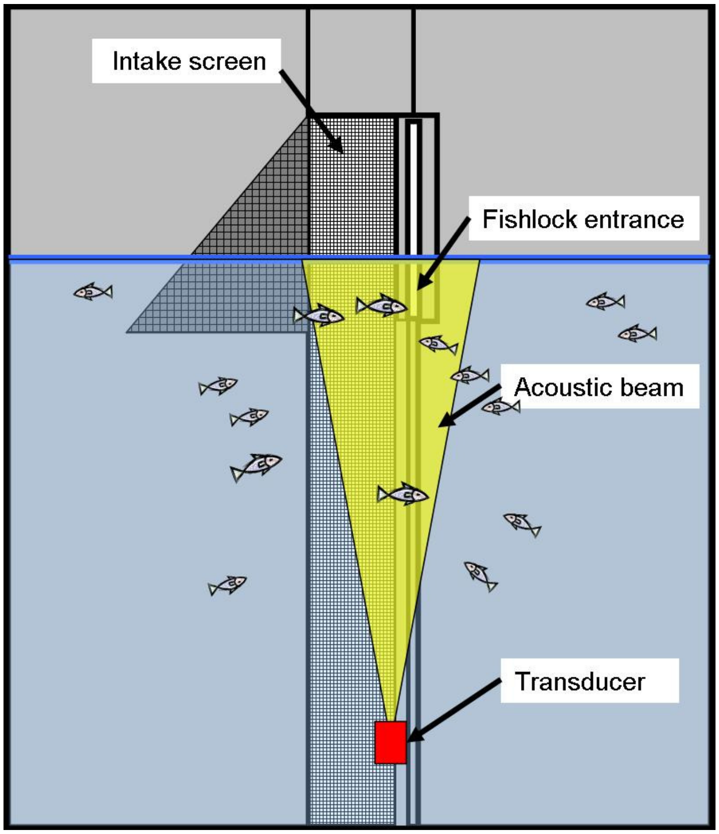


Figure 15 Schematic of a section of the upstream face of the Paradise Dam wall, yellow shading showing the approximate location of the acoustic beam (drawing not to scale).

The Echoview software analyses each echogram and identifies single targets detected within the ensonified area over the period of operation. Each single target is compared to others in the vicinity using algorithms developed from published acoustic research to determine whether they are part of a fish track.

Although the majority of fish tracks identified by the Echoview software were likely to be fish, floating debris and air bubbles rising from the river bed can be falsely identified as fish. Each fish track can therefore be visually reviewed to determine whether it does appear to be a fish, in the current study any obvious detections of debris or air bubbles were removed from analyses.

The hydroacoustic system simply detects objects moving through the beam and so does not differentiate between species or individuals. Accordingly if a fish moves into and out of the beam more than once it will be counted more than once. Analysis of the fish track does however provide important information on the behaviour of fish, a fish track with a high target strength indicates a large fish and a low target strength indicates a small fish. Data on the location and movement of the fish within the ensonified area can also be obtained and be used to determine fish behaviour.

Collection of downstream migrating fish

Introduction

In addition to the data gained from the radio telemetry study, tethered nets collected fish as they drifted downstream in river flows.

Methods

Up to 8 nets were set at various locations downstream of the dam. The 5 m long drift nets had a 1 m round opening, narrowing to a 0.5 m cod-end and covered with 28 mm diameter mesh. The nets were an open cone that permitted fish that are healthy to exit freely. At the mouth of each net, a General Oceanics 20307 mechanical flow meter is attached to quantify flow rate and volume passing through each net.

Any fish that were collected in the drift nets were assessed for condition (dead or alive), damage and the extent of damage sustained. In order to quantify any damage that may occur due to the action of the nets themselves a number of healthy fish were placed in the nets during medium to high flow conditions. Any fish that remained in the net were assessed using the criteria described above.

To provide control and impact data, the drift nets were deployed during both overtopping and outlet flows. In March 2007 the drift nets were deployed for 24 hours during a 300 ML per day release through the upstream fishway and the outlet channel. No fish were captured in the drift nets during the assessment period. After reviewing this method, drift nets were only deployed during larger irrigation releases, environmental releases and overtopping events.

During overtopping events the driftnets were deployed in the flow for approximately two hour samples when flow conditions were suitable for safe boat operations. Fish collected were assessed for injuries such as scale loss, abrasions, bruising and other obvious deformations, observations were documented and photos taken. The drift net data was used in conjunction with instream surveys by boat and bank surveys whereby injured and dead fish were collected using dip nets.

Assessment and investigative program results and discussion

DA-1 Downstream fish migration at Paradise Dam

What is the species composition and abundance of downstream migrating fish at the site?

Fish captured from fishlock sampling and electrofishing at the dam wall over the whole duration of the downstream fishway monitoring program yielded 24 species (Table 3). An additional two species; striped mullet (*Mugil cephalus*) and barramundi (*Lates calcarifer*) were captured at sites upstream of Paradise Dam. The six most numerically abundant species collected were western carp gudgeon (*Hypseleotris klunzingeri*), bony herring (*Nematolosa erebi*), fly specked hardyhead (*Craterocephalus stercusmuscarum*), snub-nosed garfish (*Arrhamphus sclerolepis*), Midgley's carp gudgeon (*Hypseleotris sp. A*) and flathead gudgeon (*Philypnodon grandiceps*)(Table 3).

Table 3 Abundance of fish species sampled from all downstream fishway monitoring methodologies from 2006 to 2010. N.B. ☹ = non-native species.

Common Name		***Fishlock sampling*** n=(34211 mins)	***Electrofishing at dam wall*** n=(230 mins)	***Size Range (mm)***
olive perchlet	*Ambassis agassizii*	329	55	25-86
banded grunter	*Amniataba percoides*	808	216	10-183
long-finned eel	*Anguilla reinhardtii*	202	101	490-1200
blue catfish	*Arius graeffei*	12	1	82-468
snub-nosed garfish	*Arrhamphus sclerolepis*	73	3063	57-222
silver perch	*Bidyanus bidyanus*	0	1	437-437
goldfish ☹	*Carassius auratus*	4	1	184-263
flyspecked hardyhead	*Craterocephalus stercusmuscarum*	1690	2545	11-82
mosquito fish ☹	*Gambusia holbrooki*	642	26	10-49
western carp gudgeon	*Hypseleotris klunzingeri*	6793	8843	9-52
Midgley's Carp Gudgeon	*Hypseleotris sp. A*	783	1116	16-52
spangled perch	*Leiopotherapon unicolor*	7	40	28-232
golden perch	*Macquaria ambigua*	9	6	22-488
Australian bass	*Macquaria novemaculeata*	0	1	330
Duboulay's rainbow fish	*Melanotaenia duboulayi*	80	146	14-81
Purple-spotted Gudgeon	*Mogurnda adspersa*	1	0	53-70
bony herring	*Nematolosa erebi*	1546	8031	24-303
Queensland lungfish	*Neoceratodus forsteri*	0	23	912-1160
Hyrtl's tandan	*Neosilurus hyrtlii*	145	1	91-352
flathead gudgeon	*Philypnodon grandiceps*	1710	3	15-82
Rendahl's catfish	*Porochilus rendahli*	336	0	38-146
speckled goby	*Redigobius bikolanus*	6	0	22-34
Australian smelt	*Retropinna semoni*	76	68	23-58
Barramundi	*Lates calcarifer*	0	0	-
Striped mullet	*Mugil cephalus*	0	0	-
freshwater catfish	*Tandanus tandanus*	2	19	222-484
	TOTAL	**15254**	**24306**	

Fish captured within the fishlock samples over the entire duration of the monitoring program yielded 21 species (Table 3). The six most numerically abundant species captured in the fishlock samples were western carp gudgeon, flathead gudgeon, fly specked hardyhead, bony herring, banded grunter (*Amniataba percoides*) and Midgley's carp gudgeon. Most of the species that were abundant during electrofishing at the dam wall successfully utilised the fishway and were well represented in fishlock captures. Species captured during electrofishing at the dam wall but not identified in the fishlock were silver perch (*Bidyanus bidyanus*), Australian bass (*Macquaria novemaculeata*) and Queensland lungfish (*Neoceratodus forsteri*). Species captured within the fishlock sample but not identified during electrofishing at the dam wall were purple-spotted gudgeon (*Mogurnda adspersa*), Rendahl's catfish (*Porochilus rendahli*) and speckled goby (*Redigobius bikolanus*).

An additional two species; striped mullet (*Mugil cephalus*) and barramundi (*Lates calcarifer*) were captured at sites within and upstream of the Paradise Dam impoundment during both PIT tagging activities and the radio telemetry study. However, neither of these two species were captured within the fishlock samples or whilst electrofishing at the dam wall.

During the monitoring program the fishlock also passed one platypus (*Ornithorhynchus anatinus*) as well as numerous freshwater turtles (*Emydura sp.* and *Elseya spp.*) and freshwater shrimp (*Macrobrachium sp.*).

When is migration occurring?

Fish were identified migrating downstream through the fishway during all months that sampling was performed (Table 4). The greatest rate of fish migrating through the fishway in a single event was recorded in June 2010 with 1.39±0.456 fish per minute from 10 species captured using the fishway. The greatest number of species recorded using the fishway was in February with 20 species documented.

Representation of species identified utilising the fishlock varied substantially between months. Fly-specked hardyhead, western carp gudgeon and flathead gudgeon were encountered in all months of sampling. Bony herring and Midgley's carp gudgeon were encountered in all months other than December, Australian smelt in all months other than September and snub-nosed garfish in all months other than March.

Some species undertook major migrations through the fishway during a single month of sampling. To demonstrate this, the species of which more than 75% of individuals were captured migrating downstream in a single month was calculated. In February 100% of Rendahl's catfish, 98.5% of long-finned eel at, 97.9% of Hyrtl's tandan, 87.2% of olive perchlet, 80.0% of Duboulay's rainbowfish at and 77.7% of banded grunter respectively were captured migrating downstream. In March, 83.3% of blue catfish and in November, 91.7% of flathead gudgeon were identified migrating downstream through the fishlock.

The CPUE for small bodied fish species migrating downstream through the fishlock varied from a calculated rate of 5261±4709.33 flathead gudgeons per day to 0.1±0.12 purple-spotted gudgeon per day. Of the larger bodied species that recorded a maximum length greater than 100mm in Table 1, the maximum rate of downstream migration was 1269.9±543.06 bony herring per day down to 0.1±0.12 blue catfish per day (Table 4).

Flow conditions had an influence on the downstream migration of fish through the Paradise Dam fishlock (Figure 16 and Figure 17). Olive perchlet, banded grunter, long-finned eel, Midgley's carp gudgeon, blue catfish, goldfish, spangled perch, golden perch, purple spotted gudgeon, Hyrtl's tandan and Rendahl's catfish were all identified migrating in greater numbers during periods when there was inflow into the dam impoundment. In contrast bony herring, flathead gudgeon, Duboulay's rainbowfish and speckled goby mostly migrated during no inflow periods. The migration of other species was shown not to be significantly influenced by either flow period. The downstream migration of relatively large numbers of neosilurid catfish such as Hyrtl's tandan and Rendahl's catfish indicated that these species were actively responding to inflows to the dam.

During February and March 2010 a number of species undertook peak downstream migrations through the Paradise Dam fishlock coinciding with periods of large inflows. The following points outline these downstream migrations.

- Banded grunter were present during all sampling events in February 2010 and were also present in similar numbers in March 2010 following overtopping of the dam (Figure 18).

- Long-finned eel were present in most fishlock samples in February 2010 and appeared to respond to the flow increases with large numbers encountered during inflows in late February 2010. Only one long-finned eel was identified in four fishlock samples during and after the spillway flow event in March 2010 (Figure 19).

- Bony herring were identified using the fishlock for downstream passage during all sampling events in February 2010 and appeared to respond to flow increases (Figure 20). No bony herring were recorded during the one sample undertaken in the March 2010 overtopping flow but were recorded following the overtopping flow.

Table 4 Rate of fish captured in the downstream fishway during different months of the years. (CPUE = number of fish/24hrs±SE)

Species	***February***	***March***	***June***	***July***	***August***	***September***	***October***	***November***	***December***
olive perchlet	20.6±7.33	24.3±22.9	0.0	0.0	0.0	0.0	9.9±6.87	0.3±0.19	0.0
banded grunter	74.5±20.2	120.9±64.79	1.1±1.09	12.5±3.95	1.5±1.5	6±6	0.0	0.0	2.4±1.45
long-finned eel	12.6±4.15	0.2±0.24	1.1±1.09	0.0	0.0	0.0	0.5±0.51	0.0	0.0
blue catfish	0.1±0.12	1.6±1.31	0.0	0.0	0.0	0.0	0.0	0.0	0.0
snub-nosed garfish	2.9±1.47	0.0	3.1±2.31	3.1±1.72	6±2.68	6±6	1.5±0.48	1.2±0.64	5.4±2.39
goldfish	0.3±0.18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
flyspecked hardyhead	81±23.72	323.4±224.29	221.9±74.84	103.1±38.61	41.4±25.53	14±7.21	0.5±0.51	1055.7±891.05	0.5±0.5
mosquito fish	26.8±16.88	32.3±27.84	151.4±46.24	42.8±31.9	0.1±0.1	6±6	0.0	0.0	0.0
western carp gudgeon	33.9±17.13	3775.4±2138.31	1321.5±444.47	952.9±203.52	521.3±290.06	416±81.19	12.9±11.85	1431.1±566.56	33.3±4.31
Midgley's Carp Gudgeon	2.8±2.66	2726±2718.81	3.1±1.69	9.4±4.2	9.9±6.1	42±9.17	1±0.99	209.4±86.85	0.0
spangled perch	0.2±0.12	6.3±4.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
golden perch	0.3±0.11	2.1±2.13	0.0	0.0	0.0	0.0	1±0.99	0.0	0.0
Duboulay's rainbow fish	3.8±1.56	0.3±0.33	1.1±1.09	1±1.04	1.5±1.5	0.0	0.0	37.7±33.88	0.0
Purple-spotted Gudgeon	1.3±1.33	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
bony herring	16.2±7.82	12.4±4.06	10.7±3.75	381±71.11	1269.9±543.06	54±18	1.5±1.48	0.3±0.19	0.0
Hyrtl's tandan	9.5±3.45	0.5±0.46	0.0	0.0	0.0	0.0	0.0	0.0	0.0
flathead gudgeon	3.5±1.42	9.5±6.05	5.5±2.7	7.3±3.18	6.7±2.67	68±26.23	1±0.02	5261±4709.33	13.7±3.31
Rendahl's catfish	24.6±8.73	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
speckled goby	0.0	0.0	2.2±1.51	0.0	4.5±3.26	0.0	0.0	3.4±3.43	0.0
Australian smelt	0.3±0.21	11.5±5.54	16.1±5.98	6.2±3.08	1.5±1.5	0.0	1±0.99	40.5±37.35	1±1
freshwater catfish	0.1±0.06	0.2±0.15	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total sample time (minutes)	18860	4440	1335	1386	1925	200	2865	4430	2550

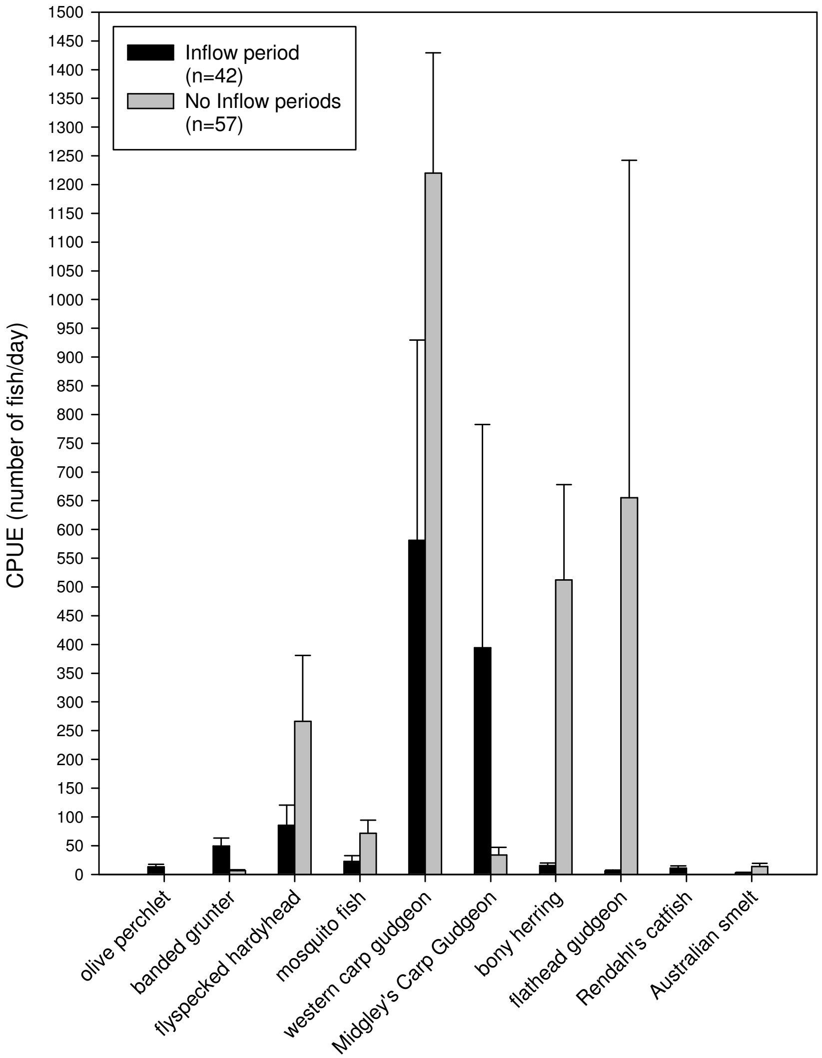


Figure 16 Rate of abundant (CPUE> 10 fish per day) fish species utilising the fishlock during inflow and no inflow periods (total sample time of 25809 minutes).

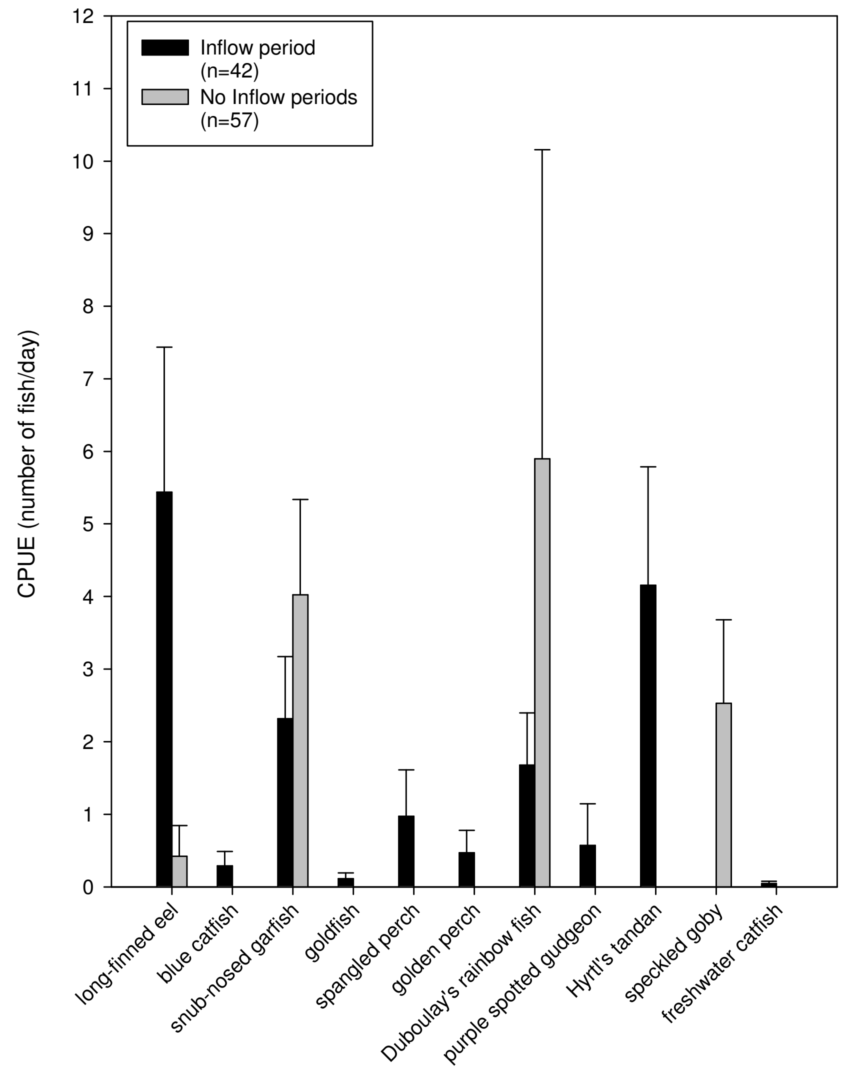


Figure 17 Rate of less abundant (CPUE< 10 fish per day) fish species utilising the fishlock during inflow and no inflow periods (total sample time 12182 minutes).

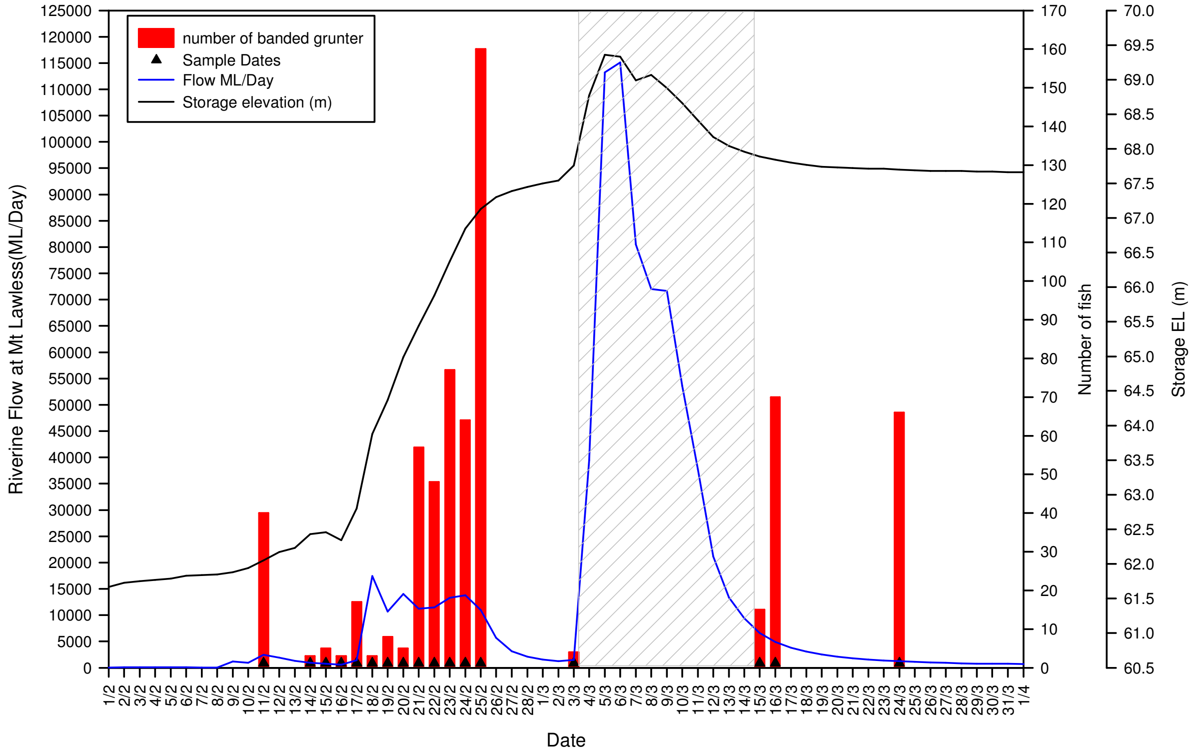


Figure 18 Number of banded grunter using the downstream fishway during inflows to Paradise Dam in February/March 2010.

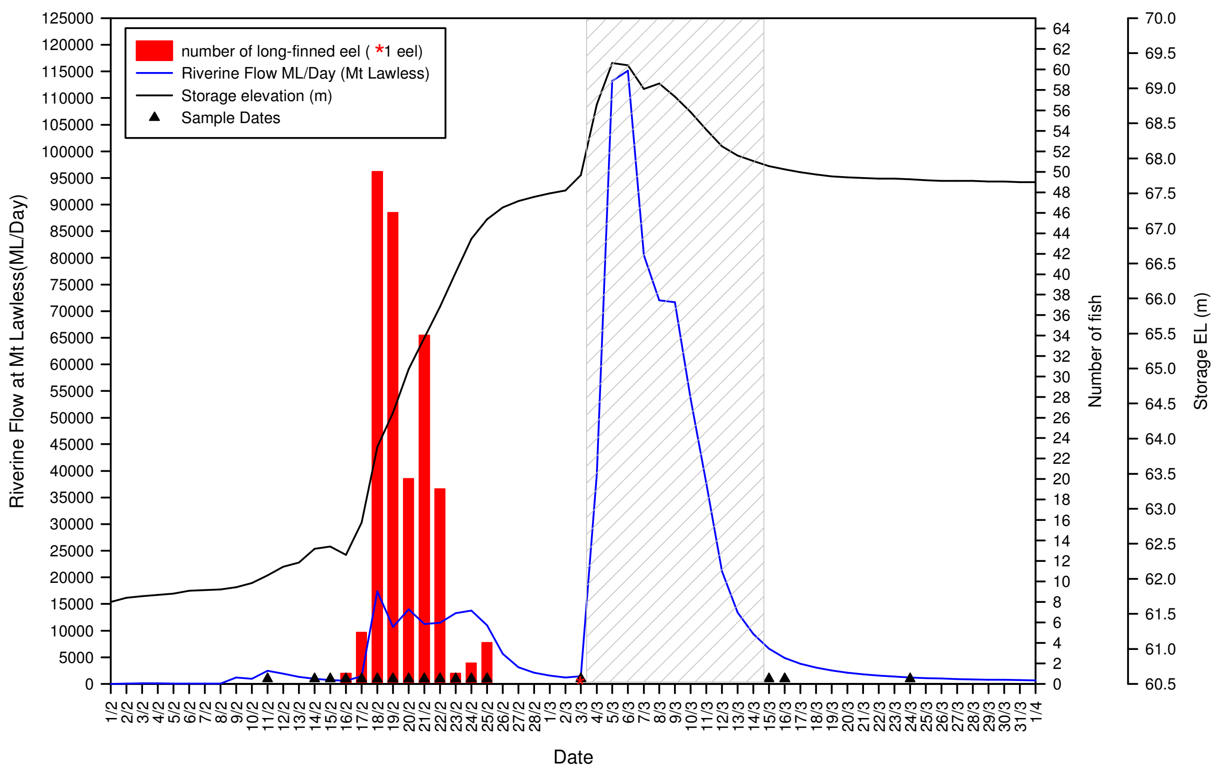


Figure 19 Number of long-finned eel using downstream fishway during inflows to Paradise Dam in February/March 2010.

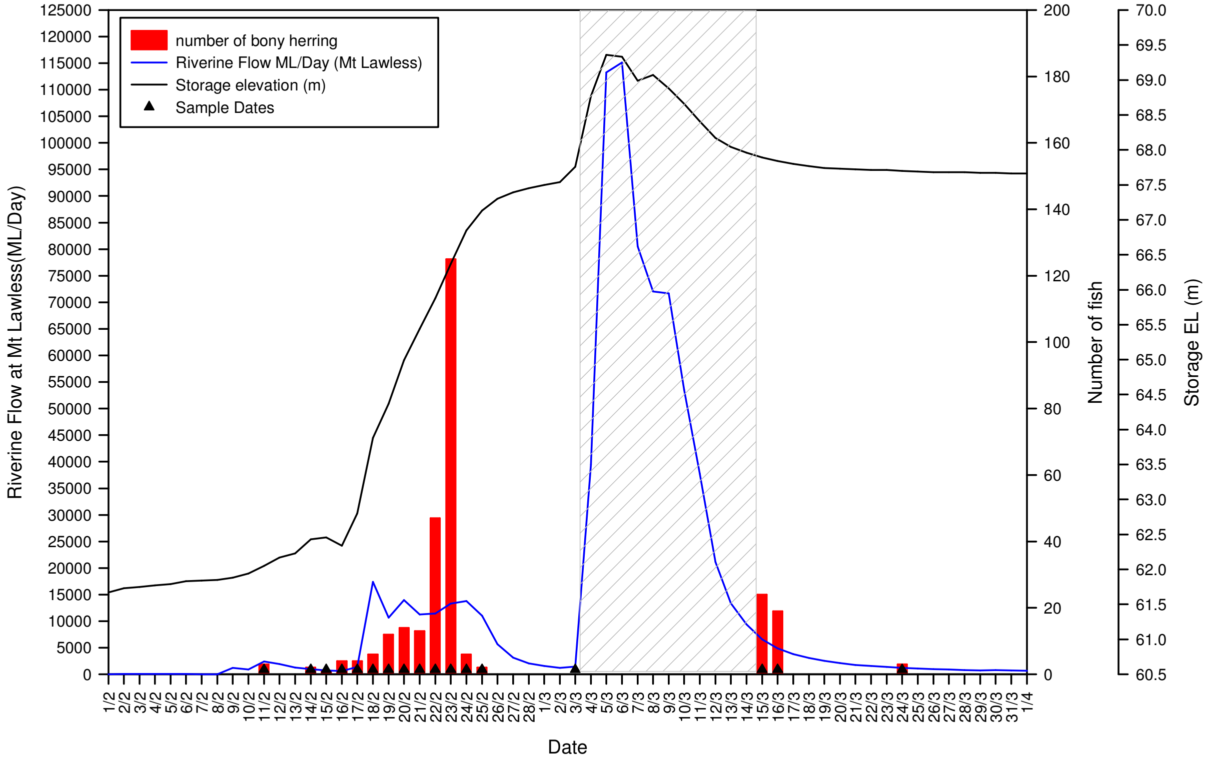


Figure 20 Number of bony herring using downstream fishway during inflows to Paradise Dam in February/March 2010.

Movement of radio tagged fish

The radio telemetry study provided data on the migratory behaviour of fish upstream of the Paradise Dam. In recognition of different migratory behaviours; catadromous and potamodromous fish species were separated into two groups. The catadromous species barramundi, Australian bass and striped mullet were grouped together and the potamodromous Queensland lungfish were considered separately. Due to reduced inflows to the dam in the first four years of the monitoring period the dam did not overtop until March 2010. The batteries of most radio tags implanted into fish in 2007 were expended or severely depleted to a level where there was a significant loss in signal strength by the time the dam overtopped. Only five radio tags implanted in 2009 would have been viable, but were not detected at the dam. No direct data relating to fish moving over the spillway could be attained from the radio telemetry program, but the data provided information on the timing and extent of movement within the dam. The following information summarises the results of the radio telemetry program.

Catadromous Species

Forty-five catadromous fish were radio tagged within and upstream of Paradise Dam, comprising nine barramundi, nine Australian bass and twenty-seven striped mullet. Most fish were released within the area where they were originally captured; six striped mullet originally captured some 85 kilometres downstream of Paradise Dam were translocated into the dam adjacent to the wall.

The total linear movement range of catadromous fish that were located since released ranged from 5 to 61956 metres. Total linear movement range is equivalent to the distance between the two most extreme radio fixes recorded during the study. The average total linear range of movement between locations was 20916.7 metres (± 26684.9 SD), with some individuals moving considerable distances and others remaining relatively stationary.

The most notable movements in the survey have occurred in the downstream direction with all catadromous fish detected at the dam having migrated considerable distances downstream. Of the 45 catadromous fish in this survey not one individual moved greater than two kilometres upstream of their original tagging location.

Catadromous fish were frequently detected at the dam wall during inflows into the dam. A total of 14 fish were detected at the dam wall during the study comprising five striped mullet (18.5% of total tagged), two Australian bass (22.2% of total tagged) and seven barramundi (77.8% of total tagged). Figure 21 shows the number and species of fish detected at the dam and inflows between September 2008 and September 2009.

Catadromous fish migrated downstream to the dam wall during

- small and large flow events
- the rise, peak and recession of some flow events.
- all seasons of the year
- a number of subsequent inflow events after their first downstream migration into the impounded waters.

Individual fish which had migrated into the impoundment were not recorded moving back upstream into riverine areas, but did move frequently and extensively within the impounded waters.
Fish remained at the dam wall from anywhere between less than one hour to five days before moving back upstream. No radio-tagged catadromous fish were located or recaptured downstream of the dam following the March 2010 or September 2010 overtopping events.

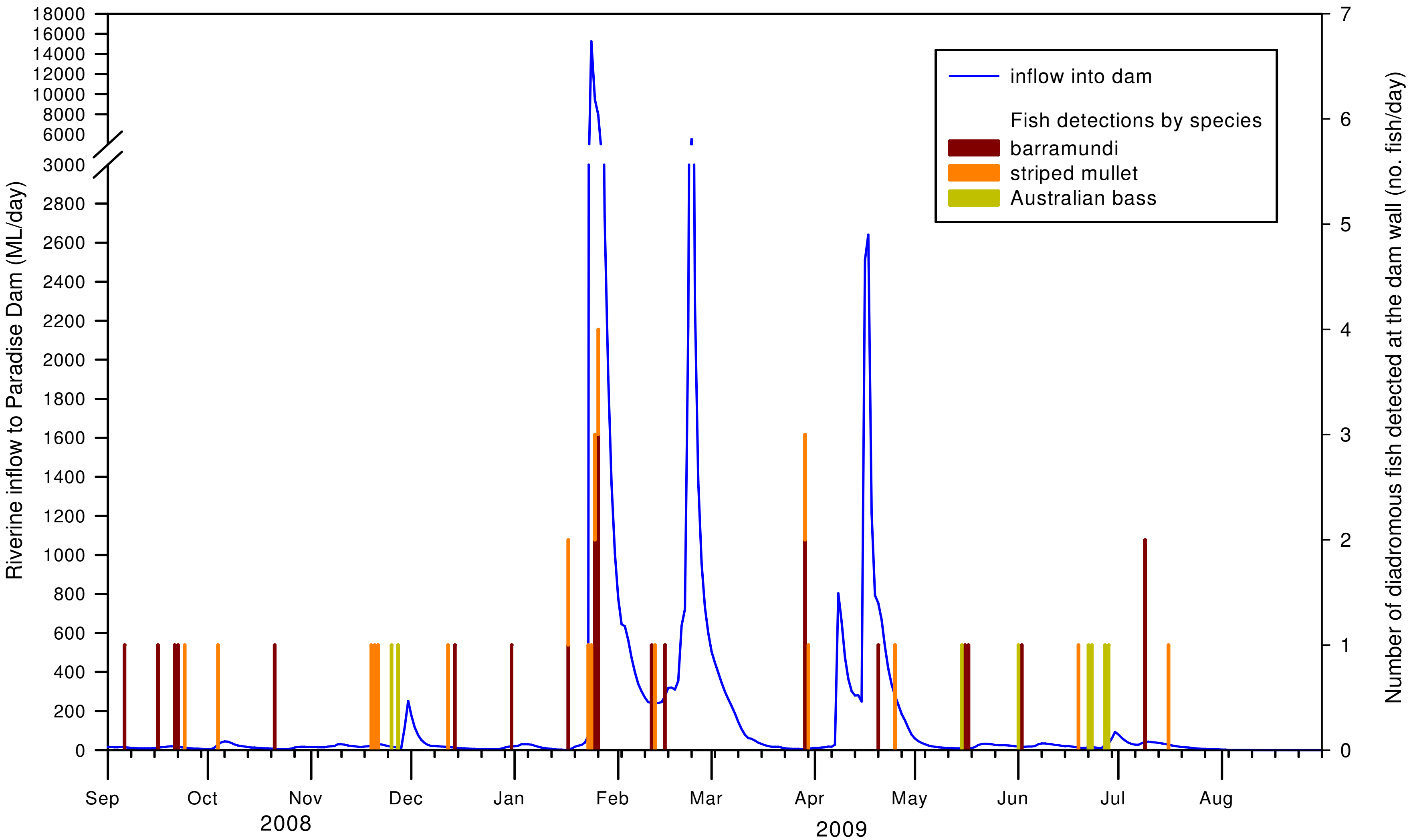


Figure 21 Detections of radio-tagged catadromous fish at Paradise Dam during inflows at Mt Lawless between September 2008 and August 2009.

Queensland Lungfish

Twenty eight lungfish ranging in size from 495 to 950mm were implanted with radio transmitters and tracked for periods ranging from 232 to 996 days. Thirteen of the 28 radio tagged lungfish were translocated from locations downstream of the dam to within the dam impoundment. On average, each fish was located on 21 separate occasions (range 9-37 locations) during the monitoring program. Most fish distributed themselves in a series of localised movements away from the release site. During tracking events, individuals were almost always located sheltering against the banks, or adjacent to or under a large inundated tree. All of the radio tagged lungfish were located subsequent to their release.

Figure 22 shows the number of lungfish detected at the dam wall and inflows between January 2008 and September 2009. The following points outline the movement patterns of radio tagged lungfish in the Paradise Dam impoundment. (Further detailed information on individual lungfish movements is provided in the 2008 and 2009 Annual Reports).

- Queensland lungfish were detected at the dam wall on most days throughout the study period over a wide range of flows with a maximum of eight fish detected per day.
- A number of individuals moved downstream to the dam wall in response to inflow events on or after the peaks of each event. Most fish returned back upstream after a short period of time at the dam wall.
- A small number of lungfish including translocated lungfish remained at the dam wall for extended periods of time over many consecutive days and even months.
- A level of site fidelity was evident, with some individuals remaining in the same location over consecutive tracking events.
- Most lungfish were active within the impoundment, moving an average distance of 3056 m ± 5214 m SD between location events.
- Fish moved similar distances in both upstream and downstream directions with an average of 2953 m ± 5172 m SD upstream and 3185 m ± 5271 m SD downstream.
- Fish moved greater distances in both upstream and downstream directions during inflows to the dam.
- The maximum distance moved by lungfish between location events was 30006 metres downstream and 31257 metres upstream.
- On a number of occasions, lungfish were recorded moving considerable distances in a single day. One translocated individual was detected 90 times at the dam wall on the 26th August 2008 between 12:01 am and 11:08 am. This fish was then located by manual radio tracking at 13:20 pm, 4266 m upstream near the junction of Yarrabil Creek and the Burnett River. This fish was then detected again at 16:27 pm at the dam wall and detected multiple times for the remainder of the day.
- There was no clear indication of seasonal migration of lungfish gained from the radio-telemetry data.

Although no radio tagged lungfish were detected moving over the dam wall in the March 2010 overtopping event, translocated lungfish #19.68 and #11.68 were recaptured at Cherelly (9.1 km downstream of the dam) in May 2010.

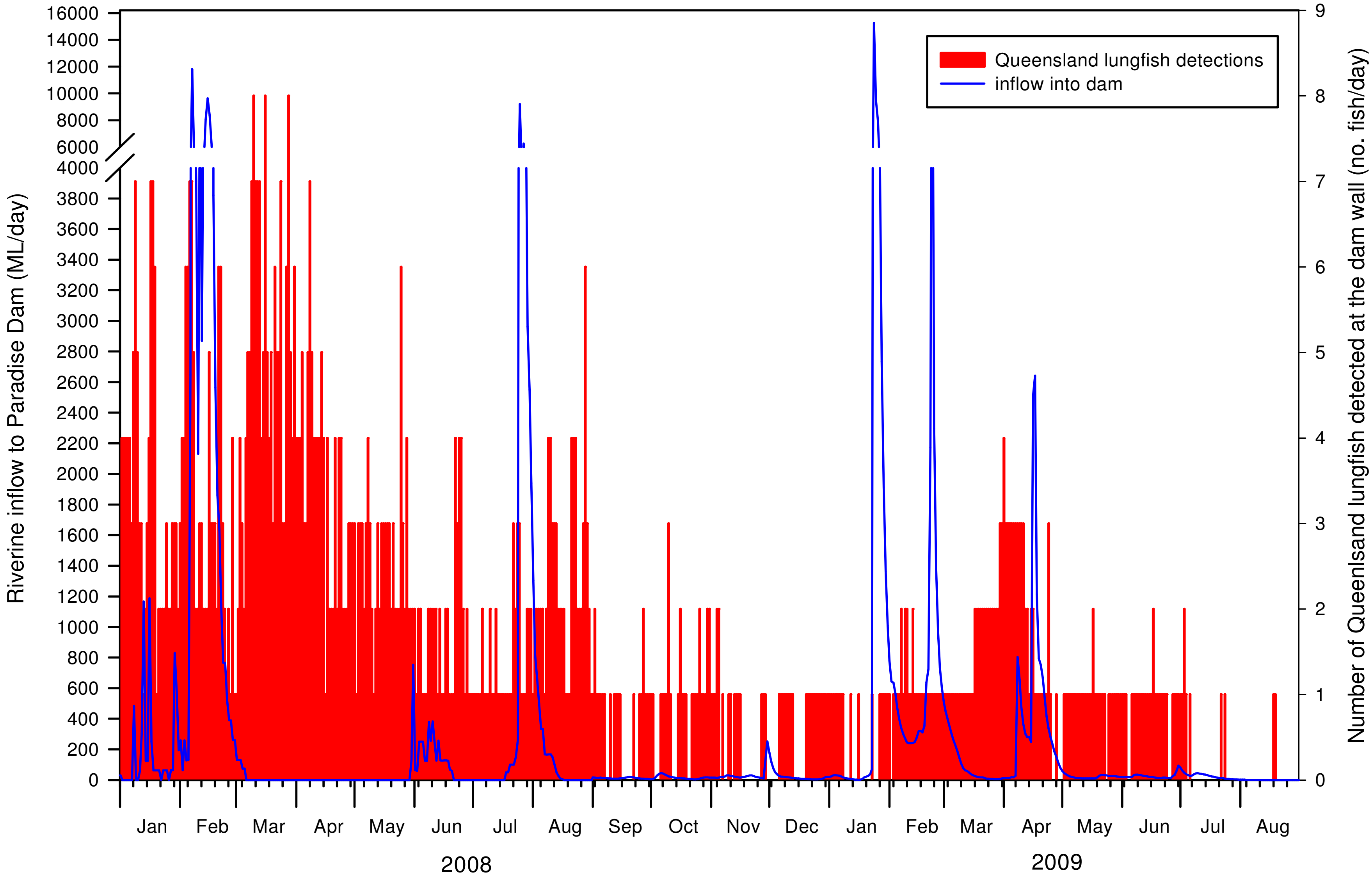


Figure 22 Detections of radio-tagged lungfish at Paradise Dam during inflows at Mt Lawless between January 2008 and August 2009.

Timing of PIT tag fish detections

A total of 61 PIT tagged fish from seven species have been detected at the downstream fishway since the commencement of the monitoring program. Table 5 below shows the number of individual fish detected at the Paradise Dam downstream fishway. The detection of PIT tagged fish represents only a small proportion of all fish that may be present at the fishway at any given time. The recapture rate of all PIT tagged fish of 6.8% (unpublished data, QPI&F) throughout the Burnett River shows that the majority of the fish population remains untagged.

Data on fish detections at the PIT tag readers was affected by a lack of reliability of the readers. No fish attempting to use the downstream fishway were detected at the downstream exit chute PIT tag reader antenna location during at any stage of downstream fishway operation. Testing of the exit chute PIT tag reader antenna in early 2009 showed that it did not detect tagged fish effectively during the exit phase of the downstream fishway.

The time of fish detections, water temperature, storage level and flows into the dam are shown in Figure 23 and Figure 24. The following points outline the patterns of fish detections during the operation of the fishway.

- The downstream fishway became operational in February 2009 after inflows increased the storage level of the dam above the minimum level for fishway operation (EL 62.0 m).
- Between 1 August and 27 October 2008 the storage level of the dam was above the invert of the downstream fishway quad leaf gate entrance (EL 61.7 m). Above this level PIT tagged fish could have been detected by the PIT tag reader antenna, however no fish were detected during this time.
- Soon after the downstream fishway became operational in early February 2009, PIT tagged fish were detected at the quad leaf gate entrance slot of the fishway.
- PIT tagged fish have been detected on a number of occasions at the downstream fishway, with increased numbers of fish detected during and after some small and large inflow events.
- Golden perch, freshwater catfish and long-finned eels have been detected at the fishway during periods of no inflow to the dam.
- A number of individual fish moved considerable distances downstream to the dam wall.

Table 5 outlines the details of fish originally tagged within the dam impoundment, which were detected at the downstream fishway. All other fish detected at the downstream fishway had originated from below the dam and would have migrated through the upstream fishway into the impoundment (Refer to Table 8)

Table 5 Fish detected at downstream fishway originally tagged upstream of the dam.

Species	*PIT ID*	*Length (mm)*	*Site tagged*	*Date tagged*
long-finned eel	15989254	930	Burnett Dam H/W	29.1.2009
long-finned eel	33454039	550	Burnett Dam H/W	3.2.2009
long-finned eel	129215459	908	Kalliwa Hut	17.8.2006
long-finned eel	140632087*	660	Burnett Dam H/W	19.10.2007
golden perch	142553046	340	Burnett Dam H/W	11.1.2010
golden perch	142554219	504	Mingo Gorge	11.9.2007
Australian bass	129216124	370	Sunday Creek	4.8.2006
striped mullet	142554067	530	Mingo Gorge	17.8.2007
Queensland lungfish	140632651	910	Mingo Gorge	7.3.2007

* this fish successfully moved through the fishway.

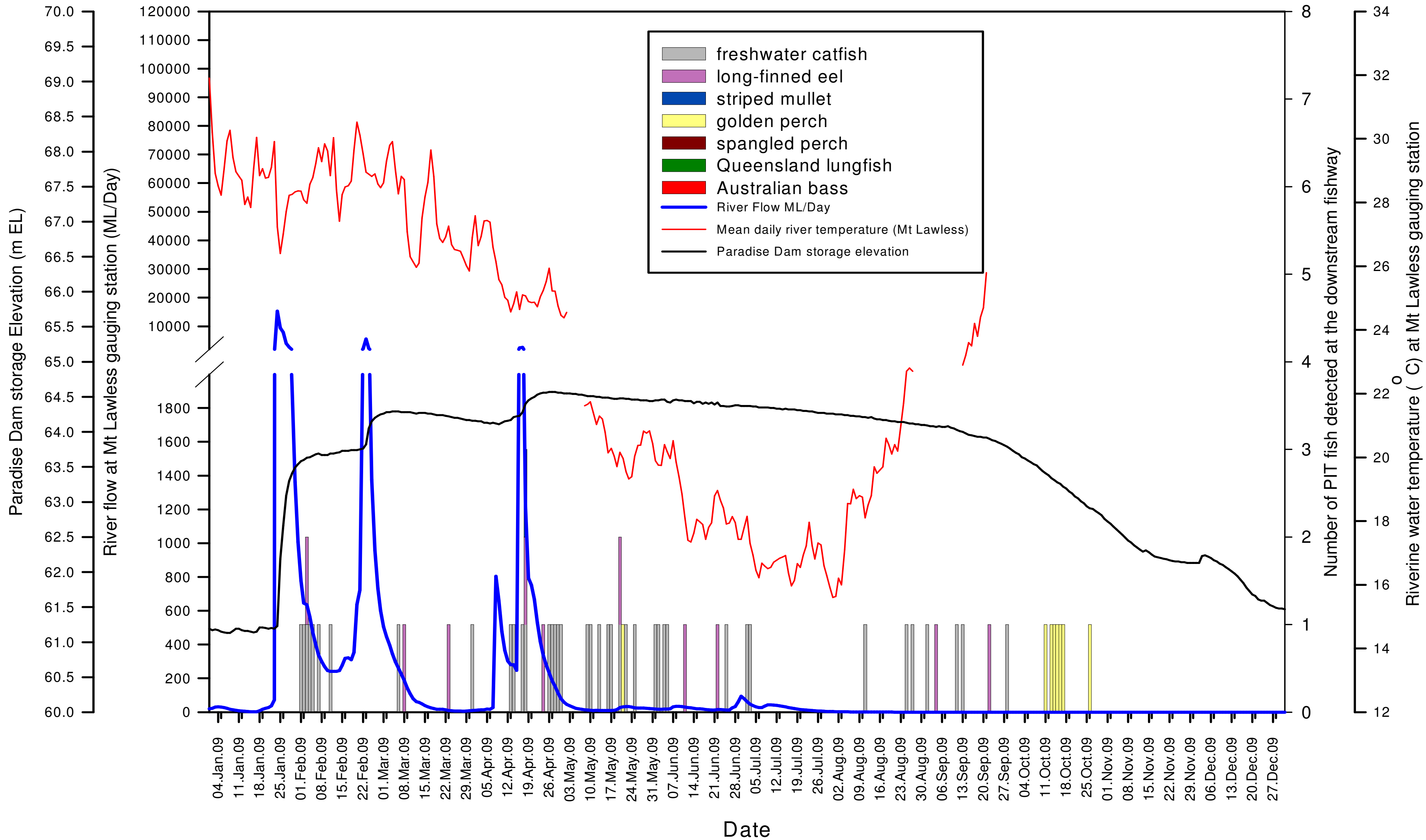


Figure 23 Detections of PIT tagged fish at the downstream fishway entrance slot from January to December 2009 compared to river flow, mean water temperature and Paradise Dam storage elevation.

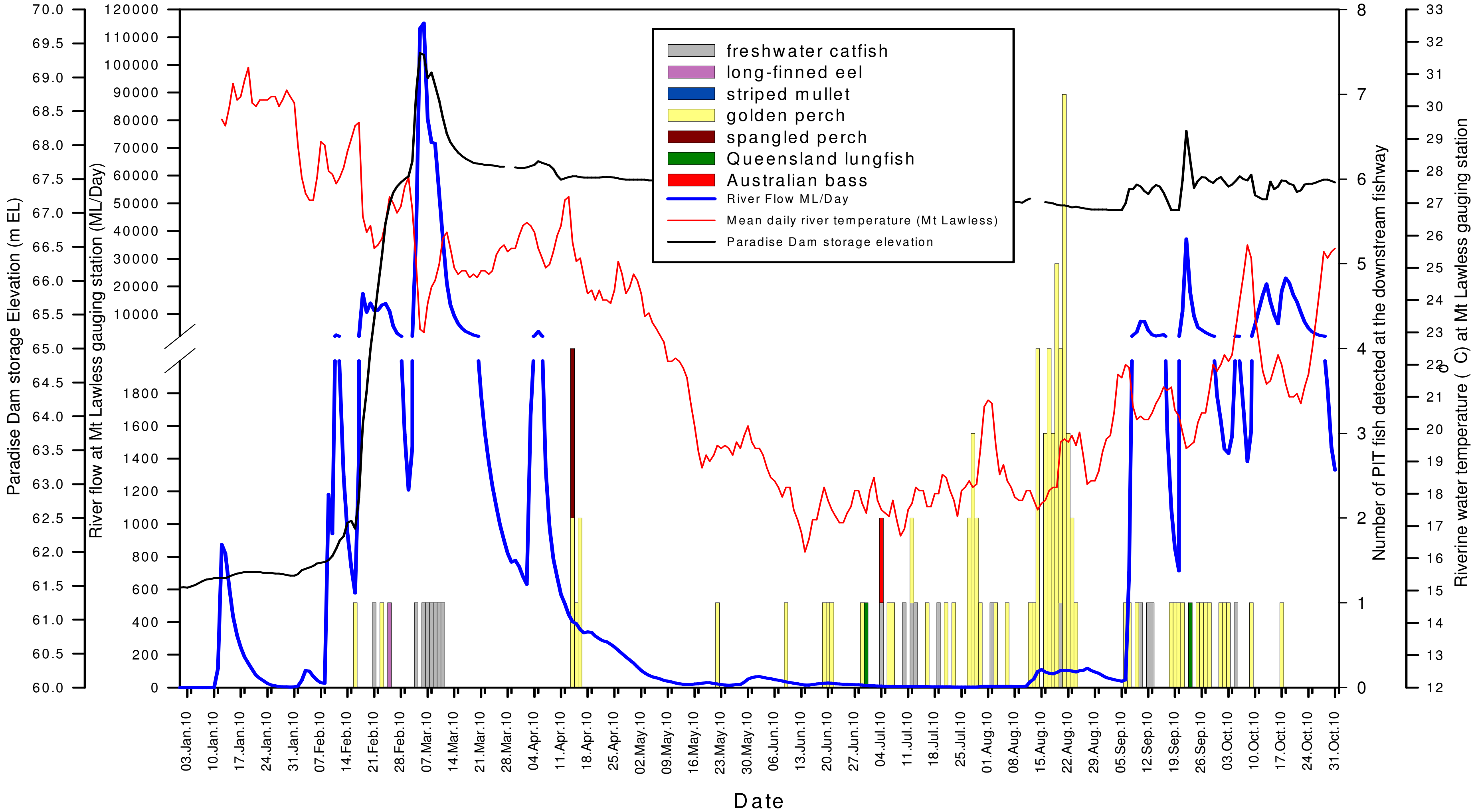


Figure 24 Detections of PIT tagged fish at the downstream fishway entrance slot from January to December 2010 compared to river flow, mean water temperature and Paradise Dam storage elevation.

DA-2 Fish attraction and operational range

Is the operation / design of the fishlock attracting fish to the fishway under the full operational range?

The downstream fishway did not commence operation until the 5th February 2009 following an increase in the water level in the Paradise Dam to EL 62.0 m (the minimum operating level of the downstream fishway). During the period from the 5th February 2009 to 31st October 2010 the Paradise Dam downstream fishlock was operational for 88.5% of the time that water was being released from the dam (Table 6). Non-operational periods were due to mechanical failures or unsuitable fishway entrance or exit flow conditions. The mechanical failures predominantly occurred early in the operation of the fishlock and may be considered part of the wet commissioning process. Unsuitable exit conditions occurred when the environmental release outlet was operated at discharges greater than 20 cumecs (Figure 34).

The fishlock was not operated when the impoundment water level fell below EL 62.0 m (the minimum operating level of the fishway) or was above EL 67.9 m (the maximum operating level of the fishway). Attraction flow conditions at the fishway entrances varied according to releases from the irrigation release outlets, the environmental flow release outlet and flows over the spillway. As the Paradise Dam did not fill until March 2010, all data pertaining to environmental flow release outlet and spillway overtopping flows is from this date onward.

Table 6 Hours of operation for the Paradise Dam downstream fishlock during flow releases (February 2009 to October 2010 when the Paradise Dam storage level was between EL 62.0 m and 67.9m).

Fishway status	**Flow release condition**			
	Irrigation Outlets and/or fishlock	Environmental flow releases	Spillway overtopping	Total
Hours operational	10748.5	492.5*	634.0*	11875.0
Hours non-operational	963.6	515.5*	62.0*	1541.0
Total hours	**11712.1**	**1008.0**	**696.0**	**13416.0**

* These figures relate to environmental flow releases and spillway overtopping events in March and September 2010.

The current control system for the Paradise Dam fishlock sets the entrance of the downstream fishway via the quad leaf gate between impoundment levels of EL 62.0 m and EL 67.0 m. At impoundment levels between EL 67.0 m and EL 67.9 m fish must enter the fishlock via the spillway flume entrance and single leaf gate. Detections of PIT tagged fish at the single leaf and quad leaf gate PIT tag reader antenna locations were compared to recorded downstream fishway operational storage levels (Table 7). The majority of fish detections occurred at the quad leaf gate regardless of which gate was operational.

Table 7 Number of detections of PIT tagged fish at the quad leaf gate and single leaf gate, shaded cell indicates the operational entrance for the specified storage level. Figure in brackets indicates the number of fish detected at the specified level.

Storage Level EL (m)	*Number of detections (Number of individual fish detected)*	
	Fishlock chamber quad leaf gate entrance	Spillway flume single leaf gate entrance
62.0 to 67.0	**409 (62)**	7 (7)
67.0 to 67.6	567 (66)	**108 (31)**
67.6 to 67.9	0	**1 (1)**
>67.9	8 (4)	15 (5)

The only PIT tagged fish to be detected at the single leaf gate entrance during the design operational level of EL 67.6 to 67.9 m was a Queensland lungfish on the 23rd September 2010. During this time the fishway was not operational due to releases being made through the environmental release intake tower. The fishway recommenced operation on the 24th of September 2010. Fish were detected at both entrance locations above the upper operational level of EL 67.9 m.

As detailed in DA-1 the majority of fish species identified within the dam impoundment utilised the fishlock for downstream passage (confirmed during sampling). Most PIT tagged fish detected at the downstream fishway entrance have only been recorded for 1-5 detection events each. These fish have either been detected as they have entered the fishlock chamber, and therefore successfully used the fishway, or they have been detected within the impoundment adjacent to the fishway entrance slot and have not actually moved through the entrance slot into the fishlock chamber. It cannot be confirmed if these fish had moved through the downstream fishway due to the poor detection capability of the exit chute PIT tag reader antenna. No PIT tagged fish detected at the downstream fishway entrance were detected at the downstream exit location (exit chute PIT tag reader). Only PIT tagged fish which were subsequently detected at an upstream fishway PIT tag reader antenna located in the tailwater could be confirmed as having successfully used the downstream fishway. No fish that have successfully moved through the downstream fishway have been recaptured below the dam.

Golden perch, long-finned eel and freshwater catfish were the only PIT tagged fish recorded successfully utilising the Paradise Dam downstream fishway. Of the golden perch detected, 41 were detected when the fishway was operational and 4 individuals were confirmed to have successfully utilised the fishway (Table 8).

Table 8 Fish detected at the Paradise Dam downstream fishway PIT tag readers and the operational status of the downstream fishway. (Fish PIT tagged as part of the Paradise Downstream Fishway Monitoring Program, July 2005 to November 2010)

Common Name	**Total number of fish tagged upstream of the dam**	**Number of fish detected at the DOWNSTREAM FISHWAY**					**Number of PIT tagged fish successfully using the fishway**[1]	
		FISHWAY OPERATIONAL	FISHWAY OPERATIONAL Gate **CLOSED (NO opportunity for fish to use fishlock)**		FISHWAY OPERATIONAL Gate **OPEN (Opportunity for fish to use fishlock)**			
banded grunter	12	-	-	-	-	-	-	-
long-finned eel	75	3	2	66%	1	33%	1	100%
blue catfish	80	-	-	-	-	-	-	-
snub-nosed garfish	1	-	-	-	-	-	-	-
silver perch	2	-	-	-	-	-	-	-
barramundi	113	-	-	-	-	-	-	-
spangled perch	42	0	-	-	-	-	-	-
golden perch	719	41	10	24%	31	76%	4	16%
Australian bass	83	1	1	100%	0	0%	-	-
striped mullet	74	1	1	100%	0	0%	-	-
Queensland lungfish	1887	1	1	100%	0	0%	-	-
Hyrtl's tandan	14	-	-	-	-	-	-	-
freshwater catfish	134	4	1	25%	3	75%	1	33%
TOTAL	**3236**	**51**	**16**		**35**		**6**	

(1) Success of a PIT tagged fish using the fishway has been determined by the following assumption: the last detection of a PIT tagged fish was at the downstream fishway exit chute antenna or an upstream fishway antenna.

DA-3 Fishlock capacity and efficiency

Is the capacity of the fishlock such that it is able to pass the migratory biomass in an acceptable timeframe?

The downstream fishway was designed to provide flexibility in the amount of time that could be set to attract fish into the fishlock chamber and these settings were detailed in the September 2009 Annual Report. When operating the fishway with a minimum of 300 mm water depth across the quad leaf gate entrance slot and a 900 mm headloss, the hydraulic conditions were optimised but still not ideal for all fish as they must continually reorientate themselves in upwelling flow patterns. Small bodied and or poor swimming species may become stressed and fatigued. The longer that fish were exposed to these conditions there was an increased risk they would be injured. For this reason a shorter attraction time of 60 minutes per cycle was adopted to reduce the chance of fish being injured, whilst still maintaining a reasonable fishway attraction time (Table 9). The capacity of fishway would appear to be adequate for the numbers of fish encountered during the 60 minute attraction cycle period.

Table 9 Operational phases and timing of the Paradise Dam downstream fishlock.

Fishlock Attraction Phase	Fishlock Drain, Flush and Fill Phase	Total Fishlock Cycle	Percentage of time fish have opportunity to enter fishlock	Number of cycles per day
60 minutes	20 minutes	80 minutes	75%	18

Are all of the most abundant species and size classes directly upstream of the weir successfully utilising the fishlock?

The six most numerically abundant species collected within the dam impoundment; western carp gudgeon, bony herring, snub-nosed garfish, fly specked hardyhead, Midgley's carp gudgeon and banded grunter were well represented at the fishlock exit. All six of the most abundant species as well as the majority of other species captured within the dam impoundment were represented at the exit of the fishlock. Hyrtl's tandan, flathead gudgeon and Rendahl's catfish were rare in upstream captures but were abundant in fishlock captures.

A variety of size classes were represented at the exit of the fishway with western carp gudgeon as small as 9 mm and long-finned eel as large as 1200 mm able to successfully utilise the fishway (Table 3). The size classes of most species were well represented in the samples of fish using the downstream fishlock. For this reason there does not seem to be any impediment for fish of different sizes within a particular species in entering and using the fishway.

Silver perch, Australian bass, barramundi, striped mullet and Queensland lungfish were the only species that have not been captured or recorded successfully using the fishlock. Silver perch were not abundant during the study period; however the other four species were regularly captured in the upper reaches of the impoundment and were identified on the radio-telemetry and PIT tag readers located at the dam wall.

DA-4 What is the attraction flow and gate level required to retain fish in the holding chamber during fishlock attraction phases?

Testing and operation of the fishway in early February 2009 determined the operational settings that were used during the monitoring program and these were detailed in the September 2009 Annual Report. Testing at various headloss levels was performed to determine suitable hydraulic conditions for safe fish passage. Water velocities and turbulence were only considered acceptable for fish when they were held in the fishlock chamber during the attraction phase of the fishway at a headloss of 900 mm between the dam storage level and the water in the fishlock chamber. At a headloss level of 900 mm any fish that move through the quad leaf gate entrance slot will not be able to move back out into the impoundment. The retention of fish once they had entered the fishlock chamber during the attraction phase would be considered to be 100%.

DA-5 Are all fish that enter the fishlock exiting during the flushing phase?

Tests to ascertain the success of fish exiting the downstream fishway were performed to determine if the flushing time and flow was acceptable. These results were detailed in the September 2009 Annual Report. A known number of fish were placed into the fishlock chamber at the start of the drain phase of the fishway. This included both small and large bodied fish species. Observations were made at the exit chute during the entire flushing phase. Fish were then collected at the exit chute after the flushing phase. Results from the test showed that the first of four large bodied fish to exit the pipe occurred 1 minute and 8 seconds after the quick release gate valve had been opened. The last of the large bodied fish exited the pipe 1 minute and 23 seconds after the quick release gate valve had been opened. No other fish were visually observed exiting the pipe after this time. Although difficult to see clearly, small bodied fish were also observed exiting the pipe over a similar time period to the large bodied fish. All fish were accounted for in the exit chute net after the 2 minute flushing time trial. From this data, a two minute flushing period with quick release gate valve V103 set at 10% opening was considered acceptable to ensure fish had exited the pipe. Further *ad hoc* tests and observations found a similar result with all fish exiting within the two minute flushing time.

DI-1 What are the optimum filling and draining regimes?

Testing and operation of the fishway in early February 2009 determined the operational settings that were used during the monitoring program and these were detailed in the September 2009 Annual Report. The design of the downstream fishway provided for a flow rate of 0.5m/s when lowering the water and fish within the fishlock chamber down the standpipe. Although not directly tested, the time it takes for the drain phase of the cycle was considered acceptable for fish within the fishway. The time it takes to lower the water level is controlled by drain control valve V108, and was initially set at 20% valve opening. As the water level was lowered, the turbulence and velocities within the fishlock chamber and standpipe were very low (pers. obs). The operation of V108 at 20% valve opening is deemed acceptable for all operational conditions.

DI-2 What is the condition of fish that exit the fishlock?

Fish injuries were recorded whilst sampling the downstream fishway. Injuries were restricted to small bodied fish species and the data suggests that injuries occurred because of sampling techniques, particularly in the fishlock entrance chamber trap. However, further testing without the fishlock trap found that attraction times greater than 60 minutes demonstrated a substantial increase in the rate of injuries occurring with small fish. Hydraulic conditions were considered acceptable for fish, but attraction times greater than 60 minutes increased the risk that small fish would become fatigued and more likely to be injured. The fishway attraction time should not be greater than 60 minutes. (Annual Report 2009).

DI-3 What proportion of fish pass over the dam crest during river flows?

At the beginning of the overtopping event on the 3rd March 2010 quantitative sampling was performed using seven passive drift nets directly below the spillway, Fish moving over the spillway were captured directly downstream of the spillway during this time for a total period of 360 minutes (3rd March 2010 between 10:00-17:00). The rate of fish moving over the spillway was determined quantitatively by using fish catch data, the known volume of water sampled for each net and the measured flow volume at the time. This determined that an average of 1.01±0.50 fish per second (60.8±30.31 fish/minute) was passing over the spillway during this time.

In addition, sampling of the downstream fishway was also conducted on 3rd March 2010 to determine the numbers and species of fish using the downstream fishway via the spillway entrance. Sampling of the downstream fishway was conducted for a total period of 135 minutes. Fish moving over the spillway were captured directly downstream of the spillway during this time for a total period of 360 minutes. Table 10 demonstrates the rate of fish using the downstream fishway compared to fish collected in the drift nets downstream of the spillway. The rate of fish moving over the spillway was considerably higher than fish using the fishway, except for gudgeons and Australian smelt, which were not captured in the drift nets below the dam.

Table 10 Rate of fish using the downstream fishway and moving over the spillway during the 3rd March 2010 overtopping event.

Species	***Fish per minute using downstream fishway***	***Calculated Fish per minute moving over spillway*** *±SE*
olive perchlet	0.10	27.6±16.11
banded grunter	0.03	1.5±1.04
long-finned eel	0.00	1.6±1.6
blue catfish	0.00	
snub-nosed garfish	0.00	0.7±0.44
flyspecked hardyhead	0.99	3.5±2.16
mosquito fish	0.12	0
western carp gudgeon	3.90	0
Midgley's Carp Gudgeon	0.02	0
spangled perch	0.00	0.4±0.39
Duboulay's rainbow fish	0.00	0.5±0.53
bony herring	0.00	24.6±7.65
Hyrtl's tandan	0.00	0.4±0.39
flathead gudgeon	0.00	
Rendahl’s catfish	0.00	
Australian smelt	0.02	0
All species	5.17	60.8±30.31

Visual observations during overtopping flows in March and September 2010 indicated that fish aggregated at the dam wall and passed over the spillway. Early in the flow event from the 1st to 4th of March 2010 aggregations of large bodied (>100 mm total length) fish species including long-finned eels, bony herring, striped mullet, golden perch and spangled perch were observed at the dam wall. Unidentified small bodied fish were also observed drifting in the flow and going over the spillway. Visual observations identified large fish such as long-finned eel at rates of up to 6 per minute going over the spillway.

Captures downstream of the dam and observations of fish passing over the dam wall during the March 2010 overtopping event identified the species listed below in Table 11. A subjective estimate of abundance relative to the observed abundance of the fish during no flow periods was assigned to each species.

Table 11 Fish species recorded passing over the Paradise Dam spillway during the March 2010 event and observed abundance compared to no flow periods.

Common Name	***Species***	***Abundance***
olive perchlet	*Ambassis agassizii*	*moderate*
banded grunter	*Amniataba percoides*	*high*
long-finned eel	*Anguilla reinhardtii*	*very high*
blue catfish	*Arius graeffei*	*moderate*
snub-nosed garfish	*Arrhamphus sclerolepis*	*low*
silver perch	*Bidyanus bidyanus*	*not observed*
goldfish ☹	*Carassius auratus*	*not observed*
flyspecked hardyhead	*Craterocephalus stercusmuscarum*	*moderate*
mosquito fish ☹	*Gambusia holbrooki*	*low*
western carp gudgeon	*Hypseleotris klunzingeri*	*high*
Midgley's Carp Gudgeon	*Hypseleotris sp. A*	*high*
barramundi	*Lates calcarifer*	*very high*
spangled perch	*Leiopotherapon unicolor*	*moderate*
golden perch	*Macquaria ambigua*	*very high*
Australian bass	*Macquaria novemaculeata*	*moderate*
Duboulay's rainbow fish	*Melanotaenia duboulayi*	*moderate*
Purple-spotted Gudgeon	*Mogurnda adspersa*	*not observed*
striped mullet	*Mugil cephalus*	*very high*
bony herring	*Nematolosa erebi*	*very high*
Queensland lungfish	*Neoceratodus forsteri*	*very high*
Hyrtl's tandan	*Neosilurus hyrtlii*	*moderate*
flathead gudgeon	*Philypnodon grandiceps*	*moderate*
Rendahl's catfish	*Porochilus rendahli*	*low*
speckled goby	*Redigobius bikolanus*	*not observed*
Australian smelt	*Retropinna semoni*	*low*
freshwater catfish	*Tandanus tandanus*	*very high*

DI-4 Are fish that pass over the dam wall surviving

Two spillway overtopping events were experienced during the monitoring program. The first overtopping event began on 3rd March 2010 and peaked at 1.81 metres above the spillway on 5th March 2010. Spillway flows continued until 9th April 2010. The second overtopping event commenced on 20 September 2010 and ceased on 23rd September 2010. The spillway flow peaked on 22nd September 2010 at 0.61 metres above the spillway.

Quantitative monitoring activities conducted during and after the March 2010 overtopping event included setting drift nets downstream of the spillway, dip netting from a boat and electrofishing. Dip netting was also undertaken during and after the September 2010 overtopping event. In addition to these quantitative monitoring activities, visual observations were also collected throughout both the March and September 2010 overtopping events. During most days of the spillway flow event in March 2010, fish were collected downstream of the Paradise Dam wall by netting from a boat and by electrofishing. Fish observations and collection was concentrated in an area from the base of the spillway to approximately 1km downstream.

The nature of monitoring activities such as drift net sampling, dip netting and the collection of visual observations inherently focus on the collection of deceased and injured fish. As such, much of the data collected focuses on deceased and injured fish.

Drift net sampling was undertaken on 3rd and 12th March 2010. Occupational health and safety issues with working in flooded rivers and the large amount of debris collected in the nets meant the drift nets could only be utilised in the early portion of the overtopping flow events. As outlined in the methods section of this report, the drift nets are an open cone which allow fish that are healthy to exit freely. 81.9% of captured fish in the drift nets were deceased and 94.5% of fish captured had injuries such as abrasion, scaling and head damage. Whilst it is possible that there was some effect from the fish being in the drift nets injuries would be restricted to minor abrasions. The majority of fish collected had more serious injuries such as removal of eyes and decapitation which could not be associated with the drift nets.

Dip net sampling performed concurrently with the drift net samples during spillway overtopping events expanded the number of species that were found injured or deceased. Injuries of these fish were consistent with the injuries that were previously encountered in fish captured in the drift nets. Subsequent to the drift net samples, small bodied fish were not enumerated but *ad hoc* dip net samples on 3rd and 4th March 2010 indicated that juvenile bony herring, gudgeons, flyspecked hardyhead and olive perchlet were injured or killed after passing over the spillway.

Dip netting was undertaken on most days during the March 2010 and September 2010 overtopping events. Large bodied fish species that were observed floating on the surface of the water downstream of the dam or deposited on the river bank or trees above the water level were documented from the 3rd to the 24th March 2010. Observational records were collected over a period of 2-4 hours a day for 15 days during the period from 3rd to 24th March 2010. Table 12 summarises the number of deceased large bodied fish observed and/or collected downstream of the dam spillway during the March 2010 and September 2010 overtopping events, respectively. Figure 29 and Figure 30 outline the distribution of deceased fish collected below the Paradise Dam during and after the overtopping events in March and September 2010.

The most abundant fish species collected and/or observed during the March 2010 overtopping event were bony herring, long-finned eel, Queensland lungfish, freshwater catfish and fork-tailed catfish (Table 12). Deceased and injured bony herring and long-finned eel were observed on the first day overtopping occurred and on most days until after the overtopping flow had subsided. Queensland lungfish were not observed until the 10th March 2010, 5 days after the flow peak, although some of these fish had been deposited on the banks and in trees several metres above the tailwater level at the time. The data indicates that Queensland lungfish were being injured and killed during passage over the dam wall during high and low flows over the spillway.

Large bodied fish species were observed and collected deceased throughout the spillway overtopping event including during skimming and nappe flow regimes, with the highest numbers occurring soon after the peak of the flow period (Table 12). A number of injured and dying large bodied fish were collected in flowing water below the spillway during a skimming flow of approximately 1.3 metres over the spillway. As the water level below the dam receded, the number of deceased fish that were located increased and large fish such as lungfish were located several metres above the water level on the day.

Fish were wedged in and against trees in the area of the main flows. Floating deceased fish were found in backwater areas where the main jet of flow had been intercepted by a tree line. Whilst not providing a conclusive date of when these fish passed over the dam wall and became deceased. The data does indicate that they were deposited during higher flows with an elevated tailwater indicating that fish were also injured on high spillway flows.

No radio tagged fish were detected moving over the spillway during the March 2010 overtopping event however two radio-tagged lungfish were recaptured downstream of the dam in May 2010.

Two deceased lungfish and one deceased striped mullet collected below the dam during the March 2010 overtopping event were PIT tagged and had originated from the upstream reaches of the impoundment. None of these fish had previously been detected at the fishway entrances. Four lungfish captured during electrofishing below the dam had injuries consistent with those found on fish after passing over the dam spillway (Figure 26). Two of the lungfish had injuries with open bleeding wounds, none of the injured fish were detected at the fishway entrances.

Live fish not displaying any injuries were captured during electrofishing and drift net sampling downstream of the dam during and after the March 2010 and September 2010 overtopping events. However the majority of live fish identified directly below the dam were likely to be fish that have been attracted upstream by the flood flows. Conversely, injured and deceased fish are not likely to have moved up to the dam wall from downstream. It is likely that these were injured passing over the dam wall or through the outlet release structures.

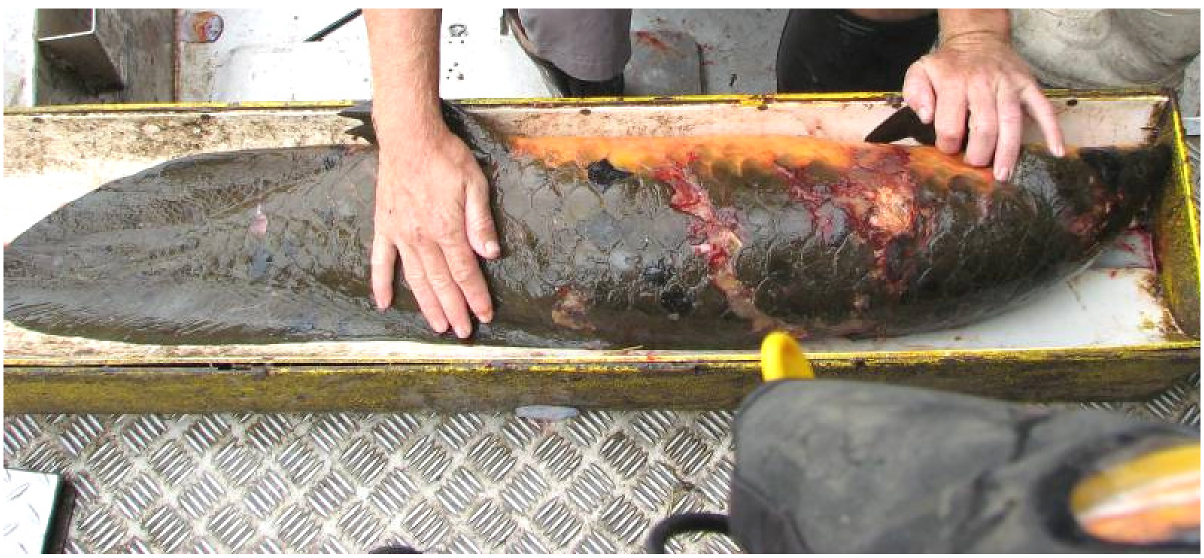
Live fish with injuries consistent with those observed in deceased fish were collected downstream of the dam during and after the overtopping event in March 2010 and within the upstream fishway in August and early September 2010 (Figure 25, Figure 26 and Figure 27). Table 12 details the species and numbers of fish collected during these times and the situation they were captured in.

A number of PIT tagged fish which originated from within the dam impoundment and not recorded using the downstream fishway were detected multiple times on PIT tag readers in the tailwater area. These fish are believed to have moved over the spillway during overtopping events. Details the species and numbers of PIT tagged fish detected in the tailwater during these conditions.

Large barramundi were captured downstream of the spillway for the first time during the monitoring program following the overtopping flows in March 2010. It is likely that these individuals had originated from upstream of the dam where they had previously been recorded.

Injuries did not always result in immediate mortality; a lungfish with partially healed injuries consistent with spillway passage was collected shortly after dying on the 15th April 2010.

Figure 25 Live barramundi captured downstream of Paradise Dam showing damage to body and



tail that is beginning to heal.

Figure 26 A living but severely injured Queensland lungfish that was captured downstream of the Paradise Dam spillway on 22nd March 2010.

Figure 27 Live Australian bass captured downstream of Paradise Dam showing damage to head, *N.B.* opercula cover was completely absent.

Table 12 Number and species of fish captured alive or detected below the dam during and after spillway overtopping flow events.

Time period	*barramundi*	*spangled perch*	*golden perch*	*Australian bass*	*Queensland lungfish*	*freshwater catfish*
Spilling to 2 weeks after, obvious injury	1	2	4		6	1
> 2 months after spilling, obvious injury	2		9	5	4	NR
Originated upstream, no obvious injury	3*	NR	NR	NR	2	NR
Originated upstream, PIT detections in tailwater	NR	1	6	1	2	1

* Fish assumed but not confirmed to have originated from upstream.

Table 13 Daily number of deceased large bodied fish species observed or collected downstream of the Paradise Dam spillway with spillway flow and condition during the March 2010 overtopping event.

Date	***Discharge (ML/day)***	***Depth over spillway (m)***	***Spillway flow condition***	*bony herring*	*long-finned eel*	*Queensland lungfish*	*Freshwater catfish*	*fork-tailed catfish*	*goldfish*	*striped mullet*	*golden perch*	*spangled perch*	*Hyrtl's tandan*	*barramundi*	*snub-nosed gar*	*banded grunter*	*Rendahl's catfish*	*Australian bass*
02/03/10	2,021	-0.06	below crest															
03/03/10	5,869	0.16	nappe and skimming	>100	7			1				3			2	3	1	
04/03/10	74,079	1.17	skimming	10	12		2		1	2		1		1				
05/03/10	115,557	1.76	skimming		1													
08/03/10	82,355	1.47	skimming					1										
10/03/10	48,166	1.06	skimming	17	10	4	3	5	6	1	1	2					1	1
11/03/10	32,212	0.81	skimming	>100	32	7	19	3	13	3	3	1	5	2				
12/03/10	18,391	0.57	nappe and skimming	40		4				1	2							
15/03/10	6,545	0.29	nappe	16	6	12	4	8		2	2			2				
16/03/10	5.011	0.24	nappe	15	5	1	4	2							1			
17/03/10	4,102	0.20	nappe		2	2				1								
19/03/10	1,996	0.14	nappe	10	2	2				1								
22/03/10	1,273	0.11	nappe	>100		4				1	1							
24/03/10	900	0.10	nappe	20	1													

In the early stage of the spillway flow period fish were observed and recorded on video passing over the spillway wall, striking the wall surface and being projected into the air before striking the wall again. The descent of fish such as long-finned eel could sometimes be followed and the fish retrieved, all long-finned eels retrieved in such a manner had obvious strike injuries and were deceased when collected.

Larger fish species such as lungfish, golden perch and barramundi exhibited localised injuries consistent with striking hard objects. Injuries were extensive and obvious and consisted of abrasions, descaling and head damage (example Figure 28).

Smaller species were also affected. Deceased bony herring and mullet were also collected shortly after passing over the Paradise Dam spillway on the 3rd and 4th of March 2010. All fish collected suffered scale removal and some also sustained head damage (photographs provided).

Figure 28 Deceased golden perch that was collected downstream of the Paradise Dam spillway on the 11th March 2010. Note the strike mark extending from the dorsal to the ventral area.

Deceased and injured fish were also collected downstream of the dam during and after the September 2010 spillway flow event. Figure and Figure 30 outline the distribution of deceased fish collected below the Paradise Dam after overtopping events. The total number of deceased large bodied fish collected or observed following both spillway overtopping events in March and September 2010 is presented in Table 14 below. The most abundant species to suffer mortality were bony herring, Queensland lungfish, long-finned eel, freshwater catfish and golden perch.

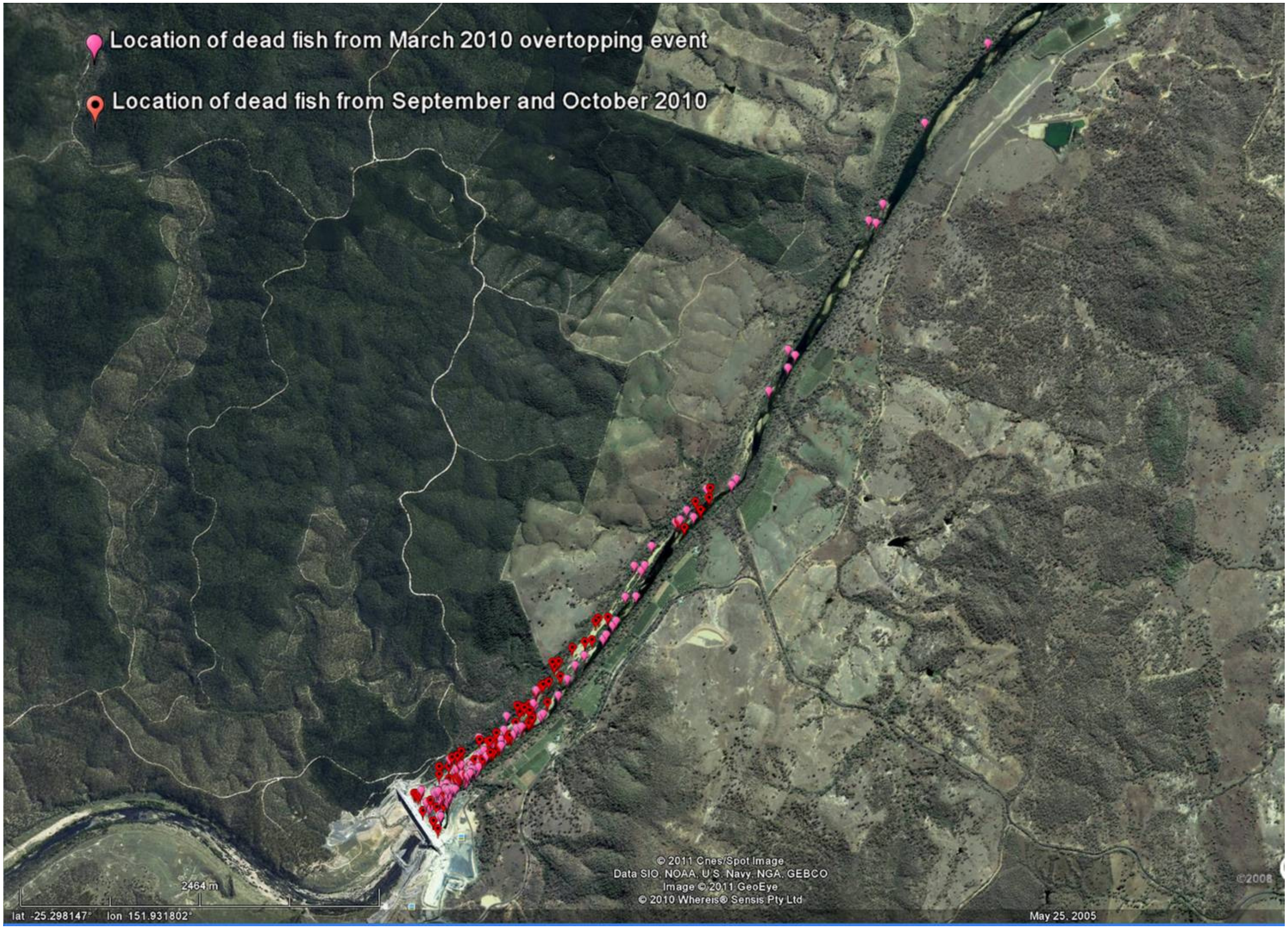


Figure 29 Location of deceased fish found below Paradise Dam in March, September and October 2010

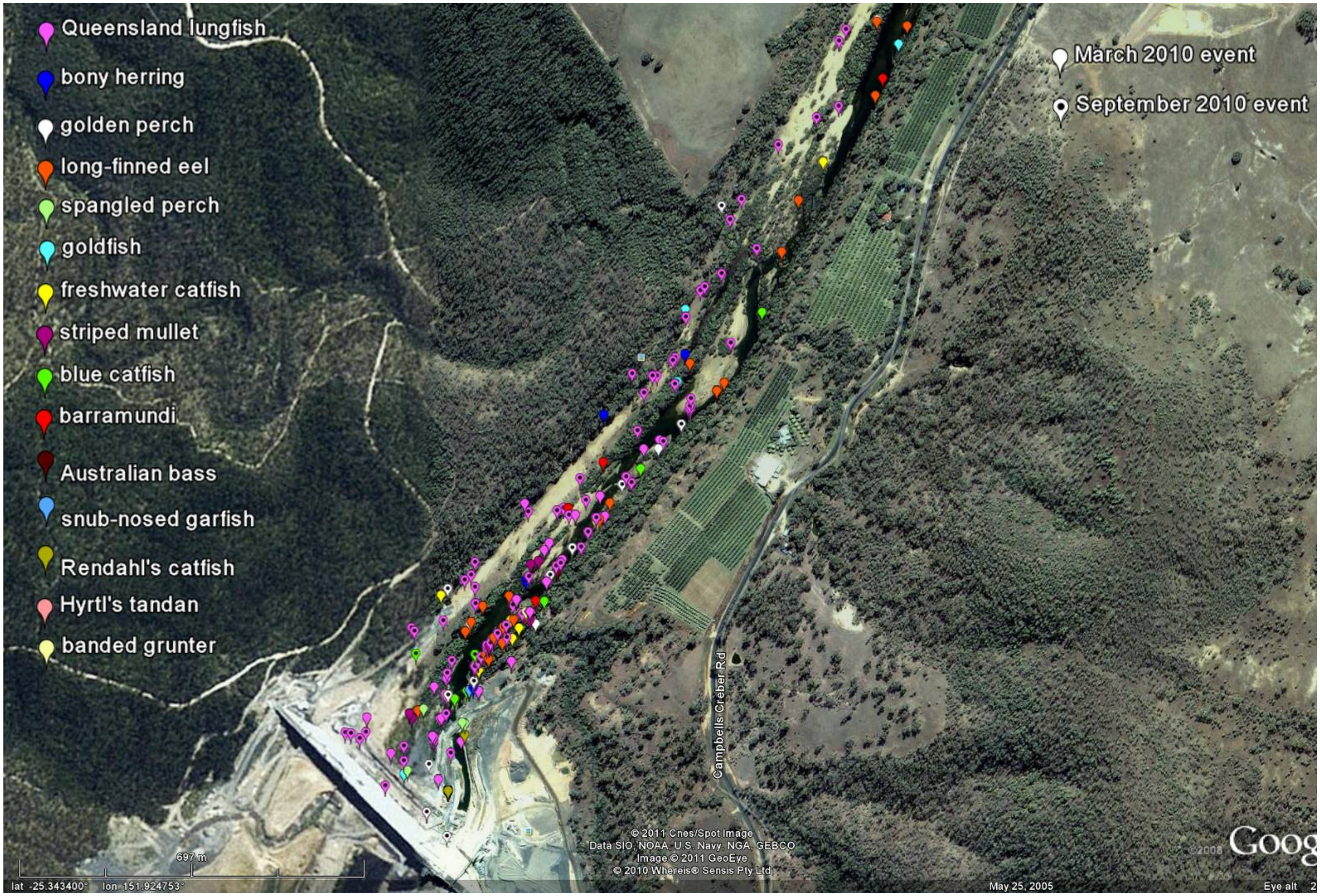


Figure 30 Species and locations of deceased fish found within 2 km of Paradise Dam in March, September and October 2010

Prior to the March and September overtopping events, releases from the environmental tower were made. During these releases deceased fish from eight large bodied species and several small bodied species were collected. Injuries to these fish were generally more severe than those observed in fish which had passed over the spillway.

Figure 31, Figure 32 and Figure 33 display the extent and severity of injuries sustained to a number of species collected deceased during and after environmental tower releases. The number of deceased large bodied fish recovered downstream of the dam during and immediately after these environmental tower outlet releases is detailed in Table 14.

Table 14 Total number of deceased large bodied fish collected or observed following spillway overtopping events and environmental tower releases in March and September 2010. (NR = not recorded).

Species name	Spillway mortalities (no. of days sampled=22)	Environmental tower mortalities (no. of days sampled=6)
bony herring	359	13
Queensland lungfish	152	13
long-finned eel	90	4
freshwater catfish	34	NR
golden perch	25	7
fork-tailed catfish	20	7
goldfish	16	NR
striped mullet	13	NR
spangled perch	7	1
barramundi	6	NR
Hyrtl's tandan	5	NR
Australian bass	2	NR
Rendahl's catfish	1	NR
snub-nosed garfish	1	1
banded grunter	2	3

Figure 31 A deceased Queensland lungfish displaying severe injuries collected after releases made through the environmental tower on the 15th September 2010.

Figure 32 A deceased long-finned eel with a broken spine collected after releases made through the environmental tower on the 15th September 2010.

Figure 33 Pieces of fish found directly at the release point of the environmental tower immediately after being shut down.

Fish injuries through dam intakes

Mortalities of small bodied fish were observed on a number of occasions during releases from the irrigation outlets. This was highlighted during trials conducted whilst sampling the upstream fishway in November 2010 when high numbers of injured and dead fish were repeatedly found in consecutive 5 minute samples of the hopper. These fish could only have originated from the attraction valves upstream of the hopper and upon further inspection large numbers of fish were also found wedged in the mesh on the outside of the hopper. The majority of fish were flathead gudgeons, with small numbers of fly-specked hardyheads, western carp gudgeons and small bony herring also recorded. The number of fish increased proportionally as the amount of attraction water was increased through the upstream fishway. High numbers of flathead gudgeons were sampled using the downstream fishway on the same day indicating a large abundance of this species in the impoundment. High numbers of this species was also recorded in the filter screens for the hydroelectric pipe work (A. Maughan pers. comm.). It is likely that these fish are being drawn through the fine screens of the main intake area and then into respective pipe work.

Conclusion

The intent of this section is to address the four key points of the monitoring framework using the data gained from the assessment components DA1 to DA-5 and investigative components DI-1 to DI-4. Due to overlap between the intent of the first two points of the monitoring framework discussion of these two points is combined below:

- **Determine whether the fish passage facilities are effective in achieving the design aims.**

The design process for the fishways at Paradise Dam incorporated consultation with DEEDI Fisheries Qld to develop a design that would satisfy the requirements of Section 116 of the Fisheries Act (1994). Objectives and conditions for the fishways were issued by Fisheries Qld in early 2004. The Burnett Dam Alliance issued a report titled Detail Design Report: Section 10 - Fishway June 2004 (BDA, 2004). The fishway scope and design specifications referred to in the Detail Design Report were compared to data collected in the current report.

- **Establish the constructed design is operating to specification.**

The design aims for the Paradise Dam upstream fishway relate to the objectives of the Waterway Barrier Works Approval mentioned in the introduction to the current report and repeated below:

1. the fishway shall operate over the entire range of headwater and tailwater levels;

Operation of the downstream fishway was delayed by an extended filling phase resulting in wet commissioning not occurring until some four years after the dam was completed. The fishlock could not physically be operated at a storage level 5.6 m below full supply level and was automatically shut down when levels exceeded 0.3 m over the spillway.

Once the fishway was able to be operated it did so for the majority of the time that water was released from the dam. Non-operational periods were due to mechanical failure or unsuitable exit conditions. The mechanical failures predominantly occurred early in the operation of the fishlock and may be considered part of the wet commissioning process. Unsuitable fishway exit conditions occurred when the environmental release tower was operated at discharges greater than 20 cumecs. At higher flow releases the water jet creates a highly turbulent zone in front of the fishlock exit which is likely to disorient and possibly injure fish that are released from the fish lock (Figure 34).

Figure 34 Fishlock exit conditions during an environmental outlet tower release of 40 cumecs. N.B. Fishlock exit chute is shown in the bottom right corner of the image.

Storage levels below EL 62.0 m provide no option for the downstream passage of fish at Paradise Dam. The current study has demonstrated that fish are moving downstream throughout the year and respond to even small inflows into the dam. No obvious evidence of peak migrations occurring at any particular time of the year was observed. It is recommended that where practical the Paradise Dam storage level should be maintained above EL 62.0 m and the downstream fishway operated.

The automatic shut-down of the fishlock at a spillway flow level of 0.3 m was designed into the operation of the fishlock under the assumption that most fish would pass over the spillway at levels greater than this. Data from the current report has confirmed that large numbers of fish ranging from small gudgeons to large long-finned eels move over the dam spillway immediately when it commenced overtopping. Larger fish such as striped mullet were observed aggregating at flows less than 0.3 m but did not appear to pass over the spillway until flows exceeded this level. It is recommended that the spillway flume entrance continue to operate up to EL 67.9 m. Fish that have moved downstream from further up in the catchment are likely to be attempting to migrate beyond the dam following the peak of the flow. Priority should be given to reinstating operation of the fishlock immediately after high flows when the spillway water level returns to EL 67.9 m.

Monitoring during spillway overtopping events was limited due to the rapid rise in impoundment levels and safety issues with using the exit chute net during high flow releases. Fish were identified utilising the fishlock during the March 2010 spillway overtopping event albeit in low numbers when compared to the number of fish passing over the spillway. It is recommended that the shut-down level of 0.3 m above full supply be retained. It is also recommended that the fishlock not be operated when releases greater than 20 cumecs are being made through the outlets.

2. ***the fishway shall facilitate the passage of all migratory fish and all size ranges in a safe manner during all times of the year;***

The current study indentified that the Paradise Dam downstream fishway provided passage for 21 of the 26 species of fish identified upstream of the dam. Most of the species that were abundant upstream of the dam successfully utilised the fishway and were well represented in fishlock captures. The downstream migration of relatively large numbers of neosilurid catfish such as Hyrtl's tandan and Rendahl's catfish indicated that these species were actively responding to inflows to the dam.

The absence of species such as striped mullet, Australian bass, barramundi and Queensland lungfish in the fishlock samples requires investigation. The current study has demonstrated that all four species were relatively abundant upstream of the dam wall, but have not been recorded using the fishlock. Whilst a small number of detections of PIT tagged Queensland lungfish, striped mullet and Australian bass has been recorded at the entrance to the fishlock, these fish have not been confirmed using the downstream fishlock.

The radio-telemetry studies indicate that inflows into the dam trigger significant downstream movements and activity of the three catadromous species tagged. All three catadromous species were recorded passing over the spillway wall in the March and September 2010 flow events. It is likely that these three species have a behavioural impediment to entering the Paradise Dam fishlock. Whether the impediment is due to the entrance design of the fishlock or the preference for these species to migrate downstream over barriers during higher flows is unknown.
Radio-tagged Queensland lungfish made downstream movements to the dam wall during inflow and no inflow periods and were present at the dam wall throughout the monitoring program. High numbers of Queensland lungfish were identified passing over the spillway wall in the March and September 2010 flow events.

A similar result to that seen in the current study was encountered in a study of downstream fish passage at the Ned Churchward Weir fishlock (Berghuis and Broadfoot 2004). Although two striped mullet utilised the fishway for downstream migration no Australian bass or Queensland lungfish migrated downstream through the fishlock despite being prevalent at the site. No barramundi were encountered at the Ned Churchward Weir but passage of the other three species over the spillway was confirmed.

Passage over the spillway wall is likely to be the major mode of passage for all downstream migrating fish species. In the study on the downstream migration of fish at the Ned Churchward weir, Berghuis and Broadfoot, 2004, found that passage over the spillway was also the major route of downstream migration. Catadromous species such as barramundi and Australian bass in particular rely on flood flows for downstream migration. The impetus for the downstream migration of Queensland lungfish remains unknown but whether volitional or not, large numbers of lungfish move downstream during flood flows. However, the recapture of two translocated radio tagged lungfish in their original capture location indicated that this species has a strong home ranging behaviour.

The size classes of most species were well represented in the samples of fish using the downstream fishlock. For this reason there does not seem to be any impediment for fish of different sizes within a particular species in entering and using the fishway.

The safety and condition of fish using the Paradise Dam downstream fishway is reliant on maintaining suitable hydraulic conditions. Water velocities and turbulence in the fishlock chamber during the attraction phase were only considered acceptable for fish at a headloss of 900 mm between the dam storage level and the water in the fishlock chamber and 300 mm depth across the entrance slot. At these operational levels attraction times greater than 60 minutes increased the risk that small fish would become fatigued and injured. For this reason it is recommended that the fishway attraction time not be greater than 60 minutes. A two minute flushing period with valve V103 set at 10% opening is recommended to ensure fish have exited the pipe.

Data from the current study has demonstrated that fish migrate downstream through the fishway during a range of flow conditions with some species migrating in high numbers during inflows and other species during no inflows. Data also indicates that fish activity adjacent to the fishway increased when there were inflows to the dam and the impoundment level rose. Monitoring of the fishway immediately after spillway flow events demonstrated that fish continued to utilise the fishway during this time. It is recommended that the downstream fishway be operated during all periods when flow is being released from the dam. However operation should currently be limited to outlet release flows less than 20 cumecs. Operation during inflows into the dam ought be specifically provided regardless of release flow requirements downstream.

3. ***conditions at the fishway entrances (both upstream and downstream) should be such that all fish seeking to migrate are attracted to the entrances;***

The results of the current study demonstrate that fish utilised both the quadleaf gate entrance and the spillway flume entrance. The data from the PIT tag detections indicates that more fish are detected at the quad-leaf gate entrance regardless of whether there is an attraction flow. The hydroacoustic data also indicates substantial fish activity in front of the quad-leaf gate entrance.

Releases from the irrigation outlets are likely to improve the attraction of fish to the quad-leaf gate entrance during non-spillway overtopping periods. However the current study collected evidence that small fish are passing through the 20mm aperture irrigation screens and being injured and killed through the pipe work. Operation of the downstream fishlock during all flow releases would reduce the proportion of fish that pass through the irrigation release screens. Improvements to the screening of these intakes would reduce the risk of fish being injured and killed during operation of the irrigation outlets. Finer screens such as wedge wire screens and/or louvered screens may help to mitigate these effects.

The intent of the spillway flume entrance was that fish that were attracted to the spillway during low spillway flows would be able to enter the fishway. Observations of the attraction flow into the spillway flume during overtopping flows indicate that proportionally the fishway attraction flow is diminutive compared to the volume of water passing over the spillway. Fish were identified using the spillway flume entrance during the overtopping flow on the 3rd March 2010. However all of the fish that utilised the fishlock during this period were small bodied fish that were also observed drifting with the flow and passing over the spillway in very high numbers. It is likely that the fish that were using the fishlock during the March 2010 spillway flow did not do so volitionally. Investigations should be undertaken to determine if both entrances can be operated simultaneously. This would provide greater opportunity for fish to migrate downstream using the fishlock during overtopping events.

4. ***fishway operations and works should be constructed so as to maximise attraction, capture and transfer of fish;***

In the Detail Design Report: Section 10, (BDA, 2004) the specified operational range of the quad-leaf gate entrance was from EL 62.0 m to EL 67.6 m and the spillway flume entrance from EL 67.6 m to EL 67.9 m. During the monitoring program the actual operation of the spillway flume entrance was from EL 67.0 m; 600mm below full supply, up to EL 67.9 m. Following the March 2010 spillway flow event the water level did not drop below EL 67.0 m and resulted in the quad leaf gate entrance not being operational. During non-spillway flows the major attraction flow is from the irrigation outlets. It is recommended that the operational settings be altered to allow the quad-leaf gate entrance to operate up to the full supply level of EL 67.6 m and the spillway flume entrance from EL 67.6 m to EL 67.9 m.

Although hydraulic conditions within the fishlock chamber were considered acceptable when there was the minimum of 300 mm depth of water across the entrance slot and a headloss of 900 mm, variation to these settings are limited. The main reason for these limitations is due to the size of the fishlock chamber. The chamber was designed at 2.5 m x 2.6 m in size and although was considered suitable for the largest fish species, Queensland lungfish, the design did not account for the dissipation of fluid energy at the design flow rate. At the design depth of water across the entrance slot of 1000 mm (Burnett Dam Alliance, 2004), the energy in the volume of water entering the fishlock is extremely high and not dissipated adequately. This has constricted and limited flexibility in the operation the fishlock.

5. ***the spillway design and operation of the dam shall be such as to minimise the adverse impact on the state of health of fish moving downstream.'***

The intent of the radio-telemetry study undertaken in the current study was to assess the flow triggers for migration and survival of large bodied fish that pass over the Paradise Dam spillway. In order to expect normal behaviour from the radio-tagged fish it was necessary to release them into the dam impoundment well ahead of spillway flows. The radio-tags used in the current study had an approximate battery life of three years and the tags were implanted in the first and second years of the study. Unfortunately the Paradise Dam did not spill until four years after the dam was completed by which time it is likely the majority of radio tags had expired. No radio-tagged fish were detected passing over the spillway during the March or September 2010 spillway flow events. Data from the radio-telemetry study did provide useful information on the movements of catadromous fish and Queensland lungfish and this data has been utilised in other facets of the current report.

Data from the drift nets placed downstream of the dam provided information on fish movement and survivorship over the Paradise Dam spillway. Occupational health and safety issues with working in flooded rivers and the large amount of debris collected in the nets meant the drift nets could only be utilised in the early portion of the overtopping flow events.

The drift nets provided quantitative data on some of the fish that passed over the spillway. The number of fish estimated to be passing over the dam wall when the drift nets were deployed on the 3rd of March 2010 was 60.8±30.31 fish per minute. The mortality rate of fish captured in the drift nets was estimated to be 81.9% and the injury rate was 94.5%. Whilst it is possible that there was some effect from the fish being in the drift nets, the majority of fish had severe injuries such as removal of eyes and decapitation which could not be associated with the nets. Dip net sampling performed concurrently with the drift net samples during spillway overtopping events expanded the number of species that were found injured or deceased. Injuries of these fish were consistent with those encountered in fish captured in the drift nets. The same dip nets were used for routine fish community surveys and no injuries or mortalities have been recorded when using these nets.

A document produced during the design phase of the Paradise Dam by the Burnett Dam Alliance titled “Design Operation and Management of the Burnett Dam Fishway” (BDA, 2004a) detailed the potential issues and management of the stepped spillway for fish passage. The greatest risk to fish survivorship over the spillway was considered to be during low flows over the spillway steps which produced a non-skimming or nappe flow. The concern was that fish may strike the steps during a nappe flow condition and be injured. The transition to a laminar or skimming flow was considered to occur at higher flows equivalent to 0.54m above the spillway crest. Skimming flows were predicted to be less injurious to fish as the chance of fish contacting the steps was reduced at higher flows.

Flow data from the March 2010 flow event demonstrated that the levels predicted for the transition for nappe to skimming flow occurred very rapidly. At 10 am on the 3rd March the flow was 0.17 m over the spillway and by 5:00pm had risen to 0.35 m, peaking at 0.78 m over the spillway at the end of the day. Injured and deceased fish were observed and collected throughout the day when the flow over the spillway steps was predicted to be nappe. The water level over the spillway was above 0.54 m from 8:43 pm on the 3rd March until the 12th of March 2010. Visual observations of the flow over the spillway during this period established that the flow appeared to be impacting a number of steps even at flows greater than 1 m over the spillway (Figure 35). Collection of injured and deceased fish that had passed over the dam wall during high flow periods indicated that either the skimming flows did not occur as predicted in the Design Operation and Management of the Burnett Dam Fishway document (BDA, 2004a) or fish are still injured and killed during skimming flows over the stepped spillway.

The types of injuries recorded on larger fish such as Queensland lungfish, striped mullet and golden perch were severe. Many of the injured and deceased fish collected exhibited defined lines of injury across their bodies as shown in Figure 28. It is apparent that these injuries are associated with striking a sharp edged surface and is highly possible that they were caused by the spillway steps.

Minor fish kills associated with spillway flows have occurred at other sites in the Burnett River but not to the extent observed at Paradise Dam in March and September 2010. At Ned Churchward Weir following a flow event in February 2003, dead fish consisting mostly of bony herring and blue catfish, with some striped mullet and long-finned eel, were observed by the authors for a short distance downstream of the weir. All of the fish observed did not display the above mentioned defined lines of injury seen at Paradise Dam. No deceased Queensland lungfish or barramundi were observed following the February 2003 flow event or at any other spillway flow event observed by the authors.

Figure 35 Flows over Paradise Dam at 10 am on the 10th March 2010 at approximately 1.03 m above full supply.

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Large bodied fish species that were injured or deceased were mainly collected when observed floating on the water surface or stranded on the bank or in riparian vegetation. The fish collected and observed downstream of the Paradise Dam spillway following the flow events in March and September 2010 would have been only a small proportion of the actual number of dead and injured fish.

Underestimation of fish kills is well documented (Southwick and Loftus, 2003) and the counts of dead fish very seldom represent more than a modest fraction of the fish killed. Most of the sampling effort to collect fish centred on the area from directly downstream of the spillway to approximately 1 km downstream. However on occasions the search was extended as far downstream as 10 km and dead and injured fish were still encountered, indicating fish were being carried further downstream in the main flow. Southwick and Loftus, 2003, outline a number of factors which contribute to the underestimation of the number of fish killed including whether the dead fish are floating or sinking, hidden by debris, taken by predators or scavengers, have decomposed, or have simply been overlooked. The above factors would have applied to the enumeration of dead fish below the Paradise Dam and would have been further compounded by fish counts conducted over multiple days.

The “Design Operation and Management of the Burnett Dam Fishway” document (BDA, 2004a) detailed some operational measures to reduce the period that nappe flows would occur over the spillway. Releases of large volumes of water through the environmental flow tower were suggested as a possible method to mitigate low level spillway flows that could potentially injure fish. As found in the current study fish that pass through the environmental flow tower were injured and killed. Large eels, golden perch, spangled perch, bony herring, blue catfish, banded grunter, snub-nosed garfish and Queensland lungfish have passed through the tower and been injured and killed indicating that the coarse screens provided on the tower intake do not currently preclude the entry of large fish.

As indicated in the current study, inflows into the dam impoundment attract fish downstream to the dam wall and large numbers of fish drift with the downstream flow. The operation of the environmental flow release tower on a rising hydrograph is therefore likely to incur large mortalities. It is recommended that operation of the environmental release tower be suspended or minimised to prevent fish deaths. It is further recommended that the practicalities of screening the environmental tower intake should be investigated.

Fish mortalities are occurring during all flows over the Paradise Dam stepped spillway regardless of the flow condition. Two spillway overtopping events occurred in 2010 and it is likely that the Paradise Dam is likely to spill more frequently now it is full. The cumulative affect of mortalities of fish passing over the spillway is likely to have a major impact on populations of fish over the longer term. In countries where large dams are used to generate hydropower, downstream migrating fish are bypassed around the hydropower intakes (Schilt, 2006). The bypassing of downstream migrating fish at the Paradise Dam may also provide a solution to the current issues of fish injury and mortality through the environmental release tower and over the stepped spillway.

Recommendations for the optimisation of operations and or design over time.

Data collected and analysed from the downstream fishway monitoring program established that the operation and/or design of the fishway might be optimised and improved. The following points outline the recommended improvements:

1. Where practical the Paradise Dam storage level should be maintained above EL 62.0 m to ensure that the downstream fishway can be operated during inflow periods where the dam does not overtop. (Refer DA-2 pp 48-50)

2. Investigations should be undertaken to determine if both fishlock entrances can be operated simultaneously. This would provide greater opportunity for downstream migrating fish to access the fishway. (Refer DA-2 pp 48-50)

3. The spillway flume entrance should continue to operate up to EL 67.9 m (with a shut-down level of 0.3 m above full supply). Access to the fishway during this time will provide safe downstream passage for a proportion of fish. (Refer DA-2 pp 48-50)

4. It is recommended that the operational settings should be altered to allow the quad-leaf gate entrance to operate up to the full supply level of EL 67.6 m and the spillway flume entrance from EL 67.6 m to EL 67.9 m. (Refer DA-2 pp 48-50)

5. Priority should be given to immediately reinstating fishlock operation when the spillway water level returns to EL 67.9 m to provide an alternative route of passage. (Refer DI-3 pp 52-55)

6. Extremely turbulent and high velocities occurred at flow releases greater than 20 cumecs through the environmental flow release outlet. It is recommended that the fishlock should not be operated when releases greater than 20 cumecs through the environmental flow release outlet are being made. (Refer DA-2 pp 48-50)

7. The fishway should only be operated with a 300 mm water depth across the quad leaf gate entrance slot and a 900 mm headloss between the fishlock chamber and impoundment water level. (Refer DA-3 pg 51)

8. Data showed that small fish species were at more risk the longer they were within the fishlock chamber. Accordingly, it is recommended that the fishway be operated with a maximum attraction time of 60 minutes per cycle at all times. (Refer DA-4 pg 52)

9. Flows entering the fishlock chamber during the attraction phase impacted upon the quad leaf gate control cable equipment. This may pose a risk to fish being injured as they enter the fishlock chamber. Accordingly it is recommended that the cabling system should be relocated or modified to address this if it is feasible to do so. (Refer DI-2 pg 53)

10. Observations of fish exiting the fishway during the flushing period, determined that a two minute sluice flushing period with valve V103 set at 10% opening was appropriate at all times the downstream fishway is operating. (Refer DI-1 pg 52)

11. Fish mortalities were identified downstream of the dam following the operation of the environmental flow release outlet. Accordingly it is recommended that the operation of the environmental flow release outlet be suspended or minimised to prevent fish mortality. (Refer DI-4 pp 55-69)

12. It is recommended that the feasibility of fine screening or bypassing the environmental flow release intake tower be investigated and appropriate modifications be implemented to ensure that fish are not entrained and injured during operation of the environmental flow release outlet. (Refer DI-4 pp 55-69)

13. Mortalities were observed in small bodied fish species when they were entrained on the back wall of the upstream hopper and within the fine filter of the hydropower/irrigation intake pipe on a number of occasions. This appears to be the case whichever pipework the fish are drawn in through. It is recommended that finer screens be used at the hydropower/irrigation intakes to prevent entrainment of small bodied fish species. (Refer DI-4 pp 55-69)

14. High numbers of fish mortalities were recorded as a result of downstream passage over the spillway. Accordingly it is recommended that an investigation be undertaken to determine options that might prevent, or minimise, such mortalities over the spillway with a view to implementation of such solutions. Potential considerations may include, but should not be limited to, screening, bypassing or modifying the spillway. (Refer DI-4 pp 55-69)

15. The plastic coated lining on the downstream exit chute pipe showed evidence of deterioration during the course of the monitoring program. This lead to fish being exposed to relatively sharp edges of plastic as they were sluiced down along the exit chute pipe. Whist repairs have been undertaken throughout the monitoring program, it is recommended that the lining of the exit chute pipe be re-surfaced and maintained as a smooth surface to reduce the risk of injuries as fish exit the fishway. (Refer Paradise Dam Downstream Fishway Monitoring Program Quarterly Report – March 2009)

Provide information that may be of use in the mitigation of the impacts of future water infrastructure developments.

In addition to the improvements listed above, the following points summarise improvements to mitigate future infrastructure developments.

- High numbers of fish from a wide range of species were recorded being injured and killed as they moved over the stepped spillway. The data demonstrated that the majority of downstream migration occurred during overtopping flows and highlights the importance of providing safe passage over spillways for the whole fish community.

  During the monitoring program a number of other risks to fish injury and deaths were also identified. This included the spillway apron area on the left bank and the raised dissipater wall downstream of the main spillway. Fish moved at relatively high velocities as they moved down the dam spillway. During nappe flows, fish were observed hitting and bouncing off multiple steps down the spillway face. During skimming flows fish were collected directly below the dam spillway with injuries consisted with striking hard surfaces. For these reasons, stepped spillways and hard surfaces which have the potential for fish strike at high velocities, should be avoided.

- Fish, particularly small bodied fish species, were recorded dead on the back wall of the upstream hopper on a number of occasions and within the fine filter of the hydropower intake screens. The current 20 mm screens on the irrigation release intake do not prevent fish from being entrained into the pipe work of the dam. A range of fish species including large bodied species were also recorded being entrained into the environmental flow release intake tower and were subsequently killed. The current 400 mm screens on this intake is inadequate to prevent this from occurring, and for this reason finer screen arrangements at all intakes should be utilised at future water infrastructure developments.

- At the design settings, flow patterns and hydraulics within the fishlock chamber during the attraction phase were found to be unsuitable for fish, particularly small bodied species. Even when operating the fishway with a 300 mm water depth across the quad leaf gate entrance slot and a 900 mm headloss between the fishlock chamber and impoundment water level, conditions were unfavourable for small bodied fish species. For this reason, the fishlock chamber for dedicated downstream fishlocks needs to be large enough to dissipate the energy with the required attraction flow. The chamber must also have resting areas of relatively still water for poor swimming and small bodied species. This would allow greater flexibility in the amount of attraction time that the fishway can be operated and reduce the risk of fish injury.

- The size of the entrance to the fishlock chamber is relatively small compared to the overall dam wall. Although physically suitable for fish species, the attraction and behaviour of fish to find and enter the fishlock chamber may be inadequate. For this reason alternative attraction water and/or entrance sizes should be investigated at future water infrastructure.

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Appendix A

Burnett River Dam Downstream Fish Passage Monitoring Program June 2005

BD1. Background

Burnett Water is constructing of a new dam located at 131.2 km AMTD on the Burnett River. The Burnett River Dam was issued with a Waterway Barrier Works Approvals and associated Fishway Directives under the *Fisheries Act 1994*. The Fishway Directives required that adequate provision was made to provide fish passage past the structures in the form of a fishway. The final fishway design was developed through a highly successful consultative process between the Dam Owner and the Department of Primary Industries and Fisheries (DPI&F). The fishway designs have been developed to meet the objectives of the *Fisheries Act 1994* approvals relating to fish passage.

Under the conditions of the *Fisheries Act 1994* approvals, a monitoring program that determines the effectiveness of the fishways is required. A Monitoring Framework has been developed for the Burnett River Dam. The monitoring framework identified that the following is required to be addressed:

- Establish the constructed design is operating to specification.
- Determine whether the fish passage facilities are effective in achieving the design aims.
- Provide data for the optimisation of operations and/or design over time.
- Provide information that may be of use in the mitigation of the impacts of future water infrastructure developments.

A fishway management plan for the Burnett River Dam is yet to be completed however it is required under the Waterway Barrier Works Approval and must provide specific links to a program of monitoring and Continuous Improvement.

BD2. Scope

This monitoring proposal has been developed using similar aims and requirements set out in the Eidsvold Weir Monitoring Plan and as such, to address the monitoring requirements under the conditions of the Waterway Barrier Works Approvals.

The monitoring proposal sets out the key assessment and investigation components that have already been identified to the Dam Owner by DPI&F. These are based on design and operational issues that could not be resolved ex-situ as well as the 'standard' fishway assessment components. As in the Eidsvold Weir monitoring plan this proposal has identified monitoring components as core (assessment) or non-core (investigative).

The Burnett River Dam downstream fishlock will be the first dedicated downstream fish passage facility over a high dam in Australia and the first use of this type of fish transfer technology in Australia. Subsequently to determine the success of the fishway it is important that both core and non-core components be fully investigated from the outset of the monitoring program. Although the Burnett River Dam has a dedicated downstream fishway it is envisaged that large numbers of fish will be swept over the spillway wall. As a result operating rules that limit the number of non-skimming spillway flows will be used to reduce the impacts of the stepped spillway. In order to quantify the impact on fish that pass over the spillway a separate monitoring component will be required.

Costings for all components are included in this proposal. It is possible that additional non-core components will be developed following the results of monitoring and costs will represent a variation in the monitoring plan contract.

The question of long-term effectiveness of fish passage provision is fundamental; the proposed monitoring methodologies recognise this. Furthermore, conditions relevant to fish at the dam are likely to remain in flux beyond the scope of the initial monitoring program. The proposed monitoring program will establish a PIT tagged fish population that can also be monitored remotely beyond the initial five years.

The more intensive fishway trapping and downstream electrofishing-based sampling will be concentrated in the first three years of monitoring. The fourth and fifth years will concentrate on monitoring that is tied to flow events and also on more detailed investigations of emerging patterns or issues identified in the initial investigations and seasonality of fish migration. Additional monitoring considered necessary beyond the five year time frame will require a variation in the contract.

An assessment of the impact of the new water infrastructure on fish communities of the Burnett River has not been included in this monitoring program. However, a requirement to monitor lungfish populations within the lower Burnett has been placed upon Burnett Water. Expansion of the methodologies to assess the entire freshwater fish community in combination with the methodologies to be utilised in this monitoring program may achieve this with little additional cost.

BD3. Costing

The total cost of the Burnett River downstream fish passage monitoring program is **$440,000 (excluding GST) over five years**. Details of the costs are provided in Table i below.

Because of the long-term nature of the study, the unpredictability of flows and peak sampling periods, the budget for the program has been based on salaries, operating and equipment costs rather than on a daily rate.

While the anticipated cost of equipment construction, maintenance, repair and replacement has been factored in to the budget, DPI&F will provide the electrofishing boat and nets as well as the hydroacoustic equipment at no additional cost. These items represent would represent a considerable capital outlay for the project if they were to be purchased by the Dam Owner or another party. Electrofishing boats operated and endorsed under the Australian Code of Electrofishing Practice are not available outside government organisations, with one exception based in Western Australia.

The hydroacoustic equipment that DPI&F proposes to use is also not being used for this application elsewhere in Australia, however it is used and endorsed overseas for fish movement monitoring.

Salaries for the dedicated monitoring team are included in the costing, however all employment costs relating to Andrew Berghuis, the Program Supervisor will also be met by DPI&F (refer Section 5.6.1 for details of experience). Andrew will oversee all the fishway monitoring, data handling and reporting. He will also assist in the field where an additional person or qualified electrofisher/boat driver is required or where particular technical skills with hydroacoustics and other remote monitoring equipment is necessary.

The Monitoring Team will be based at the DPI&F offices in Bundaberg which also has facilities for vehicle, boat and net storage and workshop facilities for modification, construction and/ or maintenance of nets and other equipment. By locating the team within one hours drive of the Burnett River Dam, overnight accommodation and travel costs will be minimised and there is the distinct advantage of a quick response time to flow events

	Years 1 to 3	**Years 4 and 5**
		PO3, TO2 salaries and 50% previous operating
Salaries	$166,173	$47,113
Operating (car, office, accommodation etc)	$28,802	$10,385
Electrofisher and nets maintenance/repair/modification	$13,937	$5,025
Hydroacoustic equipment maintenance/repair/modification	$13,937	$5,025
PIT tags and materials	$23,228	$8,375
Radiotags and implanting (Yr1)	$120,000	
Period Total (inc. CPI @ 3.2%)	**$366,076**	**$73,924**
	5 Year Total	**$440,000**

Table bd(i). Costings for Monitoring the Burnett River Dam Upstream Fishway

BD3.1 Cost estimates for contract variation

Variations in the monitoring program are likely to comprise the additional investigative components not identified in this fishway monitoring program (i.e. investigative requirements based on findings of core monitoring). Where these investigative components can be fitted in to the work program during the first three years of the monitoring when the full team is operational the only additional costs would be the cost of additional materials and equipment for these tasks, and any additional operating costs (eg fuel, accommodation etc).

If the investigative components are undertaken in the fourth or fifth years and a third team member is required then the cost of that salary (PO1=$46,700 per annum including on-costs) for the period of the monitoring and associated analysis, report writing etc would also be included in the variation cost. It is anticipated that most of the investigative components agreed to by the Dam Owner will be addressed in the fourth or fifth years.

If work under a variation is required beyond the fifth year of the program, depending on how long the monitoring is likely to extend, this can be charged at a daily rate or an annual rate. The daily rate will be based on the DPI&F non-statutory fees for Fishway Evaluations. While the 2005/2006 rate is included in the table below, allowances should be made for increases with CPI.

Fishway evaluations	**Daily Rate (GST exclusive)**
Boat Electrofishing	$1810.70
Fishway sampling	$1168.19
Report Write up	$817.72

Table bd(ii). Daily Rate Costings for Fishway Monitoring as at July 2005

BD4. FISHWAY DESIGN

The fishway design for the Burnett River Dam is considered innovative however it is yet to be proven in situ. Importantly both these fishways also caters for the whole fish community at the site, including very large bodied fish, such as the listed Queensland lungfish, down to very small and juvenile fish. This holistic approach to sustaining fish communities is in contrast to targeting designs to facilitate the movement of one or two commercial species, as practised in the USA and Europe and illustrates the Queensland government commitment to ecologically sustainable development.

BD4.1 Burnett River Dam Downstream Fishway

A separate downstream fishway has been constructed that is a combination of a fishlock for the top 9 m which empties into a 22 m long sluice pipe that terminates in the upstream fishway approach channel. Fish are attracted into the fishlock by maintaining the chamber water level just below the impoundment water level.

This structure is the first dedicated downstream fishway constructed in Australia. The major challenge in developing the design was to attract fish away from the spillway. A flume to attract fish away from the spillway and into the fishlock has been developed. While there were some physical modifications to the spillway to channel fish towards the fishlock and agreed operating rules to delay spillage over the spillway, the degree of attraction needs to be confirmed. The use of a 22 m length sluice pipe in the lower part of the fishlock is also a first in Australia. The safe delivery of fish into the channel at the foot of the dam also needs to be confirmed.

The requirement to minimise the adverse impact of the spillway design on fish moving downstream was complicated by the lack of comparable examples worldwide that could have definitively informed the best spillway design for fish. Operating rules that limit the number of non-skimming spillway flows will be used to reduce the impacts of the stepped spillway. It was recognised in the Monitoring Framework that the efficacy of this approach needs to be confirmed. This is a vital piece of information, both for the safe passage of fish at the Burnett River Dam and for any future stepped spillways in sub-tropical and tropical conditions, with such fluctuating tailwater conditions.

The complete standard and investigative monitoring requirements for downstream and spillway fish passage at the Burnett River Dam are detailed below.

BD5. MONITORING

BD5.1 Fishway commissioning

Prior to commencement of operation, the fishway will be wet commissioned to establish that the design complies with the requirements set out in the functional specifications. In particular it will be necessary for the Dam Owner to check that the following are suitable:

- Physical dimensions, including water depths;
- Operation of gates;
- Operation of diffusers in lock chamber (including visual check of turbulence and flow patterns);
- Filling times of lock;
- PLC programming;
- Measurement of water velocities at entrance;
- Measurement of water velocities at exit; and
- Operation of trapping facilities.

In order to establish the suitable settings for the initial operation of the fishways it is important that DPI&F are involved in these wet commissioning tests. Following the wet commissioning, and using the results from the fishway monitoring program, it is likely to be necessary to alter the operational settings on fishway to suit storage levels. Within the monitoring program DPI&F will visually inspect conditions in the fishway on a regular basis so as to establish whether suitable conditions are being maintained. The co-operation of the weir/Dam Operator will be required so that settings can be changed at short notice and re-assessed. Reports to the relevant operating committee for the dam and fishway, i.e. the Burnett River Dam Operating Committee (BRDOC)[1] will detail observations and recommended changes that will assist in the optimisation of the fishway.

[1] BRDOC is yet to be established.

BD5.2 Outcomes of monitoring

The Burnett River Dam Downstream Fish Passage Monitoring Program has been designed taking into consideration the requirements under the Waterway Barrier Works Approval. Thus the monitoring will evaluate the effectiveness of the fishway in facilitating the passage of all fish at all times of the year. It will also assess the conditions at the fishway entrances to evaluate whether these are maximising attraction of fish to the fishway as well as maximising capture and transfer of fish.

The monitoring will not only evaluate the fishway in these terms but will identify where the fishway is sub-optimal. One of the most important outcomes of the monitoring will be the use of the data to suggest to the Dam Operator ways in which the fishway and dam operation can be optimised in order to fulfil the design objectives. Where possible and appropriate, immediate feedback can be given to the Dam Operator on these issues.

Additionally this information and findings on sub-optimal design components can be utilised by the Dam Owner to inform the Continuous Improvement Program required under the Approval. Feedback will be used to determine what the priority actions are under this program and also what solutions there may be to optimisation issues.

Frequent reporting will mean that issues associated with the fishway and fish passage can be identified and relayed without delay. Quarterly reports will be provided to the BRDOC. Annual reports following completion of field work will also be provided to the Dam Owner. At the completion of the monitoring program a final report will be provided to the Dam Owner. This will include a document setting out the most effective operation of the weir and the fishway in order to maximise fish passage. It is anticipated that this document will be for the use of the Dam Operator.

Importantly, information and outcomes from this monitoring program can be used to further improve future fishway designs, and in particular downstream passage fishways in Queensland and elsewhere in Australia.

Summary of outcomes

- Results from the monitoring of design outcomes relating to the monitoring conditions under the Waterway Barrier Works Approval
- Provide options for optimising the operation of the Dam and fishway to facilitate fish passage
- Provide data to inform the Continuous Improvement Program and enable prioritisation of actions under this program
- Provide ongoing feedback to the Dam Operator on the operation of the fishway
- Quarterly reports to BRDOC
- Annual reports to Dam Owner

- Final report to Dam Owner at the conclusion of the monitoring program that includes optimal operation guidelines for the weir and fishway to maximise fish passage

- Body of work to inform future fishway designs in the Burnett and in particular, downstream fish passage designs.

BD5.3 Duration of the Monitoring Program

The funding requirements for monitoring in this proposal extend over a five year period. Although both core and non-core monitoring will be undertaken from the outset of the program, it is proposed that the bulk of the core monitoring would be completed in the first three years of the program. The remainder of the monitoring work plus additional non-core monitoring will be undertaken in the following two years. Timing and in particular the completion of the monitoring would depend on when the full recommended range of flows were experienced at the site. In line with the Eidsvold Weir Fish Passage Monitoring Plan this program will include a sunset clause of five years on the core monitoring regardless of flow conditions experienced during that period.

The commencement of monitoring at the Burnett River Dam fishway would be delayed until the dam has filled sufficiently that the upstream fishway is operational. However in this proposal it is assumed that this will happen within the first 12 months of the dam being closed and as predicted in the Burnett Water modelling. Prior to the dam filling, the initial effort will focus on the establishment of a PIT tagged population of fish and testing of the hydroacoustic system. Fishway monitoring will most likely commence during summer 2005/2006.

Monitoring work at the Burnett River Dam is likely to overlap with that proposed for the Eidsvold Weir and the team will be working at both sites in the same years. It is unlikely that assessment of the long-term effectiveness of the fishways will be completed within a five year period. This has informed the choice of monitoring methodologies and justifies the investment in capital items such as PIT technology. A significant proportion of the effort throughout the five years of this monitoring plan will be spent on tagging a broad cross section of fish species and size classes to enable these fish to be monitored using remote readers. The behaviour of these fish in relation to passage, particularly downstream passage can then be followed over several years and during many flow conditions.

BD5.4 Methodologies

In order to undertake a rigorous monitoring plan that will achieve the aims detailed above a range of assessment methodologies will be necessary. The following is a list of methodologies to be used.

BD5.4.1 Direct fishway sampling

Trapping of fish entering and exiting fishways has the main method of determining whether a fishway is effective or not. The disadvantage of this method is that it is a capture dependent methodology. Furthermore it does not give any indication whether fish attempting to migrate are able to find the entrances or of delays in locating entrance and behavioural impediments. At the Burnett River Dam floating traps will be used to assess the condition and behaviour of fish as they are released from the fishways. Floating traps will be constructed by the DPI&F.

BD5.4.2 Fish aggregation monitoring

Boat Electrofishing of fish aggregating at barriers during river flow and outlet releases provides an indication of how many fish are present and where they are located. The disadvantage of this method is that it is capture dependent and may affect whether a fish continues to migrate. Additionally efficiency can be affected by water quality and river flow. Use of the electrofisher upstream of and adjacent to the dam wall will be undertaken only when there is no flow over the spillway

Netting of fish is a standard method of determining fish species and abundance; however efficiency is limited when used in turbulent flowing water. Netting will be used as an adjunct to electrofishing where suitable.

Hydroacoustics is an established method of determining fish numbers, biomass and size in marine environments. Recent advances in technology have resulted in hydroacoustics also being applicable to the shallow freshwater environment, as a result it is now utilised to detect fish migrations overseas. Hydroacoustics has not previously been used for this purpose in Australia but the DPI&F has recently purchased a system costing over $80,000. Prior to commencing this monitoring program the system will be exhaustively tested to determine its suitability at Eidsvold Weir. Hydroacoustics will be particularly applicable to quantifying aggregations of downstream migrating fish adjacent to the dam wall.

BD5.4.3 Monitoring fish behaviour

PIT tag readers are to be installed on the fishways at the Burnett River Dam. Data on the behaviour of PIT tagged fish at other fishways in Queensland has contributed to improvements in the design of the Burnett Water structures. Data collected in this sampling program will contribute information on how to optimise the operation new fishways and possible design improvements. The main disadvantage of PIT tag readers is that they only detect PIT tagged fish, a major component of this monitoring program will dedicated to establishing a tagged population of fish.

Hydroacoustics also be used to identify the behaviour of fish in the vicinity of the dam and weir as well as for counting of fish entering and exiting the fishways.

Radio telemetry is an ideal method for determining the behaviour of individual fish regardless of their location. In this program lungfish and mullet in the vicinity of the Burnett River Dam will be implanted with radio tags and a fixed data logger receiver will detect their presence as they approach and leave the dam. Tagged fish that pass over the dam wall will be intensively monitored using a mobile receiver and possibly recaptured to asses whether they sustained any damage during the descent. Radio tags are very expensive so therefore only small number of fish will be radio tagged. Radio tag receivers, data loggers and installation will be provided by the DPI&F.

BD5.5 Outline of the Monitoring Program

The monitoring program presented in this document has been developed and built upon that developed for Eidsvold Weir by Martin Mallen-Cooper on behalf of the Weir Owner. The tables presented on the following page have retained the format that delineates between assessment and investigative portions of the fishway monitoring program. Codes developed in the Eidsvold Weir Monitoring Plan serve to identify how components of the program relate to questions provided in the monitoring plan.

As the Burnett River Dam represents Australia's first dedicated downstream fishway it will be necessary to address all facets of both core and non-core monitoring. Data collected from components of the program may result in modification requirements to the operation and possible structural alterations to the fishways.

BD5.5.1 Burnett River Dam Monitoring Outline

	Downstream Fishlock Assessment Program	
DA-1	What is the species composition and abundance of downstream migrating fish at the site? When is migration occurring?	Estimate abundance directly upstream using hydroacoustics and electrofishing as well as trap fishlock and data from PIT readers. Targeted sampling over widest possible range of seasons and flows.
DA-2	Is the operation / design of the fishlock attracting fish to the fishway under the full operational range?	Assess zones of aggregation under the full range of operational flows using electrofishing (no spill only), hydroacoustics across the river channel and in the vicinity of the intake tower and fishway entrance. Specific lungfish and mullet program using radio telemetry.
DA-3	Is the capacity of the fishlock such that it is able to pass the migratory biomass in an acceptable timeframe? Are all of the most abundant species and size classes directly upstream of the weir successfully utilising the fishlock?	Spp. and size classes of fish entering/exiting the fishlock using traps. Fish abundance directly below the weir determined using electrofishing, hydroacoustics compared to trap catch and PIT tagged fish.
DA-4	What is the attraction flow and gate level required to retain fish in the holding chamber during fishlock attraction phases?	Counts of fish entering and leaving holding chambers during attraction phase using hydroacoustics and PIT reader data. Adjust height of water between weirpool and lock chamber and re-assess.
DA-5	Are all fish that enter the fishlock exiting during the flushing phase?	Comparison of PIT fish detected entering the fishlock with detections exiting including experiments using PIT tagged fish that are placed in the fishlock chamber.
	Downstream Passage Investigative Program	
DI-1	What are the optimum filling and draining regimes?	Number of fish captured entering the fishlock compared with data from DA-2.
DI-2	What is the condition of fish that exit the fishlock?	Trapping of fish in floating pen in tailwater pool and observation of behaviour following release from exit pipe using hydroacoustics.
DI-3	What proportion of fish pass over the dam crest during river flows?	Hydroacoustic surveys of fish aggregations during river flow events, estimates of the number of fish that pass over the weir.
DI-4	Are fish that pass over the dam wall surviving?	Visual searches for dead/injured fish following flow events. Radio telemetry studies of lungfish and mullet survival following passage over the weir during skimming and non-skimming flows.

BD5.6 Implementation

BD5.6.1 Staffing

The monitoring and associated analysis and reporting would be undertaken over a five year timeframe. A dedicated team of three staff will work full-time on fishway monitoring program for the first three years. This will be decreased to two full time staff for the fourth and fifth years. The staff and monitoring program will be under the supervision of the current DPI&F Southern Fishway Team leader, Andrew Berghuis. Andrew will also assist with fieldwork as required.

Andrew Berghuis, Supervising Biologist
Andrew has over ten years experience working on Queensland fishways. He undertook the pre-construction fish sampling at both sites and has been closely involved in the fishway design processes for both fishways.

Andrew's expertise has been recognised nationally and he has been an important member of the Murray Darling Basin Commission's interstate Fishway Design Review Committee for the current $30 million Murray Fishway Restoration Program.

Andrew has also recently undertaken investigative studies for the Western Australian Government determining at the feasibility of re-establishing fish passage at the Ord River Dam and associated weir.

Andrew has been at the forefront of the application of remote monitoring technologies for fish passage in Australia. He has trialled PIT tag technology at Ned Churchward Weir fishlock and at Boggabilla Weir fishway on the Macintyre River for recording fish behaviour and fish movement and fishway function at those sites.

Andrew has also trialled the use of hydroacoustics for monitoring larger scale fish movements and will be attending training on this type of system in the USA in June 2005.

Andrew has been working on fish passage and fishways in the Bundaberg region since 1997. He has a unique understanding of fish communities and fish movement in the Burnett catchment and also of the hydrology of the system. Andrew has also built up relationships with local Department of Natural Resources and Mines water managers and also SunWater managers and operations staff. Andrew's salary and costs will be met by DPI&F.

Shane Piltz, Technician TO2
The technician's position will be filled by Shane Piltz. Shane has been employed on DPI&F fishway and lungfish projects over 3 years and has worked with Andrew on investigations at Neville Hewitt Weir and Boggabilla Weir during that period. He has also undertaken the field sampling for the temporary fishways at the Burnett River Dam site. Shane has over 400 hours of electrofishing experience, gained mainly in the Burnett River catchment and has participated in projects monitoring adult lungfish and lungfish spawning sites throughout the Burnett River catchment.

PO3 and PO1 biologist positions will be filled on confirmation of this proposal. The PO1 fisheries biologist would possess a minimum of a tertiary level degree or equivalent and is likely to be a recent graduate. As well as a relevant degree, the PO3 biologist would be expected to have significant experience (at least five years) in designing and running research or monitoring type projects, producing reports and presenting project results to a wide audience as well as sound staff management experience.

It should be noted that in Australia, all electrofishing boats are operated under a national code of conduct. To be endorsed as an operator under this code requires 50 hours experience and attendance at a training workshop. Most DPI&F staff who operate electrofishers have also received training from the electrofishing unit manufactures (who are based in the USA). By the commencement of the monitoring, DPI&F staff will also have received training from the hydroacoustic system manufacture by attending a dedicated training course in the USA. It is unlikely that this level of expertise in both sampling techniques exists elsewhere in Australia.

BD5.6.2 Location

As previously mentioned the team will be based at the DPI&F offices in Bundaberg, within one hour drive to the Burnett River Dam. This will allow field sampling to be undertaken at short notice and in response to localised flow events. It will also reduce costs in travel and overnight accommodation.

Intensive field sampling will be carried out by the team during spring, summer and autumn flows. The rest of the year will be used to organise, download and analyse data and for major report writing. There will also be some sampling during the cooler months and lower flows to look at lungfish movements for spawning and downstream passage of species such as mullet.

Sampling programs will be designed to enable rigorous statistical analysis of the data. It is anticipated that results from this monitoring will eventually be submitted as papers to international scientific journals and thus will be endorsed by the scientific establishment.

BD5.6.3 DPI&F advantages

The following summarises some of the advantages of DPI&F Bundaberg undertaking the upstream fishway monitoring at the Burnett River Dam:

- Familiarity with the development of the fishway design including modelling
- Unparalleled experience in fishway and fish passage monitoring within the Burnett River system and knowledge of fish communities in the Burnett
- Experience in remote monitoring methodologies such as the deployment and use of PIT tags and radio tags, including successful surgical implantation procedures on threatened fish species
- Possession of electrofishing boats and operators certified under Australian Code of Electrofishing Practice
- Possession of hydroacoustic monitoring system and trained operator
- Salary costs of Program Leader provided by DPI&F
- No capital costs for the boat electrofisher, nets and hydroacoustic equipment will be included in the costing
- Locally based resulting in rapid response time to flow events and travel cost savings
- Established network of contacts among water managers and other stakeholders in the Burnett region

BD6. Milestones and Reporting

The components of the monitoring proposal that can be completed (and when) in a given year will depend on the availability of fish to move through the fishway or over the spillway, and the incidence of flows. This means that the standard milestone and quarterly reporting structures will rarely be relevant. For this proposal, the milestones and reporting structures reflect the seasonal activities and lulls in flows, fish movement and hence sampling (refer Table bd(iii).

Milestones

- Signing of contract – June 2005

Year 1 - 3

- Commencement of intensive field seasons – late spring
- Completion of intensive field seasons – early winter
- Experiments associated with optimisation of fishway and dam operation process
- Report on fieldwork to date – late autumn
- Report on initial appraisal of fishway function – late autumn (Year 1 only)
- Field data management/analysis – winter
- Completion of annual report – end winter
- Completion of milestone report – end winter (Year 3 only)

Years 4-5

- Modified upstream and downstream fish passage sampling
- Completion of annual report – end winter (Year 4)
- Complete optimisation of fishway and dam operation process (Year 5)
- Completion of final report – spring (Year 5)

Program activity	Year 1 (05/06)	Year 2 (06/07)	Year 3 (07/08)	Year 4 (08/09)	Year 5 (09/10)
Intensive upstream fishway sampling	First flow of spring – early winter	First flow of spring – early winter	First flow of spring – early winter	Summer and autumn	Summer and autumn
Intensive downstream fish passage sampling	Throughout the year	Throughout the year	Throughout the year	Timing dependent on results for years 1 - 3	Timing dependent on results for years 1 - 4
Flow related sampling	As flows arise	As flows arise	As flows arise	As flows arise	As flows arise
Data management	Winter	Winter	Winter	Winter	Winter
Data analysis	Winter	Winter	Winter	Winter	Winter
Initial appraisal of fishway function	Late autumn				
Fieldwork summary	Late autumn	Late autumn	Late autumn	Late autumn	Late autumn
BRDOC report	Quarterly	Quarterly	Quarterly	Quarterly	Quarterly
Annual report	Winter	Winter	Winter	Winter	Winter
3 year milestone report			Winter		
Final report					Spring

Table bd(iii). Timing of Monitoring and Reporting at Burnett River Dam

BD7. PAYMENT

The proposed payment schedule is based on annual payments upon acceptance of the annual report by the Dam Owner. For the first twelve months of the project, payment of 25% of the Year 1 budget will be sought in December 2005 and June 2006 respectively. This will cover costs to DPI&F for the 2005/2006 financial year. The remaining 50% of the Year 1 budget will be sought in September 2006.

	Timeframe	Milestone	Payment (excl GST)
Year 1	December 2005	Commencement of intensive field season	$50,500
	June 2006	Completion of Intensive field season	$50,500
	September 2006	Acceptance of annual report	$101,025
Year 2	September 2007	Acceptance of annual report	$82,025
Year 3	September 2008	Acceptance of annual report	$82,026
Year 4	September 2009	Acceptance of annual report	$36,962
Year 5	December 2010	Acceptance of final report	$36,962
Total			**$440,000**

Table bd(iv): Payment schedule for the Burnett River Dam Downstream Fishway Monitoring Program

Appendix B

Annual monitoring reports - June 2007, September 2008 and September 2009.