SENSOR FISH: USING AN AUTONOMOUS SENSOR TO QUANTIFY HYDRAULIC CONDITIONS EXPERIENCED BY FISH WHEN PASSING DOWNSTREAM THROUGH RIVER INFRASTRUCTURE

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Many fish species in the Murray-Darling Basin, Australia are dependent on downstream migration, drift and dispersal at various life stages including egg, larval, juvenile or adult. During these movements, fish may be exposed to a host of hydraulic stressors (mechanical strike, shear forces and rapid changes in pressure) when passing dams, weirs and hydropower facilities. When severe, these stressors have been shown in the laboratory to cause injury and mortality. But what is the likelihood that fish will be exposed to hydraulic stressors severe enough to cause injury, and which infrastructure types are harmful for downstream migrants? Answering these questions is critical for optimising infrastructure design and operation to improve fish passage. To better understand these stressors, hydraulic conditions were measured at a range of weir and hydropower designs within the Murray-Darling Basin using state-of-the-art Sensor Fish technology. A Sensor Fish is an autonomous device that can be deployed into extreme hydraulic environments to measures acceleration, rotation, pressure, and temperature. By associating the high-resolution Sensor Fish data with injury and mortality models obtained from laboratory studies, estimations about injury and survival rates can be obtained. Such estimates can assist in management measures, result in optimization of existing operations, and can be taken into account with the design of future infrastructures to reduce or eliminate negative impacts on fish.

1 INTRODUCTION

River infrastructure, such as dams and weirs, are well known for altering and disrupting migration of fish. However, direct injury or mortality may also occur when fish pass downstream through these structures, where they are exposed to stressors like rapid pressure changes, shearing and turbulent water, and strike or collision with hard surfaces [1]. Even the simplest small weirs can cause damage to fish through the altering of hydraulic conditions [2]. Quantification of the hydraulic conditions that lead to these stressors can be acquired through the deployment of Sensor Fish, an autonomous device that records pressure, three-dimensional acceleration and rotation, orientation, and temperature (Figure 1) [3]. Data from Sensor Fish, when coupled with laboratory injury mortality metrics, can be used to predict injury and mortality rates for fish passing downstream through these structures.

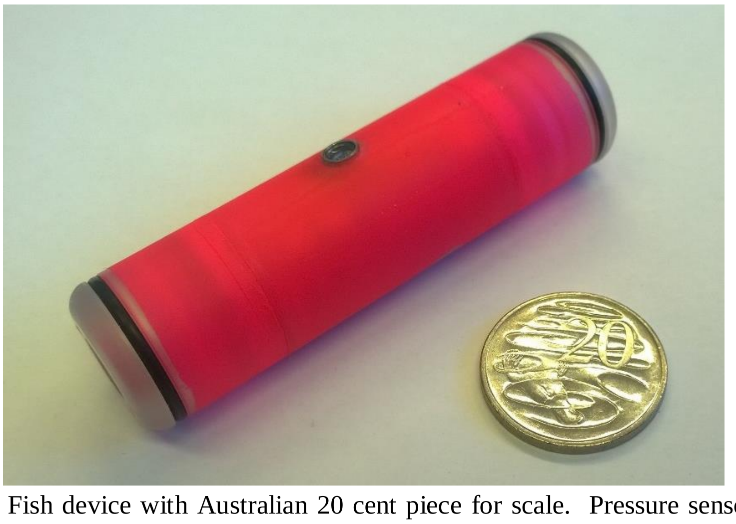

Figure 1. The Sensor Fish device with Australian 20 cent piece for scale. Pressure sensor is visible at the top centre of the Sensor Fish, and high visibility red paint was applied to aid in recovery after deployment.

2 METHODS

Sensor Fish deployments were conducted at three different hydro-structures: Yarrawonga Weir Power Station, Colligen Creek Weir, and the Drop Hydro Plant. The three structures were selected, based on their designs, as three different case studies of structures across New South Wales, Australia. At Yarrawonga Weir Power Station deployments were completed through both an undershot weir gate and vertical Kaplan turbine. At The Drop Hydro Power Station, Sensor Fish were deployed through a horizontal Kaplan turbine, and at Colligen Creek Weir, Sensor Fish were deployed through both an overshot and undershot weir. Sensor Fish were programed to record time scenarios from 30-120 seconds, depending on the structure, at a frequency of 2048 Hz.

Deployments through the turbines at Yarrawonga Weir Power Station and The Drop Hydro Power Station were completed by inserting the Sensor Fish, in front of the trash racks, through a PVC pipe. The Sensor Fish were then entrained into the turbine and passed through the power house while recording data. Sensor Fish were equipped with balloon tags [4] and radio transmitters to aid in the recovery which was conducted by boat in the downstream pool.

Weir deployments through an undershot gate at Yarrawonga Weir Power Station and an undershot and overshot gate at Colligen Creek Weir were conducted by simply dropping the Sensor Fish above the weir and allowing it to be entrained through or over the weir. For the undershot weirs the Sensor Fish were again equipped with radio transmitters and balloon tags to aid recovery. The overshot weir enabled easy recovery, allowing Sensor Fish to be deployed in a slightly buoyant state without an attached radio transmitter or balloon tag.

3 RESULTS

At the three hydro facilities a total of 95 Sensor Fish were deployed, 64 of which successfully recorded the targeted time series while passing downstream through the various structures (Table 1). Data were analyzed for strike and shear events, as well as rapid decompressions. Shear and strike events were categorized as severe, mid and slight based on the highest recorded g-force (G) [5]. The occurrence of strike was not significantly different for any of the structures, ranging in occurrence from 50% to 82% of the deployments. Shear events were negligible through all structures except for the undershot weir at Yarrawonga, which recorded shear events in 70% of the deployed Sensor Fish, significantly greater than all the other structures ($p=0.0198$).

Table1. Strike and shear event summaries, categorized based on g-force (G), for Sensor Fish passing through undershot and overshot gates at Colligen Creek Weir, an undershot gate and turbine at Yarrawonga Weir Power Station, and the turbine at The Drop Hydro Power Station.

	Colligen Creek Weir		Yarrawonga		The Drop
	Overshot	Undershot	Undershot	Turbine	Turbine
Successful Deployments	12	11	9.5*	9	22
Strike	9	9	7	5	11
Severe (>95 G)	7	5	6	3	2
Mid (<95, >50 G)	2	2	0	1	4
Slight (<50, >25 G)	0	2	1	1	5
Shear	0	1	7	1	0
Mid (<95, >50 G)	0	0	3	0	0
Slight (<50, >25 G)	0	1	4	1	0

*One Sensor Fish recorded only a partial time series of the transition through the undershot weir, sufficient to capture shear events which only occurred at the start of the transition but not sufficient to record all strike events which tended to also occur downstream along the apron, therefore analysis of strike was completed for 9 deployments and shear was completed for 10.

Rapid decompressions were quantified as maximum ratio pressure change (maxRPC), which is the pressure associated with the maximum depth prior to passage divided by the lowest pressure (nadir) recorded by the Sensor Fish. Measured maxRPCs differed significantly ($p<0.0001$) between all treatments. The lowest mean maxRPC was found through the Colligen Creek Weir overshot gate, and the largest mean maxRPC found through the Turbine at Yarrawonga (Table 2).

Table 2. Summary of rapid decompressions recorded by Sensor Fish deployments. Nadir pressure represents the lowest pressure recorded by individual Sensor Fish and maxRPC is the maximum ratio pressure change calculated for individual Sensor Fish records.

	Colligen Creek Weir		Yarrawonga		The Drop
	Overshot	Undershot	Undershot	Turbine	Turbine
Successful Deployments	12	11	10	9	22
Nadir (kPa)					
Minimum	97.7	94.7	94.7	42.5	99.8
Maximum	99.8	98.9	97.6	66.6	147.6
Mean	99.1	97	96.6	56.6	128.5
maxRPC					
Minimum	1.01	1.25	1.49	2.69	1.42
Maximum	1.03	1.34	1.6	4.42	2.12
Mean	1.02	1.28	1.52	3.4	1.64

4 DISCUSSION

Sensor Fish deployments indicate that each of these structures has the potential to cause injury to fish passing downstream. Strike and shear events were most common through the weirs and the most severe at the Yarrawonga undershot weir. The higher head pressures at the Yarrawonga undershot gate caused greater velocities under the weir gate and resulted in higher velocity collisions and more shearing interfaces that can be encountered during downstream passage. Rapid decompression was found to be the greatest through the turbines with Yarrawonga turbine having the largest rapid decompressions.

Several laboratory simulations of rapid decompression, shear, and strike have been completed on a small variety of fish species to develop injury and mortality models [5-7]. By associating the high-resolution Sensor Fish data with injury and mortality models obtained from laboratory studies, estimations of injury and survival rates can be obtained for the range of structures. For example, juvenile Chinook salmon (*Oncorhynchus tshawytscha*) have been extensively studied in the laboratory, and mortality associated with rapid decompression is well established [7]. Based on the data recorded at Yarrawonga turbine, a RPC of 3.4 (mean maxRPC) would result in a mortality rate of 30% for juvenile Chinook salmon. Estimates, such as this, can assist in the management of existing operations and with the design of future infrastructures to reduce or eliminate negative impacts on fish by implementing designs that reduce shear, strike, and pressure reductions.

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