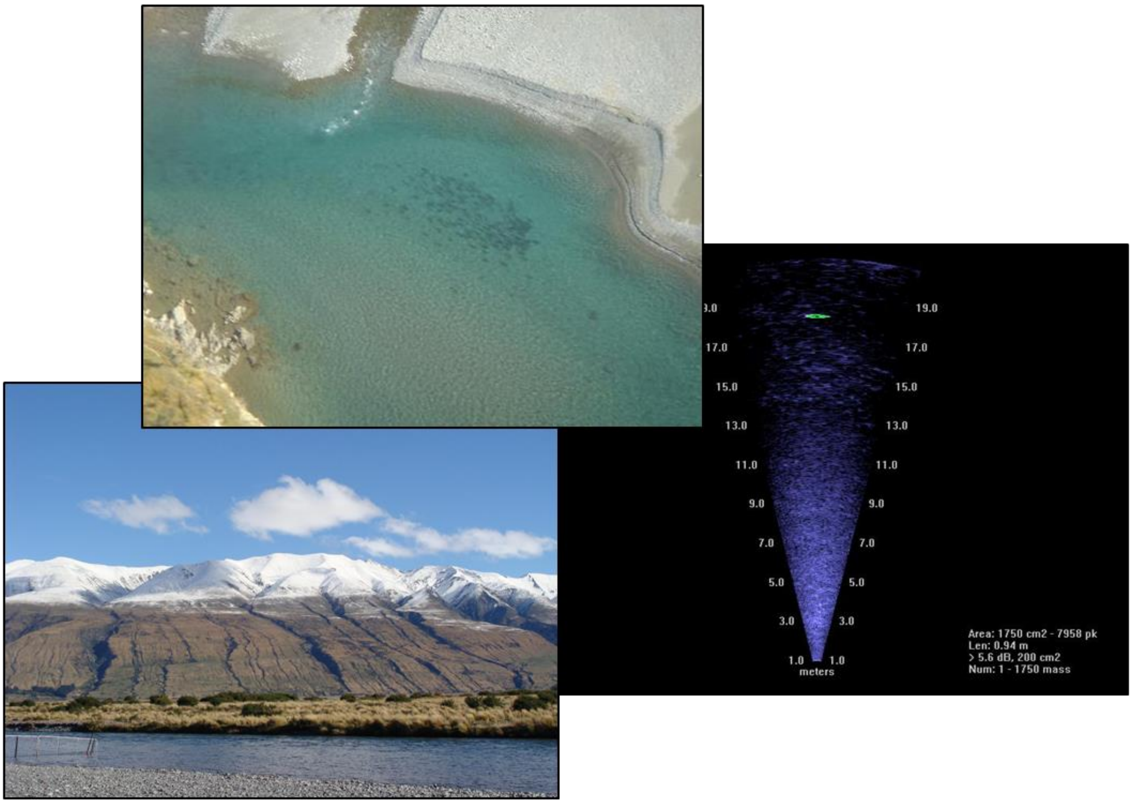
In association with:

Assessment of a Dual-frequency Identification Sonar (DIDSON) for application on salmon migration study

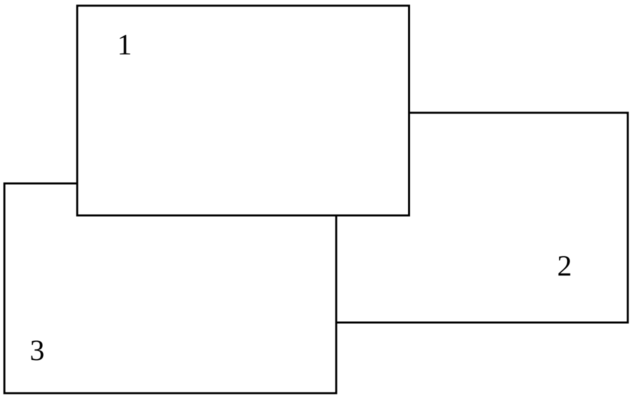


Aurélien Vivancos: Ph.D student, Otago University, Zoology department.

Contact: vivau915@student.otago.ac.nz

Iain Maxwell, Senior Freshwater Ecologist, Cawthron Institute.

Contact: Iain.Maxwell@cawthron.org.nz



Picture 1: Salmon shoal in the Rakaia River.

Picture 2: DIDSON screen capture.

Picture 3: The Hydrawaters Upper Rakaia.

All pictures by Aurélien Vivancos.

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I. Introduction

The requirement for Chinook Salmon (*Oncorhynchus tshawytscha*), to move from the ocean to upstream spawning grounds leads to one of the most impressive mass migration phenomenon observable in nature. During late summer and autumn, thousands of fish gather around the river mouths, estuaries and lower river pools before migrating upstream to their natal streams to spawn. Estimating escapement to these streams has always been a key point in order to determine population status and harvest/stock recruitment relationships (Parken, 2003).

Fish and Game New Zealand have historically monitored salmon escapement by foot counts around the peak spawning period and through trapping as they entered the spawning streams in the Waimakariri and Rakaia Rivers. For the last 18 years, helicopter counting has replaced this method which involves regular counts carried out throughout the spawning season. Since 2004, the Area Under the Curve (AUC) method has been used as described by Hilborn et al. (1999) to estimate total escapement to spawning tributaries from the aerial counts. However, this method relies heavily on an accurate assessment of the residency time of spawning salmon. To date the residency time has been assessed through mark-recapture studies associated with trapping migrating spawners (sources: Fish and Game), but this method might not be reliable since trapping is likely to change fish behaviour and affect migration dynamics. Trapping can delay salmon arrival to the spawning area (Jokikokko, 2002) which reduces the time salmon spend spawning, and consequently could bias the estimation of the residency time (Steve Terry, pers. Comm.). It is therefore very difficult to have an accurate estimation of the residency time, especially considering its wide variability throughout the spawning season (Healey, 1991). Because the reliability of the escapement estimated from aerial surveys is entirely dependent of an accurate residency time estimation, it is important to develop new methods and tools that don't rely on this parameter.

Hydroacoustic technology has historically been used in fisheries research. Hydroacoustics is a term applied to the use of echo sounding, which detects and records the return of signals of ultrasound waves. The result can be interpreted to detect fish movements or even to recognize fish species. This technology has been used for a number of years in North America to quantify salmon runs (Ransom, 1998; Thorne, 1993; Yule, 2000). In some cases, extremely accurate estimates of migrating fish have been obtained (Ransom et al., 1998). This technology also allows fishery managers to monitor fish movements in challenging conditions (turbid and/or high water volumes), and without using a trap, avoiding stress and potential delays in migration.

Dual-frequency identification sonar (DIDSON) is a recent advance in sonar technology, providing near-video-quality imaging of fish, even in dark or turbid water (Moursund, 2003; Tiffan, 2004). This technology was originally developed for naval use in harbour surveillance and underwater mine detection (Belcher, 2001). DIDSON overcomes some of the interpretation issues associated with conventional sonar, with a maximum range of 40m in low-frequency mode (1.1 MHz) (Sound Metrics Corporation 2009). With its application to fisheries research, DIDSON has revolutionized the detection and monitoring of migrating fish, especially salmon, from fixed positions (Holmes, 2005; Burwen, 2007; Maxwell, 2007). Early in 2009, the Cawthron Institute in conjunction with North Canterbury Fish and Game trialled DIDSON to quantify the salmon run in a key spawning tributary of the Rakaia River. The experiment was conducted over two months on the Hydrawaters, from the 23rd of March 2009 to the 24th of May 2009.

The aim of the study was to quantify the salmon run in this spawning stream with a view to validate the counts obtained through the AUC calculations. Helicopter counts were continued during this investigation to provide a point of comparison.

II. Materials and Method

II. a. Location

The DIDSON was used from the 23 of March 2009 to the 24 of May 2009 in the upper Rakaia River, in a major spawning stream called the Hydrawaters. Considering the high value of the equipment used and the unpredictability of natural events such as floods, the site was staffed continuously. This constant surveillance was made possible by the generosity of the owners of the Mt. Algidus Station where the trial was located.

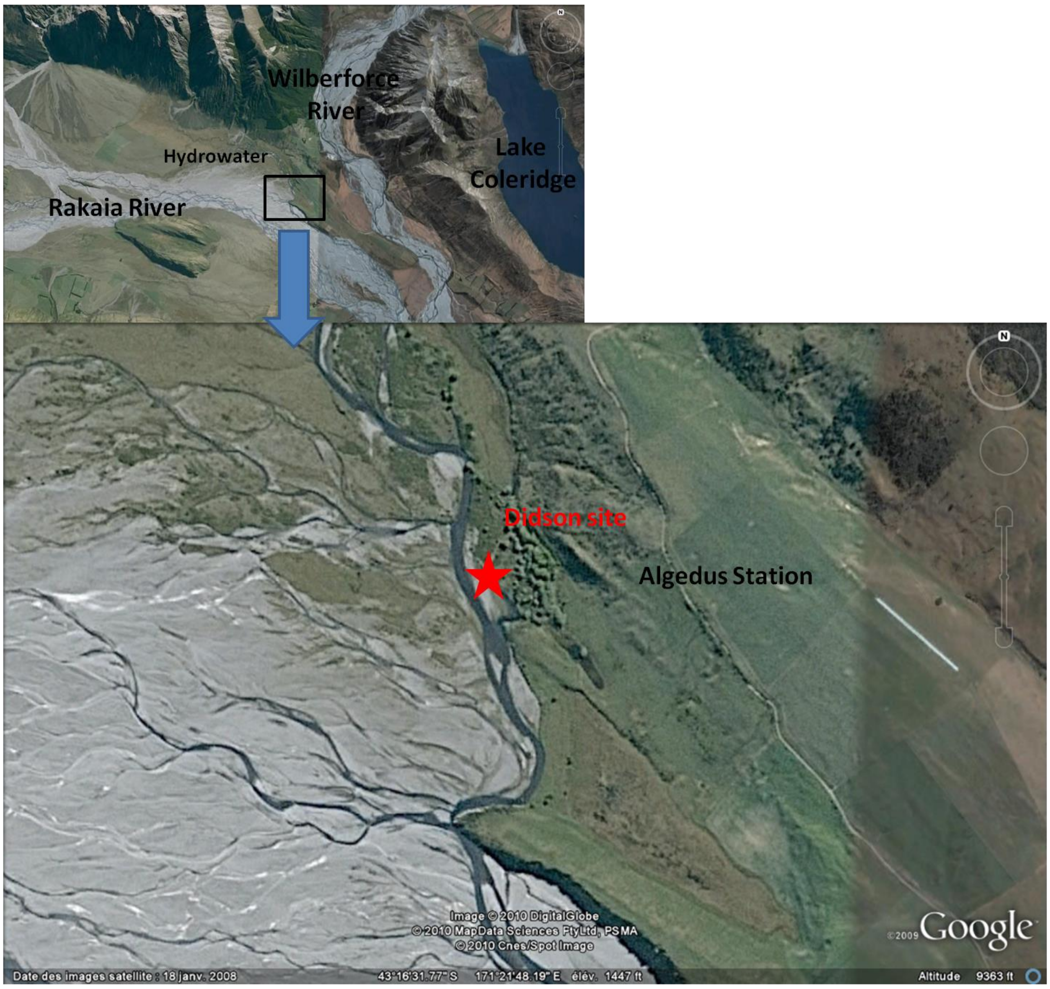

Figure 1: Location of the DIDSON site

The Hydrawaters are a series of spring fed streams and while situated in the alluvial valley of the Rakaia River, this tributary is normally not connected to the main catchment and not affected by floods. The study site was located downstream of the main spawning spots of the Hydrawaters, in order to have a reasonable estimation of the total spawning run of this tributary. The DIDSON was located on the true left bank of the stream, in the middle of a low gradient section, with low velocity. Average depth has been estimated to be around 40cm with a deeper pool on the true right bank. (cf. Figure 2). A fence was installed immediately downstream of the DIDSON camera, to prevent fish coming too close to the camera. The DIDSON was permanently connected to a laptop stored in a weather proof box. This allowed data recording for up to 36 hours. The DIDSON & computer were powered 24/7 by a generator. The recorded files were transferred daily to a high capacity hard drive to be processed later. Because of the width of the stream (20m), the low frequency (1.0MHz) mode was used which extended the range but also lowered the definition of the image.

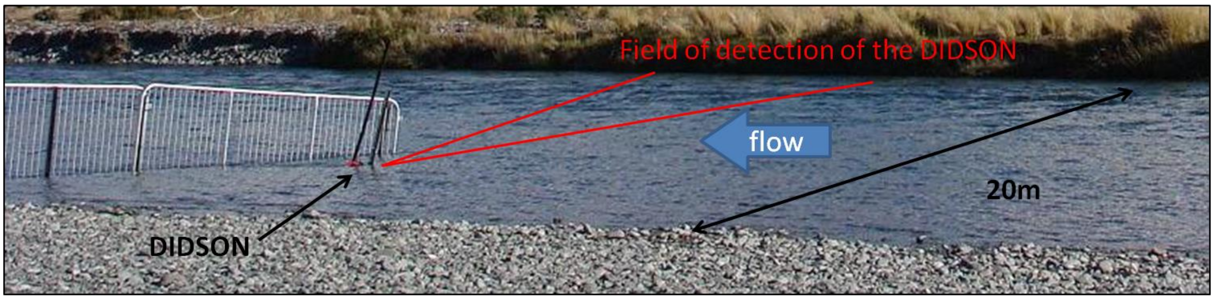

Figure 2: DIDSON position

Unfortunately, two big floods occurred, one on the 28th of April and another on 17th of May 2009, forcing removal of the equipment and making the recording impossible during nine and five days, respectively. Large floods of this magnitude had not been encountered during the spawning season for a number of years and as such there were no contingency plans in place and the DIDSON stopped recording both times. On top of this, during a helicopter survey it was noted that a significant braid of the Rakaia had diverted into the Hydrawaters upstream of the research site during smaller freshes making the site additionally unstable.

II. b. Salmon counting and file processing

The recorded files were processed in October/November 2009 using DIDSON software. Considering the huge amount of data collected during the two months of recording, it was essential to summarise the data to make it easier to manage and analyze. Soundmetrics software provided with the DIDSON offers a post processing algorithm called Convolved Samples Over Threshold (CSOT). This algorithm selects only the frames where motion is detected utilising predetermined parameters of sample size (pixel cluster) and threshold (in decibels). This allowed the recorded footage to be condensed into smaller files for reviewing.

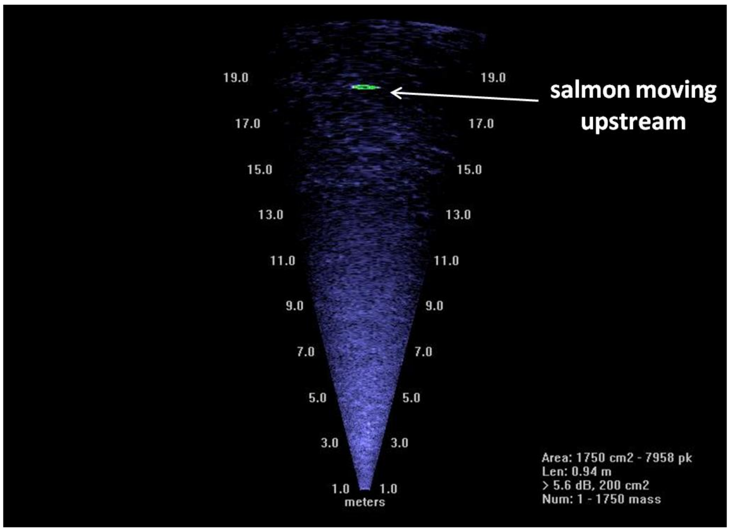

Figure 3: DIDSON screen capture

A sensitivity analysis showed that the optimum setting for the threshold was 5.6 dB. All files were subsequently processed using this setting. The processed files were then reviewed by an operator who counted every salmon manually. The orientation of each movement of fish was noted and sorted into two categories: upstream movement and downstream movement. The number of resident fish per day has been estimated by subtracting the number of downstream movements from the number of upstream movements recorded every 24 hours. Frequently, some hourly files were missing or impossible to process. When only a few hours were missing, the results were extrapolated to obtain a 24hr count (example: if 100 fish are counted in 16hr, it can be assumed that 125 fish would have been counted in 24hr). This method was tested on twelve complete files to assess the reliability of this extrapolation, with a reasonable result (< 25% of error). However, when more than 12hr of a day of data were missing, the whole file was dismissed to avoid any bias. This situation happened twice following the main floods. Once all the data was processed, the results were compared with the number of resident salmon observed during helicopter counting. Five aerials counts were conducted during the study, on the 25/03/09, 09/04/09, 19/04/09, 01/05/09 and the 21/05/09. The total number of spawners was calculated using AUC software under MatLab. Based on the residency time investigations described earlier, residency time was set at 14.67 days (Fish and Game, unpublished document).

III. Results

Using DIDSON data, the peak of the run was estimated at 1,800 which occurred around the 5th of May, with a total escapement estimated at 4,489 salmon (Figure 4).

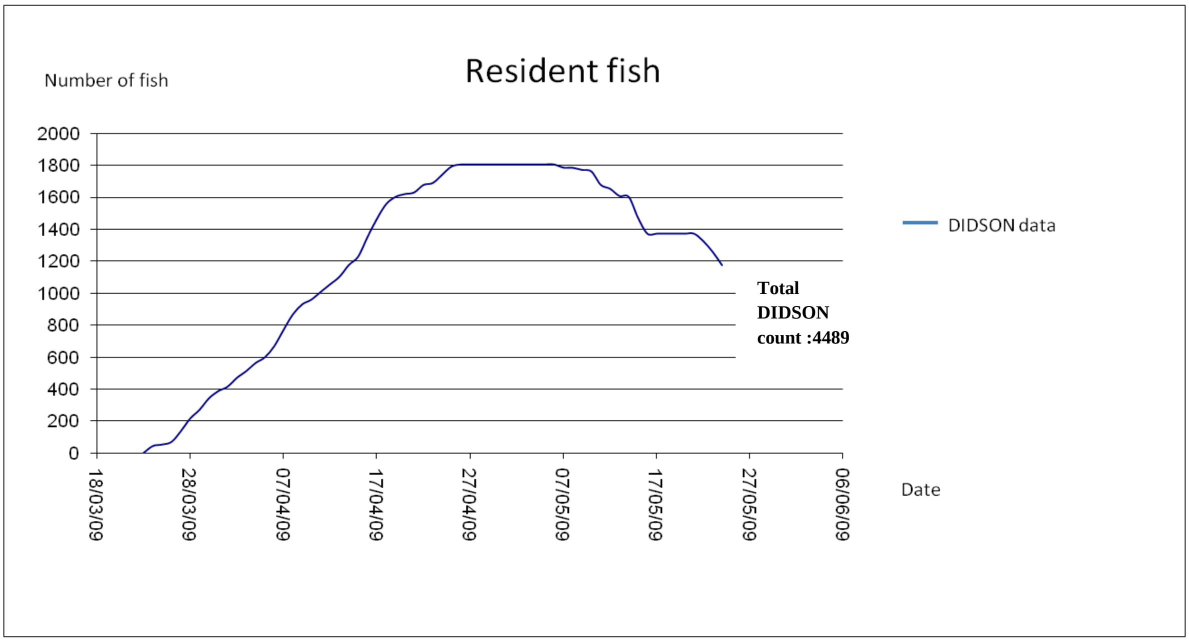

Figure 4: Estimated salmon escapement using DIDSON counts.

Helicopter counts reached 400 residents, with an interpolated peak of 422 occurring around mid-April. AUC software using helicopter counts estimated the total spawning population to be 1,372 salmon (Figure 5).

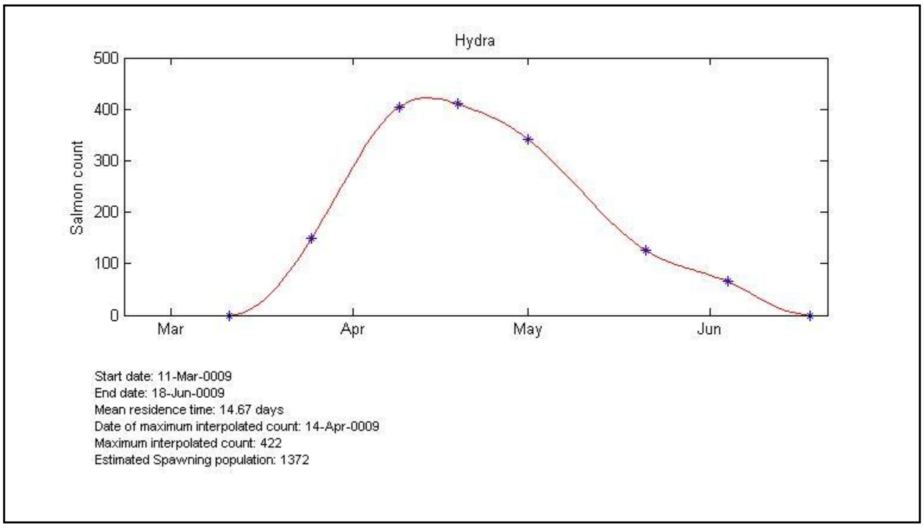

Figure 5: Output from the AUC software.

Fish movements observed on DIDSON records showed that upstream and downstream movement peaked simultaneously, which suggested that an increase in salmon activity does not favour one type of movement in the detriment of another (cf. figure 6). Peaks of activity occurred on the 30th of March and the 7th and 16th April, and were associated with small freshes. Upstream movements were higher than downstream movements from the beginning of the study to the 8th of May. The flood that occurred on the 28th of April was an unusual event for the season (1,580 cumecs recorded at Fighting Hill) with the Rakaia River remaining high for a considerable period. During this period the Hydrawaters were connected to a main braid during floods, which led to very high water levels. As a consequence, the experiment site had to be evacuated and the monitoring stopped for a period of nine days, during what appears to be the most critical period of the season (during the peak of the run, when the upstream movement trend switched to downstream movement). After this first flood, downstream movements were greater than upstream movements, which led to a decrease in resident fish. The second flood that occurred on the 17th of May was shorter in duration but more violent (2,100 cumecs recorded at Fighting Hill). For the same reasons as the previous flood, the site had to be evacuated which stopped the experiment for a further five days. The few days monitored after this event showed a high proportion of downstream movements and a decreasing number of resident fish.

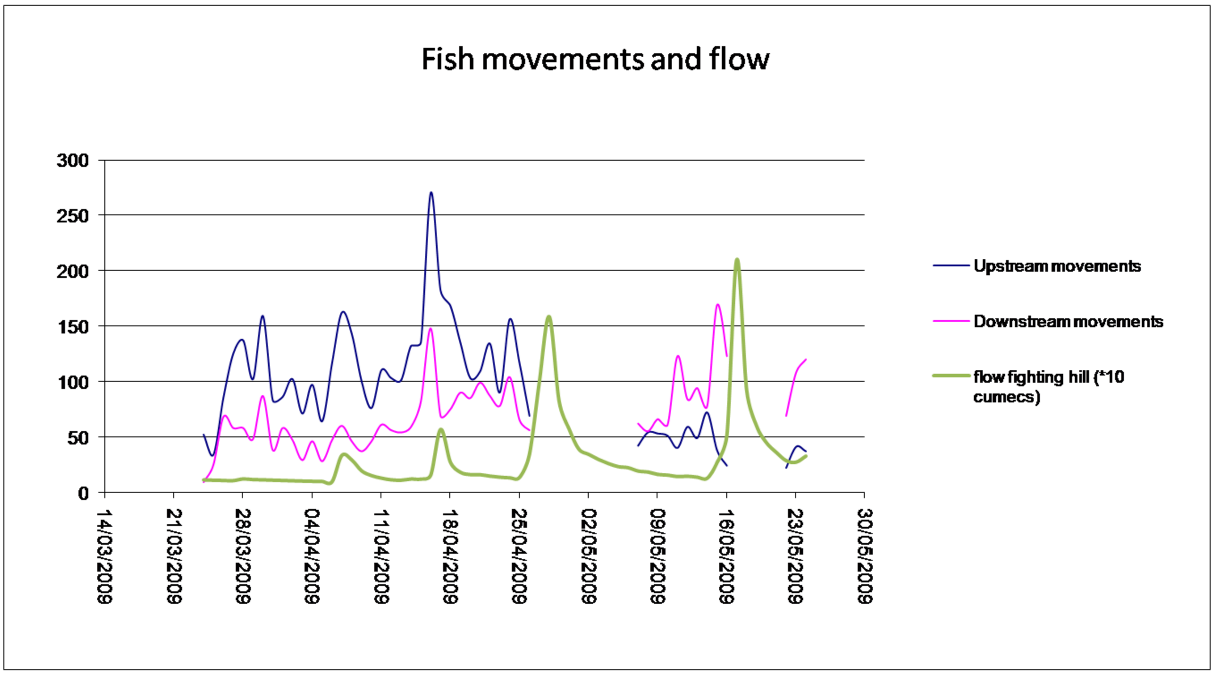

Figure 6: Fish movements recorded by the DIDSON and flow recorded at Fighting Hill.

IV. Discussion

Helicopter counts differed from the DIDSON count by a significant margin (DIDSON estimated spawning population 4,489, AUC estimated spawning population 1,372). Similar differences between the DIDSON count and aerial surveys have already been observed by the Alaska Department of Fish and Game during the monitoring of the Chinook salmon run on the Anchor River (Szarzi, 2007; Kerkvliet, 2008). Kerkvliet (2008) for instance, found that the total escapement estimated from the aerial count represented only a small percentage of the DIDSON count (13% during the 2004 survey). The significant difference in escapement estimated from this study between aerial surveys and DIDSON counts throws into doubt the validity of both methods. However, helicopter counts have been tested and validated in the Rakaia catchment (West, 1986), so at this stage we have no reason to doubt the quality of the estimate that comes from this method. Aerial counts are affected by water clarity, canopy cover, fish abundance and observer experience, but it is considered unlikely that those factors are at issue in our case, as the Hydrawaters are a series of shallow streams with crystal clear water and little canopy cover. However what is of significance and may be of relevance to this study is the assessment of residency time that drives the AUC model. Indeed, as mentioned before, AUC estimates are strongly dependent of the residency time used in the model. Recent observations by F&G staff has raised doubt over the validity of the residency time estimates, with the original estimates possibly affected by salmon behaviour around the traps used leading to delays in upstream movement during the mark-recapture investigations. However if we accept the accuracy of the AUC method this then raises concern with the validity of the DIDSON counts. Several unusual factors are likely to have impacted on the efficacy of the DIDSON for this work during this study. They are expanded on in the following paragraphs.

Firstly, the floods that occurred during the study greatly affected the accuracy of the DIDSON counts. The first flood interrupted the monitoring at the most critical time for salmon movement, just before what is believed to be the peak of the upstream run. Therefore, no “tipping point” has been recorded, which could have been an interesting event to witness and to compare to the AUC model output. Elevated flows may have forced salmon to leave their spawning point prematurely. Because the flood prevented monitoring during this period, it is likely that this event significantly underestimated downstream movement hence elevating our count of resident salmon. It is likely that the second flood occurred at the end of the run, when downstream movements appeared to be greater than upstream movements. Again this event may have resulted in many salmon being washed down without being monitored. It is possible that missing these movements resulted in a significant over estimation of escapement through not deducting downstream migrants from upstream migrants. A confounding matter in this study is however, the higher estimates from DIDSON versus AUC counts prior to any flood events.

The higher escapement estimated by DIDSON could also be explained by the fact that some downstream movements were not recorded or mistakenly interpreted when reviewing files as background noise and then dismissed. A more detailed examination of the DIDSON files by Cawthron staff showed that the deeper part of the main channel may not have been recorded through incorrect placement of the DIDSON after the first flood. This resulted in an area of ‘shadow’ whereby a portion of the river bed was not covered by the DIDSON. We know from the behaviour of upstream migrating salmon that they prefer to stay as close to the river bed as possible (Ellis, 1966; Xie, 1997) as this is energetically the best option. This combined with the shadowing is likely to have resulted in an area where upstream salmon movement was not detected (Figure 7). It is also possible (although untested) that the downstream migrating salmon display the same behaviour. This may be the result of active swimming or through the affect of currents in the deeper channels. This assumption has some basis as we observed many situations in the DIDSON files where fish signals were intermittent and usually associated with the deeper channel that was in the shadow. Another complication that as yet is also untested is what happens when dead or dying salmon are washed down the stream. It is possible that the carcasses would roll along the bottom of the river, or given that post spawned salmon usually have little or no fin area left they may be actively swimming but at right angles to the DIDSON beam and so offering a small body profile to detect. This was tested with Iain Maxwell from the Cawthron Institute. One days records were re-analysed taking into consideration signals with unusual signatures and these results were compared with the original counts. While upstream movement counts weren't significantly different, it was observed that downstream movements could have been underestimated by up to 70%. Due to the likelihood that the error associated with the shadow effect would negate any re-analysis, the remaining data was not re-analysed.

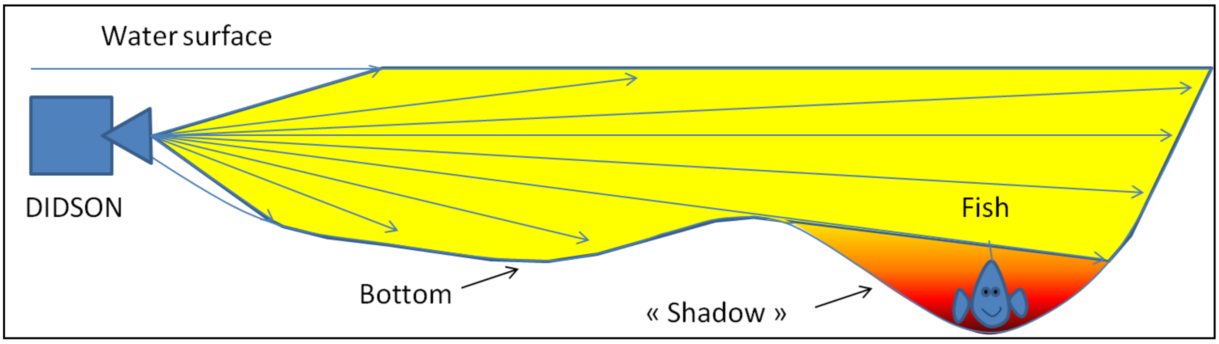

Figure 7: Illustration of the "Shadow zone".

Site selection of the DIDSON is likely to have increased this error. The DIDSON was positioned in a low gradient area of the stream, with no significant velocity downstream of the trap. Consequently, this configuration allowed fish to mill around the DIDSON, going upstream and downstream several times a day which increases the potential to over or under estimate movements. Milling issues have already been detailed by a study monitoring upstream migration of Steelhead trout in California (Pipal, 2010). They also developed a decision method called DIDSON Decision Support Tool (DST) that enables the operator to recognise milling fish and to limit the bias induced by this behaviour.

Finally recent research Faulkner and Maxwell (2009) has highlighted the importance of appropriate positioning and aiming of DIDSON to ensure adequate coverage of the river and allow accurate estimates of fish movement. During this research the DIDSON was moved a number of times as a result of rising flood waters and correct aiming may not have occurred.

V. Conclusion

The use of DIDSON technology in the project has demonstrated potential gains in understanding salmon migratory behaviour with the use of this equipment. However, this study failed to achieve its primary objective, to estimate total salmon escapement using DIDSON in the Hydrawaters. The historical basis of the AUC estimates from helicopter counts meant that in this situation they were considered the most accurate. This accuracy has not been thoroughly tested against DIDSON given the problems noted earlier with the floods and aiming of the DIDSON. The problems that have arisen confirm that it is important to engage and retain highly skilled technical support throughout any DIDSON project. This would be important at least until such time as in-house expertise was available within NZF&G. This would not preclude using NZF&G staff as the primary provider of labour for DIDSON projects but suggests that external assistance should be retained and used periodically to check progress against objectives and to ensure the correct operation of the equipment.

This is the first time that DIDSON has been used for an assessment of escapement in New Zealand. Given the challenging conditions resulting from unseasonable floods and despite the earlier comments, F&GNZ are happy with the outcome of this pilot study. Upstream movements were likely to have been better assessed than downstream movements in this study. A number of factors resulted in the reduced accuracy of the DIDSON counts that are now better understood and able to be managed in further DIDSON studies. We know from published research internationally that DIDSON will perform as expected in New Zealand with further refinement of the site selection, application of an aiming protocol and post processing of files.

This study presents a useful baseline for further development of the method. Additional considerations/protocols are noted below:

DIDSON positioning.

The location of the DIDSON is a critical part of successfully counting fish. The aiming protocol of Faulkner and Maxwell (Faulkner, 2009) should be followed at every site. The fish should be trained to a single point using trap frames or gates to ensure that they are ensonified and cannot mill around the DIDSON. Site selection should also take into consideration the available physical habitat to minimize the chances of salmon milling around the DIDSON, i.e. close to the top of a rapid. Training the migrating salmon to one point would potentially allow the DIDSON to be used in high frequency mode to provide files of a greater resolution thereby allowing easier post processing of files.

Data processing and analysis.

File storage and management is critical to the integrity of subsequent data manipulation and post processing of files. Files should be reviewed daily using the CSOT post processing options in the Soundmetrics software. Daily movement counts can then be assessed and logged.

-It is essential that experienced and trained DIDSON technicians deploy and set up the software on any remote logging station. As noted earlier in this document the positioning and aiming of the DIDSON is a fundamental part of ensuring a successful project, also as important is the correct set up and operation of the software. Once operating correctly a person with some basic training in the use of DIDSON will be able to comfortably operate the setup.

To avoid widely differing interpretation of files there should be some agreed consistent protocols for reviewing and then dealing with salmon movement as identified from the post processed files. This protocol should be documented and added to any subsequent reporting of the project.

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