CRITFC

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Validation of a Long-range Dual Frequency Identification Sonar (DIDSON-LR) for Fish Passage Enumeration in the Methow River

Final Report-PSC Southern Fund 2004/2005 Project

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November 10, 2005

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Executive Summary

A long range model of a Dual Frequency Identification Sonar (DIDSON-LR) was operated in parallel with visual observations to validate reliability of the instrument to enumerate fish passage at distances up to 40 m. Two testing designs were used. The first involved manually passing a tethered salmon to and from across the field of a DIDSON-LR installed in a pond at the Washougal Salmon Hatchery (Washington Department of Fish and Wildlife, Washougal). The second involved making visual counts of naturally migrating salmon in the Methow River (Okanogan County, Washington). In both tests, data recorded for the visual observations was compared to that noted on concurrently recorded DIDSON-LR files. The visual and DIDSON data for the hatchery pond trials were 100% concordant. Of 55 visual observations of migrating salmon in the Methow River, 48 concordant observations were noted on the DIDSON-LR recordings. In seven instances, no observation was made on the DIDSON-LR recording. These discrepancies are more likely explained by improper installation of the DIDSON or observer error rather than technical inadequacy of the instrument. When operated at low frequency (0.7 MHz), the DIDSON-LR provided images of fish at distances to 42 m (the limit of our tests). For fish passing at the farther end of this range, the recordings were easier to read when a 20m window length was used in combination with a 20m Start Length, as opposed to a 40m Window Length and a 1 m Start Length. When operated at its higher frequency (1.2 MHz) the DIDSON-LR provided images of improved resolution, although the maximum distance at which it could be operated was 33 m - a 20 m Window Length and a Start Length up to 13 m. In either case (LF or HF), however, the level of resolution of the images was only sufficient to provide a qualitative measure of size and pattern of movement. The level of resolution did not to permit distinguishing between species of similarly sized fish, e.g., between Chinook salmon *Oncorhynchus tshawytscha* and steelhead *Oncorhynchus mykiss*, which were both migrating in the Methow River during our trials and had overlapping size ranges (total range 60 to 100 cm). Additional DIDSON-LR files recorded over extended periods without visual observation confirmed that salmon/steelhead passage at the Methow River site occurred primarily during the hours from 9 pm to 2 am. Use of a DIDSON-LR in a planned series of recordings should provide data of sufficient reliability to calculate an accurate estimate of net escapement of salmon/steelhead to an open system such as the Methow River. Photos and video clips illustrating operation of the DIDSON-LR and the effects of the different settings on resolution of the resulting images are provided at: http://www.critfc.org/didson-lr.

Introduction

Mid-Columbia summer Chinook salmon Chinook salmon *Oncorhynchus tshawytscha* have been designated as an exploitation rate indicator stock for the purposes of fisheries management and harvest regulation by the Pacific Salmon Commission (PSC 2000). This composite stock includes populations which return to the Wenatchee, Entiat, Methow and Okanogan rivers, each a tributary to the Columbia River in central Washington State. Evenson and Talbot (2003) reviewed available information on population size and life history for this stock of interest. They concluded that abundance data was of limited reliability, and highlighted the need for improved methods and technologies which will yield escapement estimates of increased accuracy and precision. Table 1 provides escapement estimates of summer Chinook to the Methow River for the past 15 years (NPCC 2004, and Todd Miller, Washington Department of Fish and Wildlife - WDFW, Wenatchee WA, personal communication).

Table 1 – Estimated annual escapement of summer Chinook salmon to the Methow River, based on expanded redd counts.

Year	Total Redd Count	Expansion Factor	Escapement Estimate
1990	409	3.10	1268
1991	153	3.10	474
1992	107	3.10	331
1993	154	3.10	477
1994	310	3.10	961
1995	357	3.10	1107
1996	181	3.40	615
1997	205	3.40	697
1998	225	3.00	675
1999	448	2.20	986
2000	500	2.40	1200
2001	675	4.10	2768
2002	2013	2.30	4630
2003	1624	2.42	3930
2004	973	2.25	2190

Accurate estimates of salmonid escapement - the number of adults which return to a river system for spawning in a given year - are essential to making informed assessments and fisheries management plans for natural populations. In some river systems, direct counts of fish in traps located in impassable weirs or dams can provide abundance estimates of high accuracy. However, many rivers systems remain unimpeded by such barriers or lack appropriate counting infrastructure, and alternative methods of escapement estimation must be used. In some instances, river conditions lend themselves to making direct visual counts from counting towers or with video recording equipment, or through use of various sonar instruments (single-beam, split-beam). However, technical and financial constraints to these methodologies make their use very limited. A widely practiced alternative indirect method of calculating escapement involves counting of redds during ground or aerial surveys. Redd count data can be summed and multiplied by an expansion factor [estimated average number of adults per redd, e.g., 3.1 (Meekin 1967), 2.5 (CRITFC 1995), 2.25 to 4.1 for the Methow River (Table 1)], to provide an estimate of total spawner abundance for a population. Performing redd counts requires no special equipment nor techniques, and state fisheries management agencies have performed annual redd counts on various river systems in the Pacific northwest for many years. Redd count surveys also provide a valuable means to census spawning area distribution, and to survey carcasses for size, sex-ratio and egg retention, for Coded Wire Tag (CWT) recovery, and to collect tissue for DNA analysis. However, sources for error in calculating escapement based on redd counts are numerous. Conditions of reduced water visibility, incomplete coverage (geographic and temporal), and redd superimposition will lead to undercounting of actual redd number. While, double counting, inclusion of “test redds” in the count, and a presumption that a female will dig only a single redd can lead to overcounting. In areas where two species are spawning during overlapping time periods, counts may be attributed to the wrong species. And, variation in the level of experience of observers will lead to decreased accuracy and precision for redd count data. Escapement estimates based on expanded redd counts, therefore, are of limited reliability (e.g., Mosey and Truscott 1999, Murdoch and Miller 1999, Dunham et al. 2001, Faurot and Kucera 2005).

Recently, a multi-beam ultrasonic instrument, called a dual-frequency identification sonar [DIDSON™; Sound Metrics Corporation (SMC), Seattle, Washington], was developed for viewing objects underwater. Reflections of objects passing through the ensonified area created by the DIDSON are electronically converted to optical images. When placed in a body of water and oriented to transmit horizontally, it produces a top-down ("bird's-eye") view of the conically-shaped ensonified field. This "acoustic camera" is not constrained by conditions of darkness or turbidity as are optical video systems, and provides much higher resolution than older single or split-beam sonar systems.

The standard model (DIDSON-S) operates at one of two frequencies - 1.8 MHz or 1.1 MHz. At the higher frequency (HF), the DIDSON-S projects 96 beams which create a 29^{o} conically shaped ensonified field. At the lower frequency (LF), the DIDSON-S projects 48 beams spaced further apart (0.6^{o} versus 0.3^{o}), creating a similarly sized ensonified field. When operated at HF, the DIDSON-S produces images with relatively high resolution for objects at close range within its field. However, attenuation of the sound waves as they travel through the water limits the maximum operational range of the DIDSON-S at HF to approximately 12 m for objects of the size and reflective properties of fish. Because sound attenuates in a medium less rapidly with decrease in frequency (Edelman 1994), the range of a DIDSON-S operating at LF increases to approximately 20 m. However, this is accompanied by a decrease in image resolution associated with the decreased number of beams which comprise the LF field, and the increased beam width and spacing (Belcher et al. 2001, Moursund et al. 2003, Belcher 2004).

Although initially developed in collaboration with the US Navy for underwater surveillance purposes, fisheries applications were soon apparent. Several tests of the capabilities of a DIDSON-S for visualizing passage of fish have been conducted over the past few years. The general conclusion is that at close range (<10 m) the instrument is a useful tool for enumerating fish and making gross observations of swimming behavior (Moursund et al. 2003, Belcher 2004, Johnson et al. 2004, Maxwell and Gove 2004, Faurot and Kucera 2005). However, the limited detection range of the instrument precludes its use in many situations where observation at greater distances is required. If the desired fisheries application is fish passage enumeration in an open river, this restricts use of a DIDSON-S to relatively small rivers, or to enumeration of species which tend to migrate close to shore. Positioning of a second DIDSON-S on the opposing shore will double the range of coverage, but at the expense of increased capital and operational costs.

Recently, SMC modified the DIDSON to increase its operational range by decreasing the frequency of the LF emission. This long range model (DIDSON-LR) emits 48 beams at 1.2 MHz (HF) or at 0.7 MHz (LF). In 2003, the Alaska Department of Fish and Game (ADF&G) conducted a preliminary range limitation trial of the DIDSON-LR when operated at LF (0.7 MHz). Using a variety of artificial targets, they found the instrument provided sufficient resolution to visualize the targets at distances of 75 m or more - twice the maximum range of the DIDSON-S operated at its lower frequency (Maxwell et al. *In preparation*).

In 2004, the Columbia River Inter-Tribal Fish Commission (CRITFC) received an award from the Southern Boundary Fund of the Pacific Salmon Commission to measure the operational limits of a DIDSON-LR and to assess utility of the instrument to provide escapement counts of migrating salmon in an open river ($\geq$40 m width). Specific objectives of this project were:

Objective # 1: Acquisition of expertise by CRITFC and Yakama Nation (YN) staff in use of the long range Dual-frequency Identification Sonar (DIDSON-LR) system for quantifying salmonid escapement to a free-flowing river.
Objective # 2: Assessment of range limitations of the DIDSON-LR for detecting fish passage at known distances in a controlled experiment.
Objective # 3: Assessment of the accuracy of the DIDSON-LR for enumerating fish passage, by comparisons with data obtained simultaneously by visual counts from an adjacent counting tower.

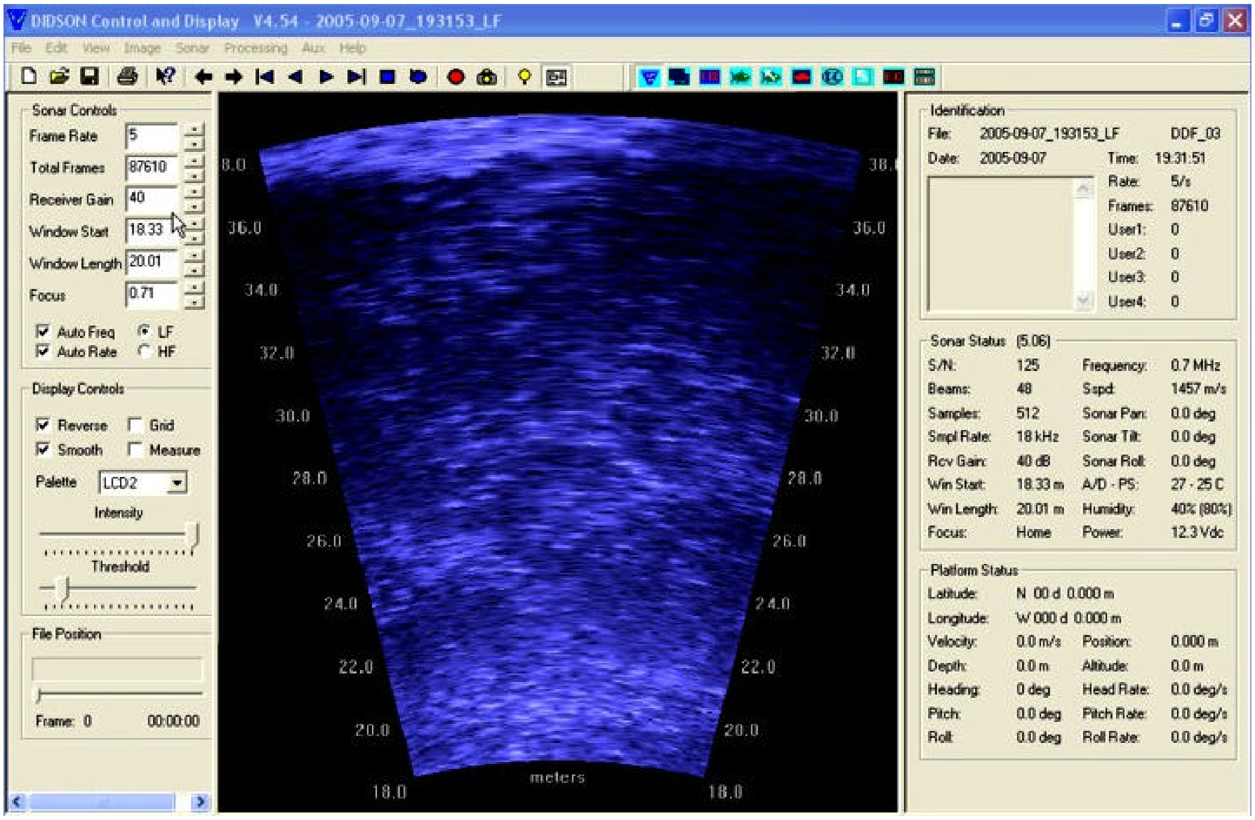
Methods

Prior to describing the project activities we will first provide a brief explanation on installation and functioning of the DIDSON-LR. Reception by CRITFC of a DIDSON-LR was made in November 2004. A stand to which the instrument could be mounted was then constructed, following a design modified from that used by ADF&G (Suzanne Maxwell, personal communication). The stand was built with 2-inch galvanized pipe connected with adjustable fittings (Kee Klamp™). The stand consisted of two inverted-T shaped legs (120 cm in height; "feet" 90 cm in length) connected with a horizontal crossbar (90 cm). From this bar was suspended a plate to which the DIDSON-LR is bolted (see photograph in Figure 1 below, and others available at (http://www.critfc.org/didson-lr).

Figure 1 – Illustration of the DIDSON-LR mounted on the stand.

The stand was placed in 50 to 120 cm deep water and the DIDSON transducer lens was adjusted to a depth approximately 20 cm below the surface, and angled slightly downward. At a shallower depth and/or higher angle, the DIDSON recording would show interference produced by reflections from waves and disturbance at the water's surface. At too steep of an angle, the DIDSON would not record objects near the water's surface; also, bothersome reflection from the pond/river bottom increases with proximity of the lens to the bottom. Once the instrument is correctly positioned, the primary settings made by the operator are Window Start (the distance at which the recording window begins), and Window Length (the total length of the field of view). We generally operated the DIDSON-LR with Gain at it's maximum setting of 40, and with Auto Freq and Auto Rate selected (boxes checked). The latter settings instruct the instrument to automatically choose the transducer frequency (HF versus LF) and maximum Frame Rate appropriate for the selected Window Start and Window Length settings. In our tests, we used a Start Length between 1 and 20 m, and a Window Length of 20 or 40 m. Depending on the total length of viewing (the sum of Start Length plus Window Length), the resulting Frame Rate generally varied between 4 and 6 frames per second (fps). The DIDSON-LR would operate at HF for total lengths below 33m, but would default to LF for total lengths greater than 33 m. See Figure 2 for an illustration of the screen generated by the DIDSON software.

Figure 2 – Illustration of the c omputer screen when operating the DIDSON-LR.



Our initial trials with the DIDSON-LR were conducted in late 2004 to early 2005 - first in the Washougal River, then in a pond at the Washougal Salmon Hatchery (WDFW, Washoughal WA), and finally in the Hood River adjacent to Powerdale Dam (Hood River OR). From July to September 2005, the DIDSON-LR was installed in the Methow River (Pateros WA, Okanogan County), adjacent to a counting tower site put in place as part of a project being conducted by CRITFC and YN (Southeast Sustainable Salmon Fund, "A Stock Assessment and Research Plan For Mid- Columbia River Summer Chinook", Project No. 45060). A summary timetable of project activities is provided in Table 2, followed by additional details for each set of trials.

For both the hatchery pond and the counting tower trials, the DIDSON-LR was set to record while the visual observations were taking place. Subsequently the files were independently reviewed by two researchers, who noted the time, distance and direction of moving objects. Review of the files was performed with Intensity and Threshold settings adjusted according to the preference of the observer, with or without use of Background Subtraction. The files were initially screened with the playback speed set between 40 and 80 fps - 10 to 16 times the rate at which they were recorded. This facilitated rapid review of the files, which in the case of the Methow River recordings sometimes involved long periods without any observed fish passage events. When a moving object was observed, the recording was stopped then replayed forwards and backwards at a slower speed to evaluate the nature of the object (relative size, swimming pattern, etc.), and the appropriate data was recorded.

Data noted during periods of visual observation from the counting tower were compared to that from the corresponding DIDSON files, providing a means to assess the efficacy of the DIDSON-LR to visualize known events of Chinook salmon and steelhead *Oncorhynchus mykiss* passage. The DIDSON-LR was operated both at high or low frequency, and at alternative Start and Window Length settings.

Table 2 – A summary timetable of project activities.

	2004							2005										
2004-2005 Project Activity	**J**	**J**	**A**	**S**	**O**	**N**	**D**	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**
Preparation – ordering of DIDSON-LR, and of other equipment and materials		X	X	X														
Delivery – reception of instrument at Sound Metrics, Kenmore WA, with 2-hr training of project personnel; construction of DIDSON stand						X												
Initial trials conducted in the Washougal River, Washougal WA.						X	X											
Controlled Visual-DIDSON tests conducted at the Washougal Salmon Hatchery								X	X									
Fish Trap release-DIDSON trials conducted at Powerdale Dam, Hood River OR									X	X								
Set-Up of counting tower equipment (tarps, lights, generator) in the Methow River, Pateros WA													X	X	X			
Performance of DIDSON-Visual counts at the counting tower site, plus additional extended DIDSON recordings during periods without visual counts.														X	X	X		
Data analysis – independent reading of DIDSON-LR files by two researchers, cross-checking of results, and comparison to visual count data														X	X	X	X	
Reporting – summarization of collected data and comparative analyses; general assessment of equipment operation and data quality; submission of final report to PSC																X	X	X

Washougal River Trials – Preliminary trials to acquire initial experience in use of the DIDSON-LR were conducted in the Washougal River, at a site approximately one mile upstream from its confluence with the Columbia River. The DIDSON-LR was installed near the shore, oriented both across the river and downstream parallel to shore. The instrument was operated at LF and HF, with 20 m or 40 m Window Lengths and varied Start Lengths, and in Auto Freq mode to maximize the Frame Rate for each setting combination (ranged from 4 to 8 fps). Frozen Chinook salmon carcasses were used as observation targets. The carcass was attached through the jaw to a light rope and drawn across the ensonified field, either by manually tossing the fish out and pulling it back, or by trolling the fish behind a driftboat.

Washougal Salmon Hatchery Trials – Difficulties encountered at the Washougal River site indicated that a situation where conditions were more easily controlled was needed. The manager of the Washougal Salmon Hatchery (WDFW, Washougal WA) was contacted for permission to conduct trials in a pond or raceway there. We were provided access to their broodstock holding pond – an asphalt-bottom pond approximately 45 m in length, bisected down its length with a wall and a catwalk, which subdivided the pond in half – one half approximately 10 m in width and the other approximately 20 m in width. The DIDSON-LR was placed at one end of the pond and oriented towards the opposite end. The instrument was operated at LF with either a 1.7 to 3 m Start Length and 40 m Window Length and a corresponding Frame Rate of 5 to 8 frames per second (fps), or a 20 to 24 m Start Length a 20 m Window Length and a 5 fps Frame Rate. Initially, visual observations and DIDSON-LR recordings were made of live fish present in the narrow side of the pond. Later, the broodstock pond was drained to remove (almost) all fish, then refilled, and a series of trials was conducted with the DIDSON-LR installed in the larger half of the pond. During these tests a live coho salmon (approximately 60 cm length) was tethered on a drop line from the middle of a rope, and served as a test target. Two researchers, one on the cat walk and one on the opposite shore, each holding an end of the rope walked up and down the length of the pond in an unprogrammed manner, drawing the target fish back and forth across the pond. At each pass when the fish was approximately in the middle of the pond, its distance from the DIDSON was estimated and noted, along with the time and direction of movement (left or right). Subsequently, the DIDSON files were read (blindly) and the same information was recorded. The visual and the DIDSON data were then compared for concordance.

Powerdale Dam Trials - We wished to conduct trials to record fish passage in a more natural setting, and arranged to operate the DIDSON-LR on days when winter steelhead were being released from the fish trap at Powerdale Dam, operated by the Oregon Department of Fish & Wildlife (ODFW). The DIDSON was positioned just upstream of the outlet from the fish trap, and recordings were to be made as fish were released upstream.

Methow River Counting Tower Trials – The DIDSON-LR was then transported to the Yakama Fisheries Field Station (Twisp WA) for use in conjunction with the tower counting project. The tower counting site was located approximately 1.9 km upstream from the confluence of the Methow River with the Columbia (N 48^{o} 03'19.44", W 119^{o} 55'38.41"). A streamside cliff there provided a vantage point approximately 20 m above the water level. The observation point overlooked the middle of a long, shallow glide (approximately 250 m long and 1 to 1.5 m deep), where the river was approximately 40 m wide. As an aid to visualization of fish passing up or downstream in the river, a series of white tarps were placed end-to-end across the river bottom - see bottom profile (Figure 3). Measurements for this profile were made on August 31, 2005; the highest water level at the site (approximately 20 cm greater) was in early July, and the lowest level (approximately 10 cm lower) was in early September. A temperature data logger was placed in the water during the months of August and September 2005, the period during which most of the DIDSON-LR recordings were performed. A profile of the average daily water temperature over this period is provided in Figure 4.

Figure 3. River bottom profile at the tower counting site in the Methow River.

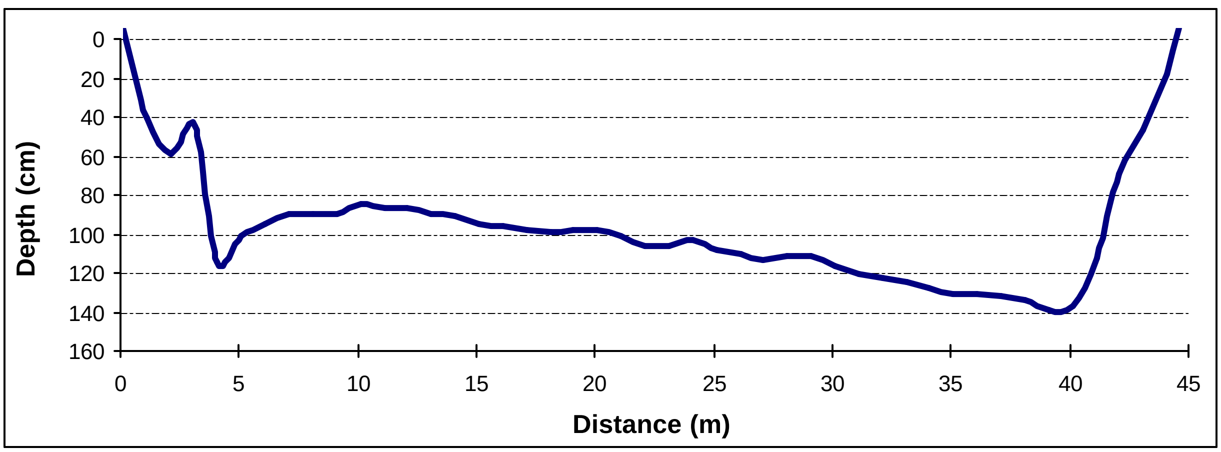
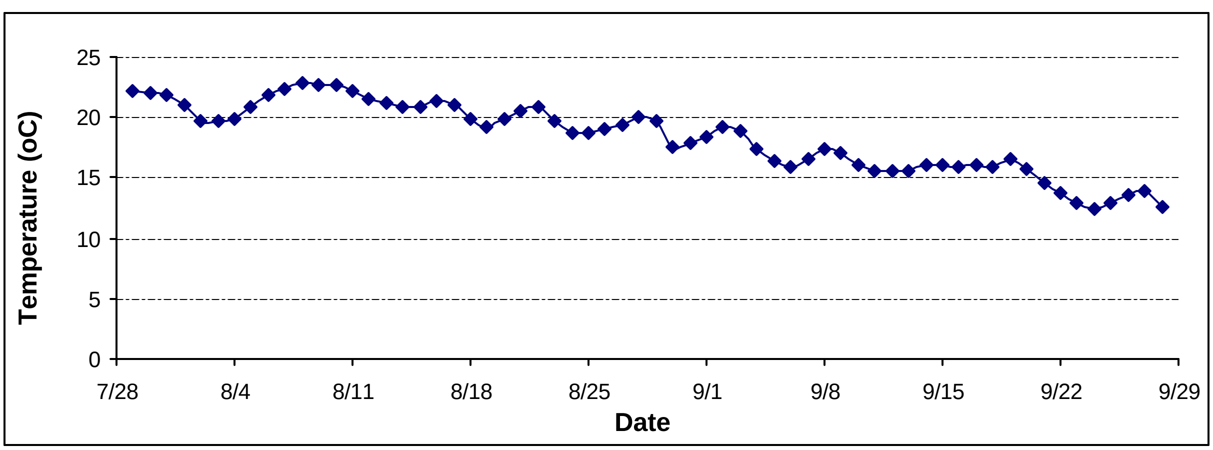


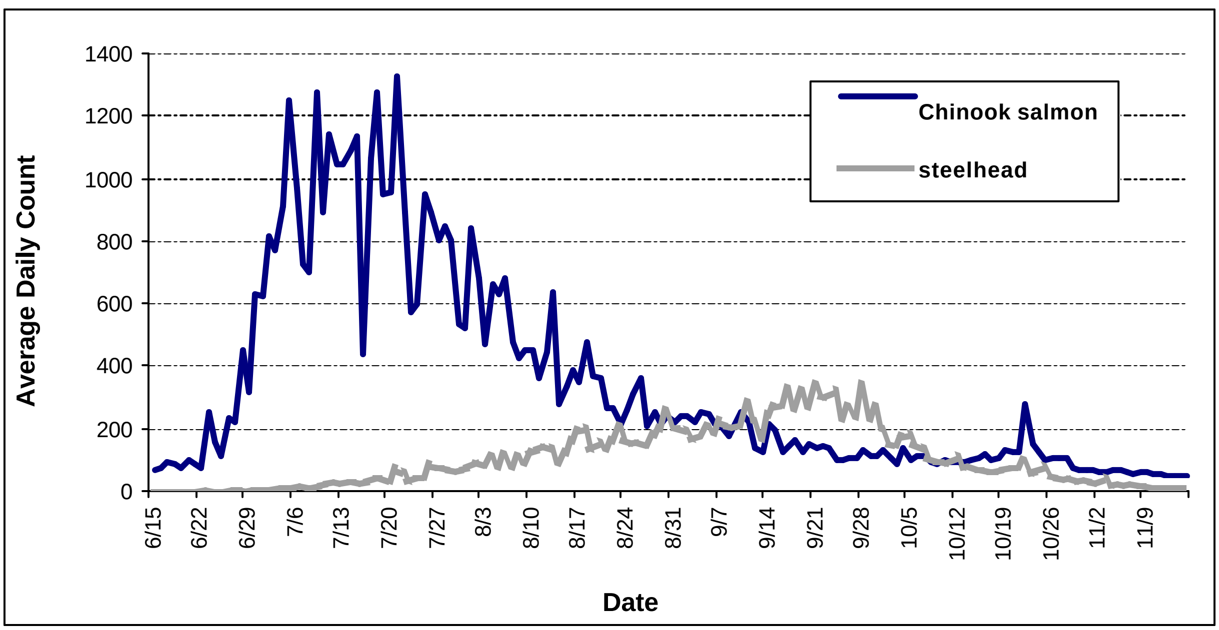
Figure 4. Profile of average daily water temperature for the period 7/29/05 to 9/28/05 at the tower counting site in the Methow River.



A series of visual counts were conducted on 22 different days during July to September 2005. These counts involved a total of 97 hours of observation during which DIDSON-LR files were simultaneously recorded. On each of these days the DIDSON-LR was placed in the river, approximately 20 m upstream of the white tarps, and oriented perpendicular to the water flow. For most readings, the DIDSON-LR was located approximately 2 to 4 m from the near shore and oriented to view across the river, parallel with the tarps. The instrument was operated primarily at LF with either a 1 m Start Length and 40 m Window Length, or a 17 to 20 m Start Length and 20 m Window Length. The Frame Rate was 4 to 5 fps for both setting combinations. At the end of the season, the instrument was moved out towards the middle of the river and operated at HF with a 7.5 m Start Length and 20 m Window Length (6 fps).

When performing the visual counts, the researcher constantly observed the river for passage of large fish, judged to be anadromous salmonids. Both summer Chinook salmon and steelhead were migrating into the Methow River during the July to September period of these trials (see Figure 5 for average daily counts of each species through the fish ladders at Wells Dam, located on the Columbia River 12.5 km downstream of the confluence of the Methow River). Spring Chinook and coho salmon also populate the Methow, however their migration times are generally earlier and later, respectively. Because the summer Chinook and steelhead overlap in their size ranges (overall range 60 cm to 100 cm in length), observations were noted of migrating salmon/steelhead, with no attempt made to distinguish between them. It was, however, necessary to distinguish between salmon/steelhead and smaller resident freshwater fish present at the site. In particular, largescale suckers *Catostomus macrocheilus*, which range in size up to 40-50 cm in length, were present and in relatively large numbers. The observer needed to be attentive to distinguish between large individuals of this species and smaller salmon/steelhead. Fortunately, the two types of fish also exhibited general differences in swimming pattern. The salmon/steelhead tended to move rapidly over the tarps, while the suckers tended to swim more slowly and for only short distances, often hovering over or near the tarps for some period of time.

Figure 5. Average daily passage of Chinook salmon and steelhead counted at Wells Dam for the years 2000 to 2004.



When a salmon/steelhead was observed passing over the tarps, the researcher noted the time, approximate distance from the near shore, and the direction of movement (upstream or downstream). At a later date, the DIDSON files were read independently by two researchers. The researchers noted each instance of passage of an image judged to be that of a salmon/steelhead, based on size and movement pattern of the image, and recorded the time, distance and direction. Subsequently, each DIDSON-LR observation was reviewed by the two researchers together for confirmation. The visual observations were then compared with the corresponding DIDSON-LR data for concordance.

Many hours of additional DIDSON-LR files were recorded during times without visual observation, including several overnight periods. Combined with files made during visual observation periods, a total of 203 hours were recorded on 26 different days. These files were read independently by two researchers, then all observations were reviewed together, as described above.

Results

Washougal River Trials – Results of these trials were disappointing. The frozen salmon carcasses proved to be poor targets. They seemed to not be very echogenic, and because the carcass tended to swirl as it was pulled through the water, its image on the DIDSON recording erratically changed in size and intensity, making it difficult to follow the image as it moved across the computer screen. More frustrating, however, were a series of technical problems we encountered with the instrument. These included instances when the electronic connection between the computer, topside box and/or DIDSON-LR did not occur despite checking and rechecking all plugs and cables. Additionally, we encountered instances when the electronic connection was good but the screen showed only a portion of the ensonified field, or showed odd patterns of "interference" or other aberrant electronic signals. Calls were made to SMC to troubleshoot the problems. An updated version of the software was installed, however, this did not completely resolve the situation.

Washougal Salmon Hatchery Trials – DIDSON recordings performed in the hatchery pond while live broodfish were present provided distinct images of these fish to the furthest end of the pond (approximately 40 m distant from the DIDSON-LR). Reading of these recordings was complicated, however, due to the presence of large numbers of salmon parr which had escaped from an upstream rearing pond. Despite their small size, the parr reflected the sound waves creating substantial "sparkling" in the recording. Subsequent trials (after the pond had been emptied of parr and broodfish) using a tethered target coho salmon were conducted. Unlike the Chinook carcasses tested previously, the live coho maintained an upright position in the water column as it was pulled perpendicular to the sound waves, creating a regular oblong moving image on the DIDSON screen/file. Data for distance, time and direction of movement of the target fish were recorded both for the visual observations and from the DIDSON-LR files. Comparisons between data sets showed essentially 100% concordance (Appendix I). The small differences of a few m for distance and sec for time were deemed as being within observer estimation error. A few passes of the target fish were not observed on the DIDSON-LR file, although in these cases the fish was likely outside the field of view settings of the instrument. Occasionally, passage of the image of the target fish was not clearly visible. These instances were often associated with times when twisting/knotting of the rope caused the researchers to have to stop pulling in order to disentangle the rope. This caused the fish to cease movement and descend to the bottom, rendering it more difficult to detect. While the target fish was moving, however, its image was readily discernable on the DIDSON-LR files at all distances within each of the combination Start Length/Window Length/Frame Rate settings tested. Unfortunately, testing at this site was again interrupted by intermittent technical problems with the instrument, prompting additional calls to SMC.

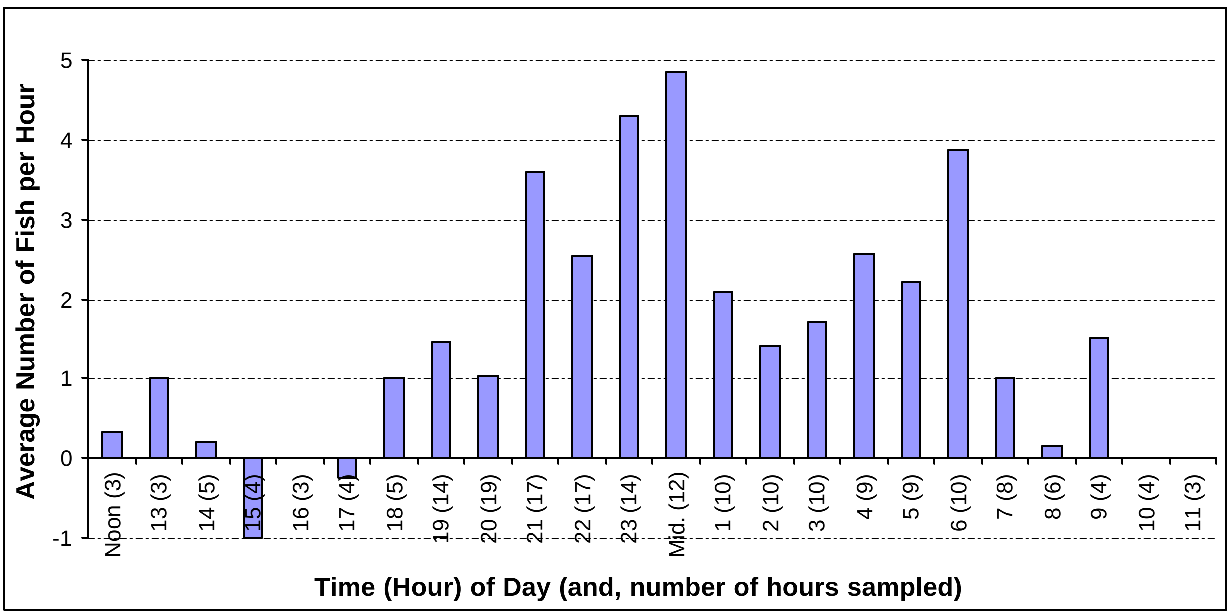
Powerdale Dam Trials – Two attempts were made to record passage of steelhead following their release from the fish trap. In both cases, however, the DIDSON-LR could not be made to operate properly. Further trials were abandoned, and the instrument was returned to SMC for inspection and repair, which consisted of removal of an air bubble from within the lens, installation of a software update, and bench testing which showed it to operate properly.

Methow River Counting Tower Trials – Preliminary testing of the instrument at the tower counting site showed the DIDSON-LR to again be operating erratically, and the instrument was returned once more to SMC. This time, analysis seemed to indicate hardware problems associated with the CPU and/or A/D cards, both of which were then replaced. However, in subsequent field testing, yet another problem was detected – a defect in the wire of the 24-volt power supply. A replacement inverter was sent by SMC, and since that time the instrument has operated reliably.

Data for visual observations of salmon/steelhead are summarized in Appendix II, presented side-by-side with data for observations made on the corresponding DIDSON-LR file. Most observations involved individual fish, although occasionally 2 or 3 fish were observed moving together. Of 55 visual observations totaling 70 fish, 48 of the observations were confirmed by notation of similar data for time, distance and direction of salmon/steelhead passage on the corresponding DIDSON-LR files. For the remaining 7 visual observations, however, a fish was not observed in the DIDSON-LR file.

Counts of fish passage for all DIDSON-LR files recorded over the July to September 2005 period were compiled and a figure for net hourly upstream migration was calculated (the total number of downstream movement events within a given hour was subtracted from the total number of upstream movements). This data is summarized in Appendix III. If the time of recording within an hour was less than 20 min, no data were recorded in the summary table. If the time of recording was between 20 and 60 min within an hour, the count was expanded proportionately to provide an estimated hourly in-migration rate. Using all available data, an average migration rate per hour within days was calculated, and is illustrated in Figure 6.

Figure 6. Average net upstream migration rate (fish per hour) for all DIDSON-LR files recorded in 2005 at the tower counting site in the Methow River.



Discussion

In the controlled situation within a hatchery pond, the DIDSON-LR produced distinct images of a target salmon drawn back and forth across the ensonified field at distances up to 42 m – the far end of the pond. Similarly, in trials conducted to enumerate salmon/steelhead migration in an open river (Methow River), 48 of 55 visual observations of passing fish were also noted in the corresponding DIDSON-LR files. The reasons why the remaining 7 visual observations were not detected in the DIDSON-LR files, are likely not associated with technical problems or limitations of the instrument. Instead, the following explanations are more probable: a) observer error - either improper recording of the time and distance data, or mis-identification of a smaller fish (e.g., largescale sucker) as a salmon/steelhead, b) improper positioning of the DIDSON-LR which created a shadowed area within the field (indeed, there is a dark area in the upper left portion of some of the files, where with the deepest part of the river channel is located, and which is possibly shadowed), or c) passage of a visually observed salmon/steelhead across the counting tower tarps which then turned out of range of the DIDSON-LR, located 20 m upstream.

While the DIDSON-LR reliably produced images of passing salmon/steelhead under the conditions of our tests, use of the instrument for escapement counting is vulnerable to the same tedium-related error as tower counting or reading of video recordings. Inattention was no doubt the cause for a few instances during our visual-DIDSON-LR trials on the Methow River, of fish passage events noted on DIDSON-LR files but not observed visually by the researcher from the counting tower. Likewise, we had several instances of salmon/steelhead passage noted in the data sheet of one reviewer but not the other. It is for this reason that independent review by two researchers, followed by review together to confirm inconsistencies between records is needed to improve accuracy and precision of the data. Reviewing of DIDSON-LR files is a tiresome and boring task. However, remaining attentive is essential in order for a reviewer to not miss any passage events and to classify an image to the correct type of fish, and thus produce an accurate count. For files where passage events are rare, and interspersed between long periods of inactivity, the temptation is to increase the Frame Rate to very high levels, in order to accelerate the review process. However, this runs the obvious danger of increasing the number of passage events which are undetected. To minimize observer error caused by tedium and inattention, we found that we could review DIDSON files for only an hour or two at a sitting, after which a break or a change to a different activity was necessary.

The level of resolution of the DIDSON-LR images of salmon/steelhead was adequate for making counts of fish passage, but was inadequate for making more than a qualitative estimate of size. A fish swimming through the ensonified field created an oblong pixelated image on the computer screen. The image reflected the overall length and width of the fish, but detail at a finer scale, e.g., fin number and placement, depth, body shape, etc. used to differentiate species, could not be discerned. And even size of an image could not be quantified properly. Between successive frames, this image could vary substantially in length and width, for reasons related to the limits in lateral and longitudinal resolution, and to confounding signals from reverberation and background noise. Stopping the recording to make quantitative measurements of the image therefore produced spurious results. Only when the image was in motion, at 20 or more fps, could the observer make a qualitative visual estimate of size and pattern of movement. As such, distinguishing between size classes of fish was possible only when the size classes were markedly different. Resolution of the DIDSON-LR images increased when the instrument was operated at HF and with shorter Window Start and Window Length settings, however, the improvement remain limited in magnitude.

To understand how operation of the DIDSON affects the image of an object as it appears on the computer screen, it is necessary to differentiate the three aspects which compose image resolution – lateral, longitudinal and temporal resolution (Edelman 1994). Lateral resolution, also referred to as cross-range resolution, is determined by the distance between sound beams at a given distance from the sonar. The smaller the cross-range spacing the greater the number of beams that will strike an object at a given time - providing more information with which to describe the shape of the object, and permitting distinguishing between multiple objects located in close proximity. Longitudinal resolution, also referred to as down-range resolution, describes the ability of the instrument to distinguish between objects at different distances from the sonar. Temporal resolution determines the "smoothness" of movement, as perceived by the reader, of an object moving through the ensonified field.

The primary constraint to resolving images of fish passing through the field of a DIDSON-LR is related to limits in lateral resolution. The DIDSON-LR (at both HF and LF) emits 48 sound waves with a 0.6^{o} spacing, creating a 29^{o} ensonified field which has a cross-range distance approximately one half the down-range distance. Thus at 10 m down-range the cross-range width of the field is 5 m, and the cross-range distance between sound beams will be 5 m ÷ 48 = 5 cm. At twice the distance (20 m), the lateral resolution will be doubled (10 cm), and so on. The form and detail in the swimming motion in the image of a passing fish thus becomes less well resolved as distance from the DIDSON increases, and the ability of an observer to distinguish between objects of increasingly similar size classes becomes increasingly difficult.

Lateral resolution is also decreased with the increase in beam width and wave length associated with lower frequency sound waves. At HF, the beam width of the DIDSON-LR is 0.5^{o}, whereas at LF the beam width is 0.8°. Thus, while the decreased frequency at LF increases operational range of the instrument, there is a concomitant decrease resolving power.

Additionally, because sound attenuates in direct proportion to the distance it travels through a medium, the intensity of the reflected sound waves will decrease as distance of the object from the instrument increases (Edelman 1994). To counteract this effect, the DIDSON software incorporates a compensation algorithm which adjusts the intensity of an image on the screen in proportion to the distance. Objects located at different distances within the field of view therefore appear to the viewer as being of similar intensity.

Longitudinal resolution of a DIDSON-LR is determined by the manner which the instrument groups signals from reflected waves into fixed time increments, called range bins – the time delay between emission of a sound wave and detection of its reflection being directly proportional to the distance of the object from the sonar. The DIDSON-LR divides the signals it receives into 512 range bins, and longitudinal resolving power is calculated as the Window Length divided by 512 . A such, for a 10 m Window Length the down-range resolution will be approximately 2 cm (10 m ÷ 512). As the Window Length setting is increased, the signal distance increase proportionately, and resolution decreases. It is advantageous, therefore, to use as short a Window Length setting as possible, while still providing the needed coverage. Decreasing the window length has the added advantage of increasing the size of the field created on the computer screen, which facilitates review of the recordings. At the Methow River site we observed that essentially 100% of the salmon and steelhead migrated past in the farther half of the river – where the depth was greater and the current faster. Therefore, we were able to operate the DIDSON-LR with a 20 m Start Length and 20 m Window Length, as opposed to a 1 m Start Length and 40 m Window Length, and remain confident that we were missing none, or only a very few, of the passing salmon/steelhead. With the shorter Window Length, the images were larger and somewhat better resolved, facilitating differentiation, for example, between images of large largescale suckers versus small salmon/steelhead. Of note: the instrument does have a Zoom option with which to produce a magnified view of a subsection of the field. However, use of the Zoom option is time-consuming and significantly slows down the file review process.

The temporal resolution of a DIDSON recording is dictated by the Frame Rate at which the recording is made. We typically operated the DIDSON-LR in Auto Frequency mode, which automatically sets the Frame Rate as high as permissible within the chosen Window Length and Start Length settings. Sound travels through a medium at a constant rate (Edelman 1994). Therefore, the longer the total length of the field, the longer the time delay between emission and reception of the sound waves, and the lower the rate at which signals can be processed to form successive image frames. Of note, frequency of a sound wave does not affect the speed at which it travels through a medium (Edelman 1994), so switching between HF and LF for a given set of Start/Window Length settings does not change the maximum Frame Rate.

At the Methow River site, we typically operated with a total distance of approximately 40 m, and Frame Rate for the DIDSON files was 5 to 6 fps. Review of the files when played back at this same Frame Rate is difficult. The image is very “choppy” and poorly resolved. Increasing the playback rate to a minimum of 3 to 4 times the recorded rate (to 20 fps or greater) was necessary to “smooth out” the movement sufficiently for the reviewer to be able to assess the size and movement pattern of the fish. This playback rate is in fact similar to the Frame Rate of commercial movies (24 fps) and television (30 fps) (http://searchnetworking.techtarget.com/sDefinition/0,,sid7_gci213531,00.html)

There were obvious limits to resolution of images produced by a DIDSON-LR, particularly when operated at LF. Nonetheless, the instrument will provide images of passing salmon/steelhead in an open river at distances up to 40 m (and likely farther) of sufficient clarity for accurate enumeration. However, two issues remain of concern in the context of our objective to use the DIDSON-LR for summer Chinook salmon escapement estimation in the Methow River. The first concerns differentiation between salmonid species. The co-migrating summer Chinook and steelhead overlap in size range, and the DIDSON-LR offered no means to distinguish between the two. To estimate escapement of summer Chinook alone, the total salmon/steelhead counts produced by the DIDSON-LR would have to be reduced by a factor representative of the proportion of the count attributable to steelhead. One means to estimate this factor would be to calculate summer Chinook/steelhead ratios from data collected at Wells Dam (see Figure 5). Because this ratio changes (generally increasing) over the summer Chinook migration period, a different factor should be calculated on a weekly basis. However, additional aspects must also be considered to improve the accuracy of this estimated ratio, including the time delay between passage at Wells Dam and passage at the counting site (e.g., see Appendix IV), and changes in these proportions determined at Wells Dam relative to the proportions for fish which migrate up the Methow River as opposed to migrating further upstream in the Columbia towards Chief Joseph Dam and the Okanogan River system.

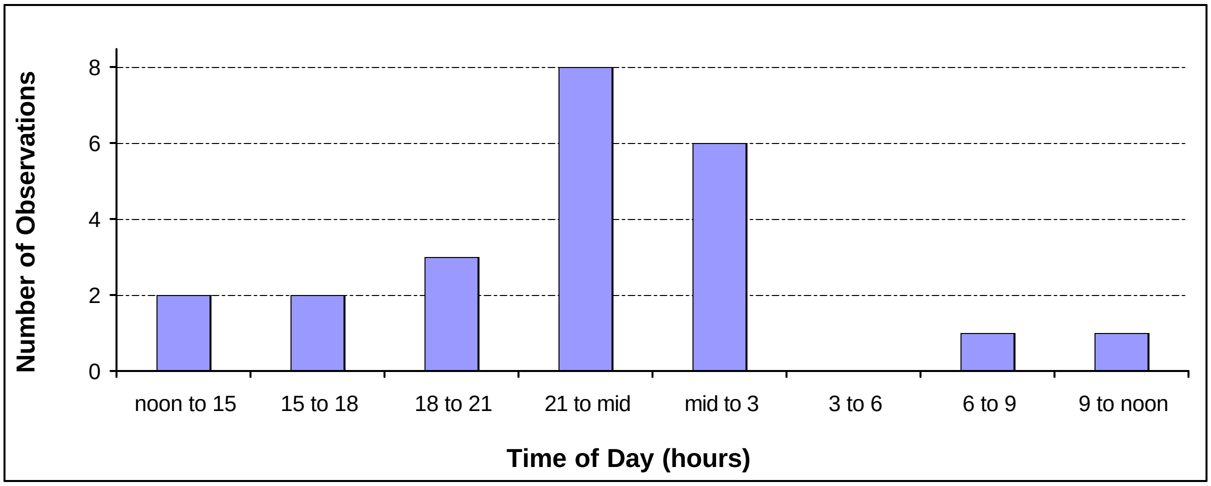
Our second concern is the level of certainty with which we could qualitatively distinguish between anadromous salmon/steelhead and residential freshwater fish, the largest of which are largescale suckers (ranging up to 40-50 cm in length). Not only did the size range of the suckers approach that of smaller salmon/steelhead, the suckers were present at the counting site in large numbers (see video clips at http://www.critfc.org/didson-lr). Images of small salmon/steelhead and large suckers were sufficiently similar, that a qualitative differentiation between the two based on size of the image alone was sometimes uncertain. Fortunately, the differences in swimming pattern of the two types of fish observed visually were even more apparent in the DIDSON-LR files. With both a qualitative estimate of size from the image on the DIDSON-LR file and an appreciation of the movement pattern, we felt relatively confident in our ability to distinguish between salmon/steelhead and largescale suckers. Nonetheless, the stop-and-go swimming pattern of the suckers was not systematic - there were instances where small images, which certainly must have been those of suckers, did move up or downstream in a steady directed manner, similar to the salmon/steelhead. Thus for some observations, we were less certain about our decision that a particular image was that of a sucker or of a salmon/steelhead. For these cases in particular, it was helpful that the files were reviewed independently by a second researcher, followed by review together to reach a consensus for those observations which did not concord initially.

In addition to making DIDSON recordings concurrently with visual counts for validation purposes, we also made numerous additional recordings. Part of the reason for doing so was our concern with the low number of visually observed fish, relative to the higher numbers we expected in view of recent annual escapement estimates of summer Chinook to the Methow River ranging from 2000 to 4000 fish (Table 1). Even after the lights were installed in order to conduct evening/nighttime counts, the number of visually observed fish was far too low relative to the number that surely must be migrating up the river. The extended DIDSON recordings permitted us to confirm that peak migration of salmon/steelhead at the counting site was indeed occurring shortly following nightfall (Figure 6). The recordings also indicated that presence of the counting panels and the bright illumination used during nighttime visual counts tended to delay migration of the fish. For each of the seven days when the DIDSON was allowed to record overnight following a visual count made during the initial hours after nightfall, peak migration occurred within the hour immediately after the lights were turned off (Appendix III). Migration continued overnight at rates generally higher than during daylight hours, with possibly a second peak near dawn.

While these DIDSON-LR recordings were not made following a sampling regime that would permit valid statistical analysis of differences in hourly migration rate within days, they do illustrate the trend of peak migration following nightfall (Figure 6). Also, corroborating data on migration timing at the counting site were obtained from a WDFW/CRITFC/YN collaborative radio-tracking project. On one to three days per week over the duration of the Chinook salmon migration in 2005, a sample of wild adults (presence of an adipose fin clip; hatchery-produced summer Chinook are adipose fin-clipped) were captured in the Wells Dam fish ladder, radio-tagged, then released above the dam. Radio receivers were installed upstream in the Columbia, Methow and Okanogan rivers to assess migration patterns of the fish, including one located immediately upstream of the tower counting site on the Methow River. At present, 23 fish have been detected at this site. Data for date and time of detection, as well as sex and date of tagging, are provided in Appendix IV. The number of observations per 3-hour time period within days is illustrated in Figure 7, and provide further evidence that peak migration at this site occurs during the hours following nightfall. Such within-day differences in migration rate should be taken into consideration in the design of a DIDSON-LR sampling protocol for a given river. (Of interest, the largescale suckers as observed in the

DIDSON files, showed a general diurnal pattern of movement - downstream at nightfall, and upstream at dawn.)

Figure 7. Time of passage of 23 in-migrating Chinook salmon radio-tagged at Wells Dam in 2005, and detected by a receiver located immediately upstream of the tower counting site in the Methow River.



For several months our DIDSON-LR functioned erratically – working correctly sometimes, and not working at other times. The problems would occur in an apparently unpredictable manner, and the variety and intermittent nature of the symptoms rendered troubleshooting very difficult. Testing at SMC eventually indicated possible defects in the CPU and/or A/D card, and we discerned that there was a "loose connection" in the wire of the power supply. SMC replaced the defective parts (May and August 2005, respectively), and installed current software updates. Since the latter repair, the instrument has worked reliably. We have personal experience only with the instrument we purchased, and cannot attest to the reliability of DIDSON sonars in general. SMC assures us that our problems were unique, likely related to defects in the original manufacture of the parts, and that the experience of other fishery agencies is that the DIDSON is a highly dependable field instrument.

Conclusions/Recommendations

A DIDSON-LR was tested in parallel with visual observation of controlled fish movement within a hatchery pond, and of naturally migrating fish in an open river (Methow River, Okanogan County WA). In the hatchery pond, observations of fish movement noted in simultaneously recorded DIDSON-LR files were 100% concordant with visual data. Likewise, 48 of 55 visual observations of migrating salmon In the Methow River were confirmed in the corresponding DIDSON-LR files. In 7 instances a corresponding image was not observed, however observer error or problems in the placement of the instrument in the river provide likely explanations for the discrepancies, as opposed to technical limitations of the instrument.

In sum, our tests indicate that the DIDSON-LR will produce readily observable images of fish swimming through its ensonified field, at distances of 40 m (the limit of our tests), and no doubt further. These images increase in size and intensity with increase in size of the moving object (fish). However, the level of resolution (the form, size and intensity of the image) is not high, and permits at most a qualitative measure of relative size (length and width) of the fish which created the image. The limits in resolution of the DIDSON-LR preclude differentiating between fish of overlapping size ranges, such as summer Chinook salmon and steelhead which were both migrating into the Methow River during our study. Additionally, distinguishing between passage of large largescale suckers (maximum size 50 cm) and small salmon/steelhead (50+ cm) was difficult based on size/intensity of the images alone. However, because the two types of fish also exhibit differences in swimming pattern, we were able to use to the two criteria together to differentiate between them with what we deem to be relatively high certainty.

Resolution of the DIDSON-LR is highest when operated at HF versus LF, and when using a shorter Window Length. When operated at HF, the maximum Window Length setting permitted is 20 m, although the Start Length can be set at up to 13 m which provides viewing out to a maximum of 33 m. If this distance is inadequate, switching to LF will be necessary. When operated at LF, the Window Length setting can be increased to 40 or 80 m. However, if one wishes to enumerate fish passage over such a long range, it may be preferable to set the DIDSON-LR to perform a succession of sample counts using a shorter Window Length (e.g., 20 m) and a timed series of different Start Lengths (e.g., 1, 20 and 40 m). Photos and video clips illustrating operation of the DIDSON-LR and the effects of the different settings on resolution of the resulting images are provided at: http://www.critfc.org/didson-lr.

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Appendix I - DIDSON-LR validation trials conducted in parallel with visual observations of a taget salmon, in a pond at the Washougal State Salmon Hatchery (Washington State Department of Fish and Wildlife, Washougal WA).

Trial #1 — Dec. 20, 2005

Frequency: HF
Frame Rate (fps): 8
Start Length (m): 1.68
Window Length (m): 20.12

Note: * - fish at surface
** - stoppage due to knot

Obs.	Visual Data				DIDSON Recording				Difference Visual - Recording) Time	Distance
No.	Time	Dist. (m)	Direction	Note	DID.Time	Dist. (m)	Direction	Note	(sec)	(m)
1	11:39:50	17	R		11:39:52	18	R		-2	-1
2	11:40:26	15	L		11:40:34	16	L		-8	-1
3	11:41:00	17	R		11:40:58	17	R		2	0
4	11:41:30	13	L		11:41:37	14	L		-7	-1
5	11:42:00	10	R		11:41:56	11	R		4	-1
6	11:42:38	12	L		11:42:38	13	L		0	-1
7	11:43:01	12	R		11:42:58	13	R		3	-1
8	11:43:30	9	L		11:43:31	10	L		-1	-1
9	11:43:58	12	R	*	11:43:54	15	R		4	-3
10	11:44:38	14	L		11:44:37	15	L		1	-1
11	11:44:56	14	R		11:44:53	17	R		3	-3
12	11:45:29	8	L		11:45:31	10	L		-2	-2
13	11:45:53	4	R		11:45:55	6	R		-2	-2
14	11:46:28	3	L	**	11:46:37	5	L		-9	-2
15	11:47:46	8	R		11:47:45	10	R		1	-2
16	11:48:20	13	L		11:48:22	16	L		-2	-3
17	11:48:48	8	R		11:48:47	10	R		1	-2
18	11:49:20	6	L		11:49:20	8	L		0	-2
19	11:49:59	19	R	**	11:49:56	22	R		3	-3
								Average :	-0.6	-1.7
								Stdev :	3.9	0.9

Trial #2 — Dec. 20, 2005

Frequency: LF
Frame Rate (fps): 5
Start Length (m): 20.11
Window Length (m): 20.12

Note: * - fish at surface
** - stoppage due to knot

Obs.	Visual Data				DIDSON Recording				Difference Visual - Recording) Time	Distance
No.	Time	Dist. (m)	Direction	Note	DID.Time	Dist. (m)	Direction	Note	(sec)	(m)
1	12:17:43	24	R		12:17:42	25	R		1	-1
2	12:18:01	24	L		12:18:10	25	L		-9	-1
3	12:18:32	28	R	*	12:18:34	28	R		-2	0
4	12:18:55	30	L		12:18:57	31	L		-2	-1
5	12:19:23	40	R		(off screen?)					
6	12:19:47	44	L		(off screen?)					
7	12:20:25	38	R	*	12:20:28	40	R		-3	-2
8	12:20:50	34	L		12:21:01	36	L		-11	-2
9	12:21:25	26	R		12:21:27	27	R		-2	-1
10	12:21:48	29	L		12:21:57	31	L		-9	-2
11	12:22:28	34	R		12:22:28	36	R		0	-2
12	12:22:59	31	L		12:23:04	35	L		-5	-4
13	12:23:27	38	R	*	12:23:24	40	R		3	-2
14	12:23:51	40	L		(off screen?)					
15	12:24:36	34	R		12:24:38	38	R		-2	-4

16	12:25:18	32	L		12:25:16	34	L		2	-2
17	12:25:45	27	R	*	12:25:44	30	R		1	-3
18	12:26:28	25	L		12:26:35	27	L		-7	-2
19	12:27:21	31	R		12:27:25	32	R		-4	-1
20	12:27:54	32	L		12:27:54	34	L		0	-2
21	12:28:21	38	R		12:28:21	40	R		0	-2
22	12:28:51	38	L		12:28:55	40	L		-4	-2
23	12:29:16	42	R	*	(off screen?)					
24	12:29:44	40	L		(off screen?)					
25	12:30:24	35	R		12:30:21	38	R		3	-3
26	12:30:53	33	L		12:30:53	36	L		0	-3
27	12:31:24	29	R		12:31:25	31	R		-1	-2
28	12:32:01	26	L		12:32:07	27	L		-6	-1
29	12:32:30	22	R	*	12:32:32	25	R		-2	-3
30	12:33:07	22	L		12:33:08	23	L		-1	-1
31	12:33:33	20	R	**	12:33:38	23	R		-5	-3
32	12:35:43	21	L		12:35:45	22	L		-2	-1
33	12:36:10	25	R	*	12:36:08	27	R		2	-2
34	12:36:40	23	L		12:36:44	24	L		-4	-1
35	12:37:18	30	R		12:37:17	32	R		1	-2
								Average :	-2.3	-1.9
								Stdev :	3.6	0.9

Trial #3

Dec. 30, 2005

Frequency: LF

Frame Rate (fps): 4

Start Length (m): 24.30

Window Length (m): 20.12

Note: * - second fish observed following target fish

Obs.	Visual Data				DIDSON Recording				Difference Visual - Recording)	
									Time	Distance
No.	Time	Dist. (m)	Direction	Note	DID.Time	Dist. (m)	Direction	Note	(sec)	(m)
1	11:50:54	25	R		11:50:56	25	L		-2	0
2	11:51:21	26	L		11:51:15	26	R		6	0
3	11:51:52	27	R		11:51:57	27	L		-5	0
4	11:52:23	34	L		11:52:22	38	R		1	-4
5	11:52:47	37	R		11:52:44	40	L		3	-3
6	11:53:05	42	L		11:53:04	44	R		1	-2
7	11:53:28	40	R		11:53:26	42	L		2	-2
8	11:53:48	41	L		11:53:46	43	R		2	-2
9	11:54:18	37	R		11:54:18	38	L	*	0	-1
10	11:54:34	35	L		11:54:34	37	R	*	0	-2
11	11:54:58	37	R		11:54:58	38	L	*	0	-1
12	11:55:22	44	L		11:55:24	44	R		-2	0
13	11:55:46	43	R		11:55:44	43	L	*	2	0
								Average :	0.6	-1.3
								Stdev :	2.7	1.3

Trial #4

Dec. 30, 2005

Frequency: LF
Frame Rate (fps): 4
Start Length (m): 24.30
Window Length (m): 20.12

Note: * second fish observed following target fish

Obs.	Visual Data				DIDSON Recording				Difference Visual - Recording)	
									Time	Distance
No.	Time	Dist. (m)	Direction	Note	DID.Time	Dist. (m)	Direction	Note	(sec)	(m)
1	12:02:03	35	R		12:02:03	40	R	*	0	-5
2	12:02:34	31	L		12:02:35	33	L	*	-1	-2
3	12:02:49	30	R		12:02:46	32	R		3	-2
4	12:03:13	25	L		12:03:16	26	L		-3	-1
5	12:03:36	27	R		12:03:36	29	R		0	-2
6	12:04:00	29	L		12:04:02	31	L		-2	-2
7	12:04:19	26	R		12:04:22	27	R	*	-3	-1
8	12:05:06	42	L		12:05:06	44	L	*	0	-2
9	12:05:20	40	R		12:05:22	43	R	*	-2	-3
10	12:05:47	44	L		(off screen?)					
11	12:06:28	37	R		12:06:27	41	R	*	1	-4
12	12:06:55	34	L		12:06:57	36	L	*	-2	-2
13	12:07:14	31	R		12:07:14	33	R	*	0	-2
14	12:07:45	26	L		12:07:43	28	L		2	-2
15	12:08:09	34	R		12:08:09	36	R		0	-2
16	12:08:34	35	L		12:08:35	37	L		-1	-2
17	12:08:54	38	R		12:08:57	40	R		-3	-2
18	12:09:29	43	L		12:09:31	44	L		-2	-1
19	12:09:48	43	R		12:09:48	44	R		0	-1
20	12:10:22	35	L		12:10:24	38	L	*	-2	-3
21	12:10:44	31	R		12:10:45	33	R		-1	-2
22	12:11:15	29	L		12:11:16	30	L	*	-1	-1
23	12:11:39	34	R		12:11:40	35	R	*	-1	-1
24	12:12:08	35	L		12:12:08	38	L		0	-3
25	12:12:26	39	R		12:12:30	40	R	*	-4	-1
26	12:12:51	41	L		12:12:52	42	L	*	-1	-1
27	12:13:15	40	R		12:13:14	41	R		1	-1
28	12:13:43	43	R		12:13:46	44	L	*	-3	-1
29	12:13:59	42	L		12:13:58	43	R		1	-1
30	12:14:22	39	R		12:14:25	41	L		-3	-2
								Average :	-0.9	-1.9
								Stdev :	1.7	1.0

Trial #5

Dec. 30, 2005

Frequency: HF
Frame Rate (fps): 7
Start Length (m): 3.35
Window Length (m): 20.12

Note: * image interrupted due to knot in line

Obs.	Visual Data				DIDSON Recording				Difference Visual - Recording)	
									Time	Distance
No.	Time	Dist. (m)	Direction	Note	DID.Time	Dist. (m)	Direction	Note	(sec)	(m)
1	12:49:20	16	R		12:49:16	17	R		4	-1
2	12:49:44	12	L		12:49:46	14	L		-2	-2
3	12:50:03	7	R		12:50:05	8	R		-2	-1
4	12:50:26	5	L		12:50:30	6	L		-4	-1
5	12:50:50	11	R		12:50:50	12	R		0	-1
6	12:51:13	16	L		12:51:16	17	L		-3	-1
7	12:51:31	19	R		12:51:31	20	R		0	-1

8	12:51:50	22	L		12:52:13	20	L	*		
9					12:52:33	20	R	*		
10	12:52:48	18	L		12:52:50	19	L		-2	-1
11	12:53:18	18	R		12:53:19	19	R		-1	-1
12	12:53:35	23	L		12:53:36	24	L		-1	-1
13	12:54:08	15	R		12:54:11	16	R		-3	-1
14	12:54:22	14	L		12:54:22	15	L		0	-1
15	12:54:52	8	R		12:54:54	9	R		-2	-1
16	12:55:04	7	L		12:55:04	8	L		0	-1
17	12:55:22	5	R		12:55:23	6	R		-1	-1
								Average :	-1.1	-1.1
								Stdev :	1.9	0.3

Trial #6

Dec. 30, 2005

Frequency: LF
Frame Rate (fps): 4
Start Length (m): 24.30
Window Length (m): 20.12

Note: * image interrupted due to knot in line

Obs.	Visual Data				DIDSON Recording				Difference Visual - Recording)	
									Time	Distance
No.	Time	Dist. (m)	Direction	Note	DID.Time	Dist. (m)	Direction	Note	(sec)	(m)
1	13:00:08	24	R		13:00:06	25	R		2	-1
2	13:00:35	27	L		13:00:38	29	L		-3	-2
3	13:00:49	28	R		13:00:52	30	R		-3	-2
4	13:01:24	38	L		13:01:24	40	L		0	-2
5	13:01:41	39	R		13:01:43	41	R		-2	-2
6	13:02:13	41	L		13:02:14	42	L		-1	-1
7	13:02:28	44	R		13:02:30	44	R		-2	0
8	13:02:56	39	L		13:02:58	41	L		-2	-2
9	13:03:17	35	R		13:03:23	37	R		-6	-2
10	13:03:50	27	L		13:03:48	28	L		2	-1
11	13:04:10	32	R		13:04:13	34	R		-3	-2
12	13:04:36	33	L		13:04:36	35	L		0	-2
13	13:04:57	26	R		13:05:00	28	R		-3	-2
14	13:05:26	23	L		13:05:29	24	L		-3	-1
15	13:05:57	39	R		13:06:01	42	R		-4	-3
16	13:06:21	43	L		13:06:22	44	L		-1	-1
17	13:06:37	42	R		13:06:42	42	R		-5	0
18	13:07:06	34	L		13:07:06	37	L		0	-3
19	13:07:24	37	R		13:07:27	40	R		-3	-3
20	13:08:12	28	L		13:08:15	30	L		-3	-2
21	13:08:32	30	R		13:08:32	32	R		0	-2
22	13:08:53	29	L		13:08:55	30	L		-2	-1
23	13:09:11	35	R		13:09:12	37	R		-1	-2
24	13:09:32	38	L		13:09:33	40	L		-1	-2
25	13:09:49	43	R		13:09:50	43	R		-1	0
								Average :	-1.8	-1.6
								Stdev :	1.9	0.9

Appendix II - DIDSON-LR validation trial conducted in parallel with visual observations of salmon migrating by at a tower counting site in the Methow River.

Visual Observation						Observation on DIDSON LR Recording					
Obs #	Date	Time	# of Fish	Dist. (m)	Up or Down	DIDSON File Name	Time	# of Fish	Dist. (m)	Up or Down	Note
1	7/26/2005	15:11	2	38	down	2005-07-26_B_LF.ddf	15:12	2	33	down	
2	7/25/2005	15:03	1	35	down	2005-07-25_A_LF.ddf					no observation on DIDSON file
3	7/28/2005	7:07	1	35	up	2005-07-28_A_LF	7:07	1	31	up	
4	8/1-2/05	9:49	3	40	up	2005-08-01_191112_LF.ddf	9:49	4	35	up	a 4th fish observed in file
5	8/1-2/05	9:59	3	40	up	2005-08-01_191112_LF.ddf	9:58	3	36	up	
6	8/1-2/05	10:26	1	40	up	2005-08-01_191112_LF.ddf	10:26	1	37	up	
7	8/2-3/05	20:55	1	35	up	2005-08-02&03_A_LF.ddf	20:55	1	32	up	
8	8/2-3/05	8:44	1	35-40	up	2005-08-02&03_C_LF.ddf	8:43	1	33	up	
9	8/16/2005	20:54	1		down	2005-08-16_A_LF.ddf	20:52	1	29	down	
10	8/16/2005	21:35	1		up	2005-08-16_A_LF.ddf	21:34	1	33	up	
11	8/16/2005	21:40	1		up	2005-08-16_A_LF.ddf	21:39	1	35	up	
12	8/16/2005	21:48	1		up	2005-08-16_A_LF.ddf	21:47	1	24	up	
13	8/16/2005	21:55	1		up	2005-08-16_A_LF.ddf	21:53	1	23	up	
14	8/16/2005	22:04	1		down	2005-08-16_A_LF.ddf	22:06	1	30	down	
15	8/17/2005	21:46	1		up	2005-08-17_A_LF	21:45	1	23	up	
16	8/17/2005	22:32	1		up	2005-08-17_A_LF					no observation on DIDSON file
17	8/17/2005	23:06	1		up	2005-08-17_A_LF	23:06	1	32	up	
18	8/22/2005	21:07	1			2005-08-22_A_LF	21:07	1	18	down	
19	8/22/2005	21:11	1			2005-08-22_A_LF	21:11	2	33	up	a 2nd fish observed in file
20	8/22/2005	21:20	1			2005-08-22_A_LF					no observation on DIDSON file
21	8/22/2005	21:28	1			2005-08-22_A_LF	21:28	1	32	up	
22	8/22/2005	21:40	1		up	2005-08-22_A_LF	21:40	1	27	up	
23	8/29/2005	20:57	2	30	up	2005-08-29_A_LF.ddf					no observation on DIDSON file
24	8/29/2005	21:02	1	38	up	2005-08-29_A_LF.ddf					no observation on DIDSON file
25	8/30/2005	19:58	1	38	up	2005-08-30_A_LF.ddf	19:58	1	25	up	38 vs. 25 m ?
26	8/31/2005	19:53	1	35	up	2005-08-31_09-03_A_LF.ddf	19:53	1	30	up	
27	9/1/2005	17:35	1	40		2005-08-31_09-03_E_LF.ddf	17:35	1	32	up	
28	9/1/2005	21:20	1	40	up	2005-08-31_09-03_F_LF.ddf	21:20	1	30	up	
29	9/1/2005	22:52	2	25&32		2005-08-31_09-03_F_LF.ddf	22:52	2	21&28	up	
30	9/2/2005	17:23	1	25	down	2005-08-31_09-03_I1_LF.ddf	17:23	1	21	down	
31	9/2/2005	23:20	1	30	up	2005-08-31_09-03_I2_LF.ddf	23:20	1	29	up	
32	9/2/2005	23:43	1	35	up	2005-08-31_09-03_I2_LF.ddf	23:43	1	33	up	
33	9/6/2005	23:50	1	30	up	2005-08-09-06_LF.ddf	23:50	1	28	up	
34	9/6/2005	0:05	1	35	up	2005-08-09-06_LF.ddf	0:05	1	31	up	
35	9/7/2005	19:53	2	30	up	2005-08-09-07_LF.ddf	19:53	2	28	up	
36	9/7/2005	20:13	1	35	up	2005-08-09-07_LF.ddf	20:13	1	30	up	
37	9/7/2005	20:32	1	32	up	2005-08-09-07_LF.ddf					no observation on DIDSON file
38	9/13/2005	19:47	1	35	up	2005-09-13&14_B_LF	19:47	1	35	up	
39	9/13/2005	20:01	3	35	down	2005-09-13&14_B_LF	20:01	4	36	up	a 4th fish observed in file
40	9/13/2005	20:14	1	32	up	2005-09-13&14_B_LF	20:14	1	36	up	
41	9/13/2005	20:18	1	25	up	2005-09-13&14_B_LF					no observation on DIDSON file
42	9/13/2005	20:26	1	35	up	2005-09-13&14_B_LF	20:26	1	36	up	
43	9/13/2005	20:28	1	28	up	2005-09-13&14_B_LF	20:28	1	29	up	
44	9/13/2005	20:44	2	42	up	2005-09-13&14_B_LF	20:44	2	34	up	
45	9/13/2005	21:00	1	42	up	2005-09-13&14_B_LF	21:00	1	34	up	
46	9/13/2005	21:01	1	28	up	2005-09-13&14_B_LF	21:00	1	30	up	
47	9/13/2005	22:02	3	35	up	2005-09-13&14_B_LF	22:01	3	26	up	
48	9/14/2005	20:09	1	25	up	2005-09-14&15_B_HF	20:09	1	28	up	
49	9/14/2005	23:16	1	30	up	2005-09-14&15_D_HF	23:16	1	27	up	
50	9/14/2005	23:23	1	35	up	2005-09-14&15_D_HF	23:22	1	34	up	
51	9/14/2005	23:25	2	35	up	2005-09-14&15_D_HF	23:25	2	35	up	
52	9/15/2005	20:57	1	32	up	2005-09-15&16_B_HF	20:57	1	34	up	
53	9/15/2005	22:32	2	35	up	2005-09-15&16_B_HF	22:32	2	35	up	
54	9/15/2005	22:41	1	32	up	2005-09-15&16_C_HF	22:41	1	30	up	
55	9/15/2005	22:42	1	30	up	2005-09-15&16_C_HF	22:42	1	33	up	
		sum:	70								

Appendix III - Summary of upstream migration rate (number of fish per hour) for all observations from DIDSON-LR recordings performed at a tower counting site in the Methow River in 2005.

	PM												AM											
Dates	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
7/19/05								0	0															
7/25/05			1	0	0																			
7/26/05			0	-6																				
7/27/05	0	0	0					0	0															
7/28/05																			0	0				
08/01-02/05								0	2	1	2	0	0	0	1	2	0	1	2	2	0	7	0	
08/02-03/05								-1	1	28	10	6	0	-1	-2	2	0	3	2	0	1	0	0	0
08/03-04/05								0	0	14	4	4	1	1	-1	-1	2	1	0	0				
08/16/05									-1.3	3	3	0												
08/17/05									0	3	3	1	6											
08/22/05									0	5	2													
08/23/05									0															
08/29/05									2	0	1													
08/30/05								3	0	3	2													
8/31-9/01								1	1	2	1*	17	9	4	2	2	2	1	0	0	0	0	0	0
9/01-02/05	0	3	0	0	0	0	0	-1	1	1	2*	4	1	3	-2	0	2	2	0	0	0	-1	0	0
9/02-03/05	1	0	0	2	0	-1	1	0	0	0	1	2*	18	3	6	1	3	3	2.8					
09/06/05									0	0	0	1												
09/07/05								12	1	0	0	1	1.2											
9/12-13/05								0	0	0	0*	5	0	1	3	2.1								
9/13-14/05						0	4	4	11	1	8*	10	6	5	2	0	3	4	14	3	0			
9/14-15/05						0	0	0	2	0	0	5*	7	6	4	6	5	4	4	3	0			
9/15-16/05							0	2	1	0	4	4*	9	-1	1	3	6	1	14					
Average:	0.3	1.0	0.2	-1.0	0	-0.3	1.0	1.5	1.0	3.6	2.5	4.3	4.9	2.1	1.4	1.7	2.6	2.2	3.9	1.0	0.2	1.5	0	0

* denotes that the lights were turned off at the end of the hour

Appendix IV - Data for Chinook salmon radio-tagged at Wells Dam and detected at a location immediately upstream of the tower counting site on the Methow River.

Fish		Tagging	Detection		Tagging to Passage
#	Sex	Date	Date	Time	Time Delay (days)
1	F	07/05/05	07/25/05	1:30	20
2	F	07/06/05	07/09/05	1:57	3
3	M	07/06/05	07/11/05	21:42	5
4	F	07/06/05	08/19/05	2:36	44
5	F	07/11/05	07/12/05	1:42	1
6	F	07/11/05	07/12/05	22:11	1
7	F	07/13/05	09/13/05	19:20	62
8	F	07/13/05	08/17/05	0:44	35
9	M	07/18/05	08/24/05	6:32	37
10	F	07/18/05	07/20/05	10:32	2
11	M	07/18/05	07/25/05	21:48	7
12	F	07/25/05	08/22/05	14:07	28
13	F	07/25/05	08/02/05	22:21	8
14	F	07/26/05	09/10/05	17:28	46
15	M	08/01/05	08/23/05	16:49	22
16	M	08/01/05	08/02/05	21:13	1
17	F	08/03/05	08/28/05	22:36	25
18	F	08/09/05	09/11/05		33
19	F	08/10/05	08/29/05	23:28	19
20	F	08/30/05	10/10/05	20:30	41
21	M	08/30/05	10/15/05	21:54	46
22	M	10/18/05	10/23/05	18:51	5
23	M	10/18/05	10/23/05	1:54	5
24			09/21/05	14:01	
				Average All:	22
				StDev All:	18.5
				Average Females (n = 15):	25
				StDev Females:	19.1
				Average Males (n = 8):	16
				StDev Males:	17.1