Assessing Chinook Salmon Escapement in Mill Creek using Acoustic Technologies in 2006

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ABSTRACT

Mill Creek is a tributary of the Sacramento River and supports an ESA listed spring-run Chinook salmon population with an average estimated escapement of 1,000 to 2,000 fish. Historically, adult spawner estimates have been derived using a variety of methods including redd counts, carcass surveys, snorkel surveys, and fishway counts. All these methods have inherent assumptions and logistical constraints related to the hydrologic and water quality characteristics of the system that can adversely influence the accuracy and precision of the estimates. Therefore, in a 2006 pilot study, we evaluated the efficacy of two different acoustic technologies to estimate adult Chinook salmon escapement on Mill Creek: a Biosonics split-beam system and a dual-frequency identification sonar (DIDSON) system.

The acoustic systems were operated at River Mile 2 on Mill Creek over the period 28 March to 15 July to sample the upstream migration of spring Chinook salmon. In this application, the DIDSON system was more effective for counting adult salmon and estimating run timing compared to the split-beam system due to its greater sample volume, and ability to detect targets near the creek substrate across a range of flows and water levels. DIDSON counts totaled 1,447 fish from 28 March through 23 June whereas split-beam counts totaled 458 for the time period 5 May through 15 July. Run timing trends indicated that spring Chinook salmon passed the study site in three modes: mid-April through mid-May, early June and early July. Peak passage occurred in late April. Results from this study demonstrate that acoustic technologies, especially DIDSON, can be used to reliably estimate salmon escapement in systems similar to Mill Creek in terms of size, turbidity, and flow.

The index estimate of escapement for 2006 determined using acoustic methods (> 1,447) is higher than the population estimate derived from redd counts (1,002). The explanation for the difference in estimates is likely the result of several factors including the validity of the assumptions used in the two methodologies.

The management implications of the results from this study are significant in that the acoustic methods can be readily transferred to other waterways in the State in order to achieve similar goals. Additionally, run timing data acquired from the acoustic systems can allow for more effective water management for anadromous fish.

INTRODUCTION

Background

Mill Creek supports runs of spring- and fall-run Chinook salmon (*Oncorhynchus tshawytscha*) and Central Valley steelhead (*O. mykiss*). Prior to 1997, spring Chinook salmon escapement estimates were based on a variety of methods including station counts at Clough Dam, redd count surveys, and carcass counts. Population estimates derived from surveys during that period, as well as comparisons of those estimates among years, should be viewed with caution given the inconsistent methods used. Since 1997, methods used for estimating populations based on redd counts have been consistent across years. Historically, the spring Chinook salmon spawning population has been estimated to range from as high as 3,500 fish in 1975 to as low as 61 fish in 1993 (CDFG 1998). Over the last 10 years, the population estimates have ranged from 200 to 1,594 and averaged 900 fish.

Population estimates based on redd counts and carcass surveys are extremely valuable since they provide indices of the status of the spawning populations of these threatened Chinook salmon. The utility of the population estimates derived from the spawning grounds is somewhat limited though with respect to water diversion management and its effect on fish passage. Ideally, information on spring Chinook salmon run timing could allow for management of water diversion resulting in less impact to these anadromous fish. Obtaining increased flows to allow adult and juvenile salmon and steelhead unimpaired up- and downstream passage is a high priority of management agencies (CDFG 1993). Knowledge of real-time fish passage timing would put exchanged water to the most beneficial use. Coupling knowledge of run timing trends with spawning population indices would enhance our understanding of the dynamics of spring Chinook salmon stocks in Mill Creek and increase the efficacy of water diversion management while reducing consequences for the fish.

Acoustic technologies have been used to successfully estimate anadromous fish passage in rivers and streams in the U.S. for several decades (Maclennan and Simmonds 1991). Bendix sonars have been used since the early 1970s to provide an index of salmon passage for many river systems across the state of Alaska (Barton 2000; Chappel 2001; Davis 2002; McKinley 2002). Split-beam sonar is presently used in Alaska for estimating upstream migrant Chinook salmon in the Kenai River (Miller and Burwen 2002) and chum salmon in the Chandalar River (Daum and Osborne 1998). Recent developments in sonar technologies has created the Dual-frequency Identification Sonar (DIDSON) system, which yields near-video quality streaming images of fish targets (Belcher and Lynn 2000). The DIDSON has been used to estimate abundance of up-migrating adult salmon in river systems at several locations including rivers in Canada (Holmes et al. 2006) and Alaska (Maxwell and Gove 2002). Due to the effectiveness of acoustic methods for estimating salmonid escapement across numerous applications in various locations, there is a high likelihood of success for using such methods for indexing escapement of spring Chinook in Mill Creek.

Rationale

The project rationale is rooted in language in the Central Valley Project Improvement Act (CVPIA). The CVPIA authorizes and directs the Secretary of the Department of Interior (DOI), in consultation with other State and Federal agencies, Indian tribes, and other affected interests, to develop and implement a program which makes all reasonable efforts to at least double natural production of anadromous fish in California's Central Valley rivers and streams. The CVPIA also requires that this program give first priority to measures which protect and restore natural channel and riparian habitat values through habitat restoration actions, modifications to Central Valley Project operations, and implementation of the supporting measures mandated therein. The DOI is implementing these directives through the United States Fish and Wildlife Service (FWS) Anadromous Fish Restoration Program (AFRP). The species and races of anadromous fish addressed by the AFRP include fall-run, late-fall run, winter-run, and spring-run Chinook salmon and Central Valley steelhead. This pilot study evaluates the effectiveness of using acoustic technologies for estimating salmon escapement. If found to be effective, escapement data derived from acoustic sampling helps facilitate achievement of the desired results of the CVPIA by providing critical and necessary data to enumerate the escapement of threatened spring Chinook salmon and facilitate recovery planning efforts.

Objectives

The specific study objectives were to:

1. Evaluate the suitability of several potential sites for deployment of acoustic technologies in Mill Creek to estimate spring Chinook salmon escapement;

2. Operate a split-beam hydroacoustic system to estimate spring Chinook salmon escapement at the selected site throughout the migration season;

3. Operate a DIDSON to estimate spring Chinook salmon escapement at the selected site for a majority of the migration season and compare the results with those obtained with the split-beam system;

4. Assess run timing and diel distribution of spring Chinook salmon escapement;

5. Analyze target strength data acquired with the split-beam system and relate to fish size of upstream migrants;

6. Compare acoustic count results to population estimates based on redd counts provided by California Department of Fish and Game (DFG);

7. Assess the feasibility of acoustic technologies for long-term monitoring of adult escapements in Mill Creek; and

8. Provide a document outlining one-time and annual costs for operating an acoustic counting program on Mill Creek.

METHODS AND MATERIALS

Mill Creek

Mill Creek, a tributary of the Sacramento River (Figure 1), originates on the southern slope of Mount Lassen at an elevation of 7,000 ft. It flows westerly about 60 miles to its confluence with the Sacramento River at RM 230, about one mile north of the city of Tehama, CA. It drains about 134 miles^2, and its mean monthly runoff ranges from 105 to 465 cfs with a median runoff of 333 cfs (USFWS 1995; USGS 2001).

Mill Creek has no major reservoirs but does have two water diversion projects: Ward Dam and Upper Diversion Dam. These dams have historically diverted most of the natural stream flow from Mill Creek, particularly during dry years. Clough Dam, a private diversion structure serving the properties of two local landowners, was partially washed out during a major flood event in 1997 and no longer diverts Mill Creek flow.

Study Site Evaluation

In November of 2005, study partners evaluated five potential study sites to determine their suitability for sampling with acoustics (Dawson and Nass 2006). The characteristics of a suitable site have been identified by previous researchers including Mesiar et al. (1990), Mulligan and Keiser (1996) and Ransom et al. (2000), who reviewed how site conditions, fish behavior, and hardware configuration affect the efficacy of acoustic sampling systems. Ideal sites include (1) a channel with uniform slope through the sample area; (2) minimal water level variation; (3) non-turbulent flow; (4) a smooth substrate with low acoustic reflectivity (i.e., sand, gravel or silt composition); (5) water velocity sufficiently high to minimize fish holding or milling; and (6) suitable access to both river banks. The extent to which acoustic sampling could be used to count anadromous fish in Mill Creek was based upon these factors.

Four sites on Mill Creek were suggested by FWS/DFG personnel as potential sites for monitoring migratory salmonid adults using acoustics. These sites are located near Highway 99 Bridge, Ward Dam, Clough Dam, and Upper Dam, respectively. A fifth site called Sherwood Bridge was also proposed in discussions with DFG personnel during the on-site survey. All the sites were evaluated based on a matrix of suitability criteria (Table 1) to determine the relative suitability of each site for conducting an effective hydroacoustic study. We chose the Sherwood Bridge site as this location stood out as being considerably more suitable based on the evaluation criteria matrix. See Dawson and Nass (2006) for a detailed discussion regarding the study site evaluation.

Sherwood Bridge Site

The Sherwood Bridge site (Figure 2) is located at approximately RM 2, N 40.04565° by W 122.0951°. The site is located in a wooded residential section, with trees overhanging the creek banks throughout most of the reach. The creek passes through an upstream riffle and turns right into the sampling area, about 200 ft upstream from the bridge. After a straight run under the bridge, the river shoals into a downstream shallow riffle and curves again to the right. The river is deeper on the left bank throughout this stretch. The substrate material is somewhat graded in size, with larger cobble 4-8 inches in diameter along the left half of the river bottom, and gravel changing to silt in the right half of the river. Entrained air from the upstream riffle appears to dissipate out by the time the water reaches the sampling area. The channel profile, as measured during the site evaluation, indicated the cross-sectional sample area was about 50 ft wide with a maximum depth of 3.5 ft at a flow of 200 cfs (Figure 3).

Deployment

We mounted a split-beam transducer and a DIDSON on aluminum frames (Figure 4) and deployed them just off the river right bank of the study site on 28 March (Figure 5). River left and right banks refer to deployment locations when facing a downstream direction. Due to extremely high flows early on in the study period, the split-beam transducer was removed from the site and the DIDSON was moved to the river left position on 5 April to allow for easier access to the gear in case it needed to be removed quickly (the river left bank abuts the property of Matt Johnson, one of the study partners). The DIDSON was moved back to the river right position on 23 April after flows began to mediate and the split-beam transducer was again deployed (on 27 April), also in the river right position. In an attempt to optimize sample volume coverage and improve overall DIDSON data quality, it was moved back to the river left bank on 1 May. We determined that the DIDSON data quality did not sufficiently improve, and with lower relative flows sampling was observed to be optimal from the river right bank. On 7 May, the DIDSON was again moved to the river right position where it remained for the duration of the study along with the split-beam transducer. Sand bags were used to secure the aluminum frame mounts to the substrate. To insure that fish would not swim behind the sampling gear and thereby avoid detection, we installed a fish fence perpendicular to the flow and extending out from the river right bank (Figure 5). This reduction in the cross-sectional area in which fish could pass allowed for better sample volume coverage. Initially, the fence was made of plastic mesh used in roadside construction sites, but was replaced by stronger fence material in mid-season (Figure 6).

Data Collection and System Operation

DIDSON

The DIDSON system (manufactured by Sound Metrics, Inc.) consisted of the sonar unit (the field-of-view is 29^o x 12^o), signal transmission cable, a Dell laptop computer used for system operation, and external hard drives for storing raw data. Data collection parameters varied throughout the season to test for optimal sampling ranges (start range varied from 1.3 to 8.2 ft and the sample window was set to either 33 or 66 ft) and sample frequency (1.1 and 1.8 MHz). The DIDSON was located just above the substrate and aimed with a slight down angle perpendicular to the flow (Figure 7). Data were collected in 20-minute files at 8 to 10 frames per second 24 hours per day throughout the period 28 March to 23 June 2006. Interruptions in data collection (Figure 8) were the result of high flood events, computer malfunction, data drive removal, and changing the deployment of sampling gear. At times, silt collected inside the DIDSON lens case resulted in degradation of image quality. After several iterations of attempted preventive measures, we found that wrapping the DIDSON in a plastic garbage bag solved this problem.

<u>Split Beam</u>

The Biosonics, Inc., split beam system consisted of a 200 kHz 6° nominal beam-width transducer, DT-X echosounder, digital signal cable, Dell desktop PC for system operation, electronic dual-axis rotator and controller, and external disc drives for storing raw data. System source level was 212.4 dB ||1 μPa and the receive sensitivity was -53.3 dB ||1 μPa. We used a data collection threshold of -50 dB, sampled with a pulse repetition rate of 10 pings per second, and used a pulse width of 0.3 msec. The transducer was located just above the substrate and aimed across the creek perpendicular to the flow (Figure 7). Split beam data were collected 24 hours per day 29 March through 15 July (with the exception of 5-23 April when it was removed due to high flows). Interruptions in data collection (Figure 9) were the result of high flood events, computer malfunction, and data drive removal.

All electronic components for both the DIDSON and split beam systems were housed and secured in a project trailer located on the Johnson property on the river left bank of the study site (Figure 10).

Data Processing and Analysis

<u>DIDSON</u>

The raw DIDSON data files were processed with a beta version of software developed by Peter Withler (Pacific Eumetrics Consulting, Inc.) to output single target detections. The software processes the DIDSON image data files and generates single targets that meet the Image Processor criteria for intensity 9dB over threshold and an area of 31 sq inches. These targets were written to file with the following fields:

Day, time, frame number, track number, X (derived from the beam location), Z (range), and target strength (image size). Fish tracking was accomplished using the Alpha-Beta tracker (ABTrack software) developed by Tim Mulligan (Department of Fisheries and Oceans, Canada) and Peter Withler. The tracking parameters used for the Mill Creek analysis were:

	X	Z
Alpha	0.68	0.95
Beta	0.25	0.60
Wt (off)	0.07	0.03
Wt (slp)	0	0
Initial velocity	0	0
Search radius	8	
Max missed pings	30	

The single target output files were then concatenated and summarized with another beta software program developed by Peter Withler. This program created a comma-separated format file that summarized all tracked fish. This summarization file was then filtered to remove tracks generated from noise and smaller fish using Polaris software (also by Peter Withler). The filtered tracked fish files then were visually compared with the raw DIDSON data files to identify those fish larger than 24 inches, as measured with the DIDSON software measure tool. We used the 24 inch threshold to eliminate smaller non-Chinook salmon targets from the data set. This filtered file was then stored as an Excel format file with a record for each tracked fish counted.

We conducted a quality control process on the DIDSON data to verify the effectiveness of the autotracking software performance. The process entailed manually reviewing a subset of the raw data using the DIDSON software, and counting the number of upstream and downstream fish passage events observed for fish larger than 24 inches. The relationships of manual to autotracked counts were plotted and the slope of the regression lines were used to adjust autotracked results to better reflect counts as if the data had all been manually processed.

Split Beam

Split-beam data files were replayed through the commercial trace formation program EchoView (by Sonardata, Ltd.). Preliminary analysis focused on identifying large fish targets and extracting them from the high acoustic noise background. The date/time and range (m) were recorded, as well as an estimate of the mean Target Strength (TS) or acoustic size of each fish. These data were identified by visual examination of the acoustic records. A subsample of data collected from 15 to 22 June was analyzed using EchoView's manual trace formation algorithm to derive the direction of movement of each fish.

After further review, the data strongly suggested that the analytical procedures had been counting smaller non-salmonids. A filtering process was imposed on the entire data set to select against these fish counts in the following manner and order:

All fish smaller than –30 dB were excluded; and
All fish smaller than –28 dB and within 14.8 ft of the transducer were excluded.

The rational for the first filter is that adult Chinook salmon should, in most cases, reflect a signal with TS greater than –30 dB. We selected a –30 dB filter with the assumption that the reported TS are biased low due to the acoustic noise (Kieser et al. 2000). The rationale for the second filter is two-fold. Initial analysis of the data showed a cluster of small targets (< –30 dB) extending to 14.8 ft from the transducer face. Also, when fish pass relatively close to the transducer, they may violate an assumption that they are reflecting sound like a point-source target (Dawson et al. 2001). For example, at 14.8 ft from the transducer face the acoustic beam is approximately 1.5 ft in diameter. Fish greater than 1.5 ft in length will be larger than the beam and since the fish no longer appears as a point source, its estimated target strength will be biased. We therefore filtered out fish near the transducer (< 14.8 ft) and increased the minimum target strength to –28 dB to account for non-point source violations.

Target Strength to Length Correlation

The target strength is the acoustic energy reflected from an ensonified fish. The measured target strength of a fish can be affected by fish size, fish aspect relative to the acoustic beam, and swimbladder shape and size. Empirical relationships have been developed to relate target strength to fish size so as to provide a convenient and common metric for assessing the fish population under consideration. This is not a deterministic relationship, but rather represents the expected target strength of a group of fish with specified mean length. It is important to note that side-aspect target strength, even when combined with pulse-width analysis, is a highly variable indicator of fish size (Dawson and Karp 1987).

In this report we use Love's (1971) equation for side aspect targets to approximate fish size.

$$\mathrm{Log}\,(L) = [TS - 2.8\mathrm{Log}(F) + 69]/22.8 \qquad (1)$$

Where:

L = Length in cm
TS = Target strength in dB
F = Frequency of transducer in kHz.

As reported in Keiser et al. (2000), the target strength and estimated size of the fish are likely biased low due to the acoustic noise present in the system. In split beam analysis when the signal to noise ratio decreases, the targets' projected distance off-axis of the acoustic beam is underestimated. As a result, insufficient correction is applied to the returning echo when target strength is calculated. To correct for this underestimation of target strength we adjusted the reported targets strengths by 6 dB. This adjustment factor was selected because it represents the median correction for fish distributed in a 6^{o} beam.

Run Timing and Diel Distributions

Trends in run timing based on the DIDSON data were developed by calculating the daily net upstream count of spring Chinook. Daily counts reflect the difference between the total number of upstream and downstream fish passage detections. Split-beam counts do not indicate net upstream counts since directional information from split-beam targets was compromised due to low signal-to-noise resulting from turbulence and entrained air induced by excessive flow events. Instead, split-beam run timing trends reflect total number of daily fish targets detected that met data processing criteria described above. Diel distributions of fish passage are based on net upstream counts for DIDSON data and total number of fish detections for split-beam data.

Defining Effectiveness of Sampling Systems

A primary objective of this study was to determine the feasibility of acoustic sampling techniques for long-term use in estimating Chinook salmon escapement in Mill Creek. Assessing feasibility requires determination of the effectiveness of the sampling techniques, which further necessitates defining the term effectiveness. In the context of this study, we define effectiveness as functional and reliable operation over a range of environmental conditions that results in a data set useful for management purposes.

Environmental Variables

Flow and temperature on Mill Creek were tracked via the Internet (CDWR 2006; USGS 2006) from permanent stream gauges at the Los Molinos station upstream and the Highway 99 Bridge downstream from our study site. Diversion for irrigation occurs between these two gauging stations at Ward Dam about one mile upstream from the Sherwood Bridge site and at Upper Dam, about 2 miles upstream of Ward Dam. Temperature data were also acquired with loggers deployed at the Sherwood Bridge site.

RESULTS

Temperature and Flow

Water temperature in Mill Creek generally increased throughout the study period, with peaks over 20^{o} C observed starting in late June (Figure 11). Mill Creek flows in 2006 were high, periodically exceeding maximum daily flows of 3,000 cfs from early through mid-April (Figure 12). Flows in Mill Creek moderated in the latter half of the study period.

Bathymetry

As a result of the high flows, the cross-sectional profile of the study site was modified substantially (Figure 13). Deposition occurred near the river left bank and scouring occurred to some extent in mid-channel and to a large extent near the river right bank.

Escapement

Sample Volume Coverage

Due to periodic high flow events throughout much of the study period, we used various configurations of gear placement (river left and right banks for the DIDSON) and aiming angles to optimize sample volume coverage. As a consequence, cross-sectional sampling coverage at the Sherwood Bridge site was inconsistent through the study period. We estimate cross-channel coverage for the DIDSON and split-beam sonar ranged from 70 to 100%, and 80 to 100% of the study site width, respectively. As a result of having less than complete coverage across the study site for the entire study period, all reported counts are not considered census counts of absolute numbers of fish. Instead, our results in this pilot study are estimated relative counts of spring Chinook salmon and should be viewed as an escapement index.

DIDSON Data

The quality control process of manually reviewing DIDSON data to verify effectiveness of the auto tracking software indicated that the automated tracker undercounted upstream passage events by about 23% during the river right bank deployment and 13% during river left bank deployment (Figure 14). Based on the tracker-to-visual count relationships, we applied the slope of the regression lines as a constant multiplier to adjust the automated counts to better reflect escapement estimates that we would likely have produced had all the data been manually reviewed. We manually processed 51 hours of river right-bank deployment data and 52 hours of river left-bank deployment data.

DIDSON count data revealed that the spring Chinook salmon run was episodic, with the primary mode of passage occurring mid-April through mid-May, and a secondary mode occurring in the early part of June (Figure 15). A total of 1,447 fish were counted from 28 March through 23 June, with a daily peak of 70 fish occurring on 28 April.

Split-Beam Data

Split beam count data also indicated Chinook salmon passage was episodic, and up and down trends in daily passage tracked those observed with the DIDSON data fairly well, although daily counts were usually lower for the split-beam than with the DIDSON (Figure 16). A total of 458 fish were counted using the split-beam system from 5 May through 15 July. An additional mode of passage is evident based on split-beam sampling in the first half of July, after the DIDSON was removed from the field site.

Comparison of Acoustic and Redd Count Estimates

Based on redd count surveys in 2006, the population of spring Chinook salmon in Mill Creek was estimated to be 1,002 fish. We estimated escapement based on acoustic sampling at the Sherwood Bridge site in 2006 at something greater than 1,447 fish, as indicated by continued fish passage after removal of the DIDSON (Figure 16), although the problems inherent in classifying fish by size from the split-beam data preclude any more precise estimate.

Fish Passage and Environmental Variables

The data suggests an apparent indirect relationship between fish passage and flow when mean daily flow exceeded about 1,000 cfs in Mill Creek (Figure 17). Early in the study period, peak flow events seemed to coincide with lulls in relative fish passage based on DIDSON counts. After early May when mean daily flows dropped below 1,000 cfs, the indirect relationship between fish passage and flow is no longer apparent. After mid-May, there is some indication that fish passage followed daily flow patterns to a slight degree. No discernible pattern was evident in the relationship between daily fish passage and Mill Creek water temperature.

Diel Passage

Passage of spring Chinook salmon increased just prior to dusk, sustained higher relative proportions through the nighttime hours and decreased after dawn to lower levels through the morning and afternoon hours (Figure 18). These passage patterns were observed with both the DIDSON and split beam systems.

Target Strength and Fish Size

Target strength distribution based on split-beam data indicated that most detected fish had target strengths ranging from -23 to – 19 dB (Figure 19). Using Love's equation (1971), this range in target strength correlates to total fish lengths of about 21 to 32 inches. Relatively few detected fish had target strengths greater than – 17 dB (39 inches).

DISCUSSION

Performance of Acoustic Systems

To a large extent, the high flow observed in Mill Creek in 2006 (Figure 12) confounded our ability to sample with split-beam hydroacoustics. Flows in 2006 were much higher than in the previous years, as mean daily flows from the Upper Dam Gauge from 1998 through 2005 never exceeded 600 cfs (USGS 2006). The split-beam system is more sensitive to turbulence and air entrainment induced by high flow events than is the DIDSON. We were unable to collect useable split-beam data until the early part of May after the majority of spring Chinook salmon had passed the Sherwood Bridge site, as revealed by the DIDSON count data (Figures 15 and 16). Despite the unusually high flow conditions of 2006, the DIDSON system performed remarkably well by reliably detecting migrant Chinook salmon throughout the study period. The larger sample volume of the DIDSON (29^o x 12^o wedge-shape composite beams) as compared to the split beam (6^o circular beam), coupled with its functional reliability through a range of high flow events, indicates that the DIDSON outperformed the split beam in terms of sampling effectiveness in 2006. Results from this study underscore the viability of using sonar, and especially DIDSON, for indexing escapement of spring Chinook salmon in Mill Creek.

During the study period when both DIDSON and split-beam systems were operational, count data from the two sampling methods were not consistent, especially with respect to estimates of daily passage (Figure 16). In general, daily counts were higher based on DIDSON sampling as compared to split-beam sampling, and we suggest that the lower relative split-beam counts resulted from issues related to sample volume coverage and use of a range threshold. The split-beam sample volume is inherently smaller than the DIDSON sample volume, and therefore it is likely that the DIDSON would detect a greater number of fish than would the split-beam system. The range threshold we used to eliminate targets within 14.8 ft of the split-beam transducer (see methods section) further diminished the sampling volume, and likely contributed to fewer relative targets detected as compared to the DIDSON.

Given these differences in sample volumes between the two methods, it becomes somewhat difficult to explain days in which split-beam counts were higher than DIDSON counts. However, we infer that the inability of the split-beam system to determine directionality of detected fish contributed to escalated split-beam counts on several days when split-beam counts were higher relative to DIDSON counts. On some days in which split-beam counts were higher, DIDSON sampling revealed considerable movement of downstream migrants, which if subtracted from the daily split-beam counts, would result in more comparable count estimates between the two sampling methods (Table 2). Although lack of directionality information explains some of the suspect split-beam count data, some dates with higher relative split-beam counts had very few or no downstream counts. We speculate that some of the higher relative split-beam counts may have resulted from multiple counting of the same fish or inclusion of non-Chinook salmon targets in the data set, but we are uncertain if this was the case.

It is important to note that although split-beam and DIDSON systems are both sonar technologies, the two sampling methods are distinctly different in their utility. As discussed above, the split-beam system has limited effectiveness in high flow, turbulent conditions that confound its ability to sample fish. In contrast, DIDSON sampling is not hindered by these same flow conditions, as evidenced by the results reported herein. The DIDSON provided reliable counts throughout the study period, and allowed for a fairly complete account of spring Chinook salmon run timing in Mill Creek in 2006 (Figure 16). As such, the performance of the DIDSON system meets our definition of effectiveness: functional and reliable operation over a range of environmental conditions that results in a data set useful for management purposes. The split-beam system did not meet this standard in this study. Given more typical flow conditions in Mill Creek, the split-beam system would likely have been more effective in terms of reliability and functionality. However, given average flow conditions, it is unclear as to what value the split-beam data would have added to the project with respect to achieving study objectives regarding escapement of spring Chinook that the DIDSON system did not already provide.

Comparison to Redd Counts

Results from acoustic sampling for spring Chinook salmon escapement indicated that more than 1,447 fish passed the Sherwood Bridge study site on Mill Creek (Figure 16). The population estimate of spring Chinook salmon based on redd count surveys conducted by DFG in 2006 was 1,002 fish. These two estimates, derived from very different methods, are within a reasonable range of one another. Potential causes for the disparity of these estimates are numerous. One important factor that may have contributed to the disparity is the method in which population estimates are calculated from redd count data. The method assumes a 1:1 male to female sex ratio, and redd counts are multiplied by two to obtain the population estimate. If the sex ratio assumption is invalid, and males predominate over females, than the reported population number is an underestimate of the actual population. Stocks of Chinook salmon in tributaries of the Yukon River in Alaska have been observed to have male to female sex ratios that range from 5:1 (USFWS 2005) to 3:1 (O'Brien 2006).

Another factor that may have resulted in the difference in estimates involves the area in which redd count surveys are conducted. An estimated 3 miles of spawning habitat is not surveyed due to inaccessibility and crew safety concerns. This reach is predominately high gradient boulder cascades and not considered suitable spawning habitat, although some redds may be present. If fish spawn or otherwise die there then not counting redds in this stretch of Mill Creek could reasonably cause the population to be under estimated. Other potential causes may be that DIDSON data set included non-target fish that the 24-inch threshold did not separate out, some proportion of detected fish were steelhead or non-spawning Chinook salmon jacks, and/or poaching or some other source of pre-spawning mortality removed some fish before they reached the spawning grounds.

Implications for Water Management

The spring Chinook salmon escapement data sets acquired with acoustic sampling methods provide opportunities for making informed water management decisions during the spring and summer up-migration period. Diversion of Mill Creek flows for irrigation could be timed to coincide with periods when water diversion would be least likely to negatively affect Chinook salmon migration. For example, run timing patterns (Figure 13) indicate that the Chinook salmon migration was highly periodic with several distinct modes of passage. The primary passage mode occurred from mid-April through mid-May and a secondary one occurred from late May through most of June. The lull in passage that occurred between these two modes would have been an opportune time for a water withdrawal event that would have had negative consequences on relatively few fish if the timing made sense for irrigation purposes. Similarly, patterns in diel passage (Figure 18) show that relatively fewer fish pass during the day than at night. It may be that daily water withdrawal could be implemented during the hours in which relatively few fish are moving upstream, thereby reducing the effects of water diversion on spring Chinook salmon. Run timing information over various water year types would allow for determining the variability in migration timing, and help facilitate water exchange agreements or pulsed flow implementation for fish passage.

Viability of Long-term Assessment / Program Costs

To help develop planning efforts for recovery of Chinook salmon we have included a standard operational protocol for long-term monitoring of Chinook salmon escapement in Mill Creek (Appendix A), and an outline of general one-time and annual costs for operating an acoustic counting program on Mill Creek (Appendix B). The monitoring protocol describes in detail the elements necessary to conduct an acoustic sampling program for estimating Chinook escapement including project set-up, biological and physical data collection, data processing and analysis, and reporting. Projected first-year setup cost for purchase of both split-beam and DIDSON systems and appropriate software is approximately $139,000. Annual lease cost for the sampling gear is $61,000. Cost for annual labor, travel, and supplies is about $118,000.

Training Costs

The FWS is interested in potentially conducting future studies involving the use of DIDSON and split-beam systems for estimating salmon escapement in Central Valley waterways. In order to conduct these types of studies, the FWS has requested a cost estimate for training agency personnel to become self-sufficient in study setup, data collection, and data processing and analysis.

DIDSON:

In terms of formal training, a 1-day short-course covering operation, maintenance, and data collection and processing is offered periodically by Sound Metrics Inc., in Seattle, WA for DIDSON users. There is no cost for this training course.

For on-site training of agency personnel, the cost would depend upon the desired level of project involvement for the trainee and the trainee's level of experience. Training an entry level biological technician would include DIDSON operation, troubleshooting, site setup, data collection and archiving, and data processing. We estimate that this level of training could be accomplished during one week in the field, at a cost of about $7,000 (includes LGL senior scientist labor and travel expenses). Training a junior biologist responsible for analyzing the data and managing the entire project would include the week of on-site training plus two additional days of senior scientist labor and travel expense at a cost of about $2,000 (total cost of about $9,000 to train both an entry level technician and a junior biologist). Training time and cost will vary based on level of trainee experience.

Split-Beam:

Biosonics, Inc. of Seattle, WA, as well as other vendors of hydroacoustic equipment, offers formal training of split-beam techniques through workshops and short-courses. A 5-day hydroacoustic workshop emphasizing theory and application, and data collection and processing offered by Biosonics, Inc. costs $900.

For on-site training of agency personnel, the training effort would be similar to that with the DIDSON in terms of topics covered, costs, and training time. For a total cost of about $7,000 (includes Biosonics Inc., senior scientist labor and travel expenses), an entry level biological technician could be trained in split-beam deployment, operation, data collection and archiving, and data processing. Data analysis training would involve an additional $2,000 (includes two days of senior scientist labor and travel expenses). Data processing and analysis are typically more complicated with split-beam data as compared with DIDSON, so additional training time may be required periodically on an as-needed basis. And as with DIDSON, training time will vary depending upon the trainee's level of experience.

CONCLUSIONS AND RECOMMENDATIONS

Knowledge gained regarding the dynamics of the spring Chinook salmon up-migration compliments the spawning ground-survey information collected by DFG. The redd count data allows for inferences about the stock status of the spawning population, and the acoustic sampling provides an escapement index and run timing characteristics of the migration, which could be used in determining in-stream flow needs for fish in low water years or over critically low passage riffles and to aid in water management decision-making as discussed above. Coupling knowledge from migration dynamics and spawning stock surveys enriches our understanding of spring Chinook salmon in Mill Creek and will help facilitate recovery planning efforts for this threatened species.

We recommend a second year of sampling for escapement of spring Chinook salmon using both DIDSON and split-beam hydroacoustics. Excessive flow and consequent low signal-to-noise ratio in 2006 confounded our ability to sample with the split-beam system during the primary period of upstream passage at the Sherwood Bridge site. As a result, our 2006 study could not completely assess the effectiveness of split-beam acoustic methods for sampling adult up-migrant Chinook salmon. A more typical water year would allow for a more thorough evaluation of and comparison between DIDSON and split-beam hydroacoustic methods for estimating Chinook escapement.

Mill Creek is among the flashiest and most turbid waterways in the Sacramento River watershed (CDFG 1993; Jones and Stokes 1994; C. Harvey Arrison, CDFG, pers. obs.). Despite the exceedingly high flows observed in 2006, results from this study suggests that acoustic sampling (especially DIDSON) provides an effective and viable method for indexing escapement and developing run timing patterns for spring Chinook salmon. Given these results in what may be, with respect to flow conditions, the worse-case scenario in the Sacramento River drainage area, it is reasonable to assume that acoustic sampling could be used effectively in other locations both within and beyond the Sacramento River watershed. Based on the results described herein, there is a very high likelihood for success using an acoustic monitoring program over the long-term in waterways that support anadromous fish populations in the Central Valley of California.

The pilot study of 2006 demonstrated the effectiveness of DIDSON for estimating escapement of spring Chinook salmon in Mill Creek and provided insights into sampling a challenging and physically variable waterway. What we learned in 2006 allows for refinement of future study designs for sampling escapement that will result in more robust count estimates and enhance recovery planning efforts for this threatened species. Future escapement studies on Mill Creek will be improved by increasing the size of the fish fence to permit total sample coverage across Mill Creek. This would also likely result in a single, stationary deployment and consistent sampling effort throughout the study period. Deployment of a stage elevation gauge at the study site will allow for gaining understanding of the water level / discharge relationship and insight into variable stage effects on sampling effectiveness. We also recommend adding a weekly snorkeling survey element (water clarity permitting) to the study to aid in determining species composition for improving our ability to discern Chinook salmon from non-salmonid targets. Lastly, we suggest sampling with the DIDSON for the entire period in which spring Chinook salmon migrate up Mill Creek in order to ensure a more complete account of escapement and run timing.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge Shawn Tyerman and Megan Mathews (LGL Limited, Sidney, BC) for their efforts in manually tracking Mill Creek DIDSON data. We also thank Michael Burger (Biosonics, Inc) for processing and analyzing split-beam data. And a special thanks to Carl Schilt (LGL Limited, North Bonneville, WA) and Dorothy Baker (LGL Limited, Sidney, BC) for lending their expert editing skills to a previous version of this report.

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TABLES

Table 1. Site evaluation matrix.

Location	**Highway 99**			**Sherwood Bridge**			**Ward Dam**			**Clough Dam**			**Upper Dam**		
Rating	*Good*	*Feasible*	*Poor*	*Good*	*Feasible*	*Poor*	*Good*	*Feasible*	*Poor*	*Good*	*Feasible*	*Poor*	*Good*	*Feasible*	*Poor*
Acoustic															
Substrate		x			x			x				x		x	
Entrained Air			x[1]	x			x					x	x		
Channel Profile			x	x				x				x		x	
Water Level Variation			x[9]		x			x				x		x	
Physical															
Channel Stability		x		x			x					x		x	
Water Velocity	x				x				x	x					x
Habitat Type	x			x					x[8]	x					x
Flow (laminar)		x[5]		x				x			x[5]			x	
Biological															
Species Composition		x			x				x		x			x	
No spawning in area	x			x				x			x			x	
No milling in area			x		x				x		x			x	
Proximity to Stream Mouth	x			x				x				x			x
Regional															
Stream Access	x			x				x				x			x
Property Access Permission		x		x				x[4]				x[6]		x[4]	
Accomodations		x		x				x			x			x	
Public Use		x			x				x[7]		x			x	
Wildlife Use		x[2]			x			x			x			x	
Power Available		x[3]		x			x					x			x
Subtotals	5	9	4	11	7	0	3	10	5	2	7	9	1	12	5
Final Score[10] and % of max points		**37**	**64%**		**47**	**81%**		**34**	**59%**		**29**	**50%**		**32**	**55%**

Notes

1 May be unsuitable at high water
2 Bat Restoration Site - regular activities may have negative impact
3 AC Power within 1500 feet
4 Undetermined - No Land Owner Interview
5 Some ripples and agitation
6 Water right holder concerns
7 Private shore use
8 Site would require weir
9 Site would require moving transducer with substantial changes in water level
9 Final Score = Good x 3 + Feasible x 2 + Poor x 1

Table 2. Chinook salmon counts for DIDSON and split-beam sampling for selected days when split-beam counts exceeded DIDSON counts at the Sherwood Bridge site on Mill Creek in 2006. Daily upstream and downstream counts are presented for the DIDSON and split-beam counts are combined since directionality of split-beam targets was unknown.

	DIDSON Counts		Split-Beam Counts
Date	Upstream	Downstream	Combined
27-May	5	1	12
28-May	0	8	19
29-May	13	9	17
30-May	15	7	27
2-Jun	7	5	13
3-Jun	16	5	22
15-Jun	8	0	16
16-Jun	17	14	34
17-Jun	6	12	23
22-Jun	7	0	10
23-Jun	9	2	13

FIGURES

Figure 1. Drainage map of the Sacramento River watershed. Arrow indicates approximate location of Sherwood Bridge study site on Mill Creek.

Figure 2. Photograph of the Sherwood Bridge study site taken in November, 2005. Photo was taken while standing on Sherwood Bridge looking upstream.

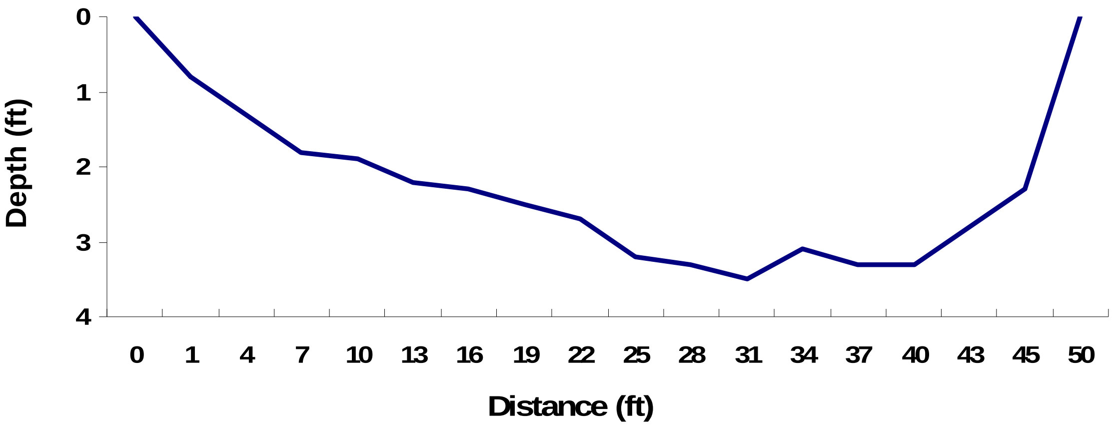

Figure 3. Cross-sectional channel profile of Sherwood Bridge study site on Mill Creek as measured in November, 2006. The gradually sloping bottom is on the river right bank and the perspective of this figure is looking upstream.

Figure 4. Photograph of aluminum frame mount used to deploy the split beam transducer in Mill Creek in 2006. The transducer and dual-axis rotator are shown mounted on the frame. An identical frame was used to deploy the DIDSON.

Figure 5. Photograph showing the fish fence and deployment of the split beam transducer and DIDSON off the river right bank at the Sherwood Bridge study site on Mill Creek in 2006.

Figure 6. Photograph showing material used to build improved fish fence. Study partner Matt Johnson is shown in the background.

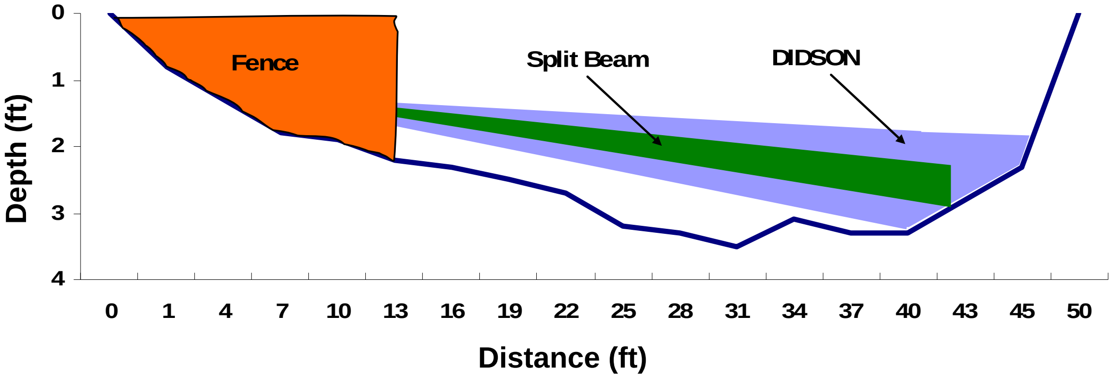

Figure 7. Cartoon depiction of the sampling beams and fish fence at the Sherwood Bridge study site. The fish fence is located on the river right bank, and the perspective of this figure is looking upstream.

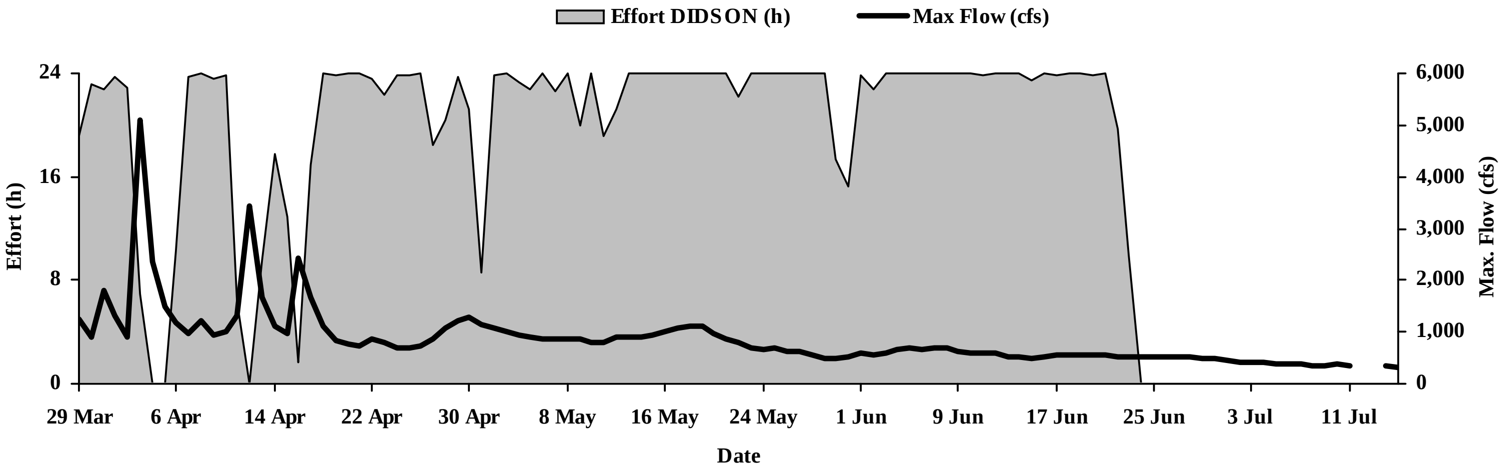

Figure 8. DIDSON sampling effort at the Sherwood Bridge site on Mill Creek, 29 March – 23 June 2006. Maximum daily flow values from Upper Dam stream gauge.

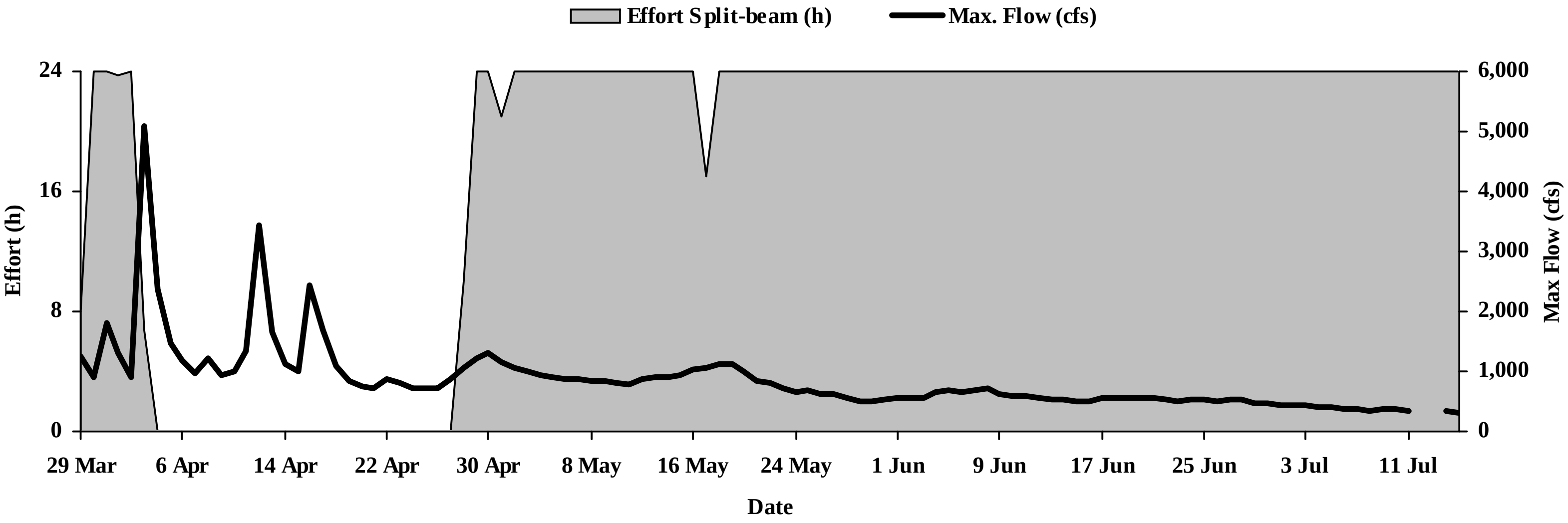

Figure 9. Split-beam sampling effort at the Sherwood Bridge site on Mill Creek, 29 March – 15 July 2006. Maximum daily flow values from Upper Dam stream gauge.

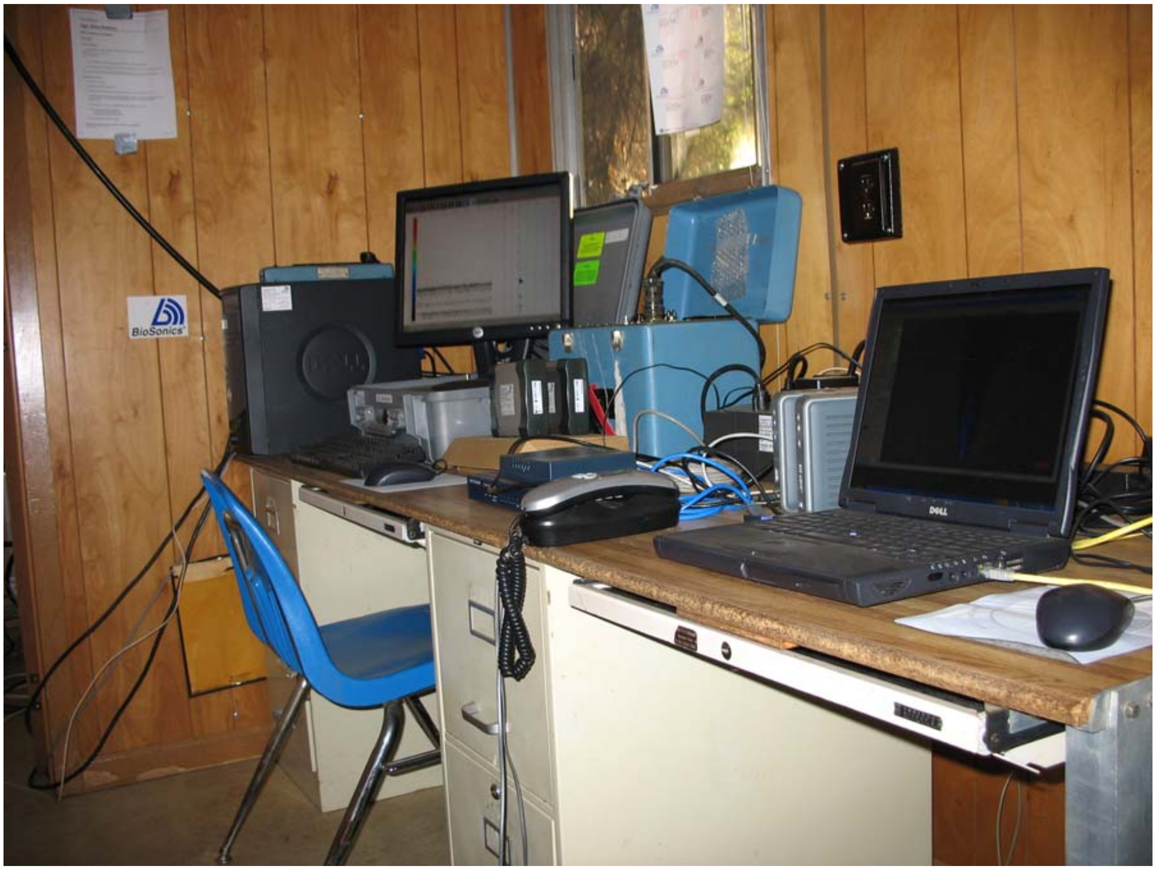

Figure 10. Split-beam echo sounder surface unit, data collection PC, rotator control box, and data collection PC installed in project trailer. Laptop on the right controlled the DIDSON system.

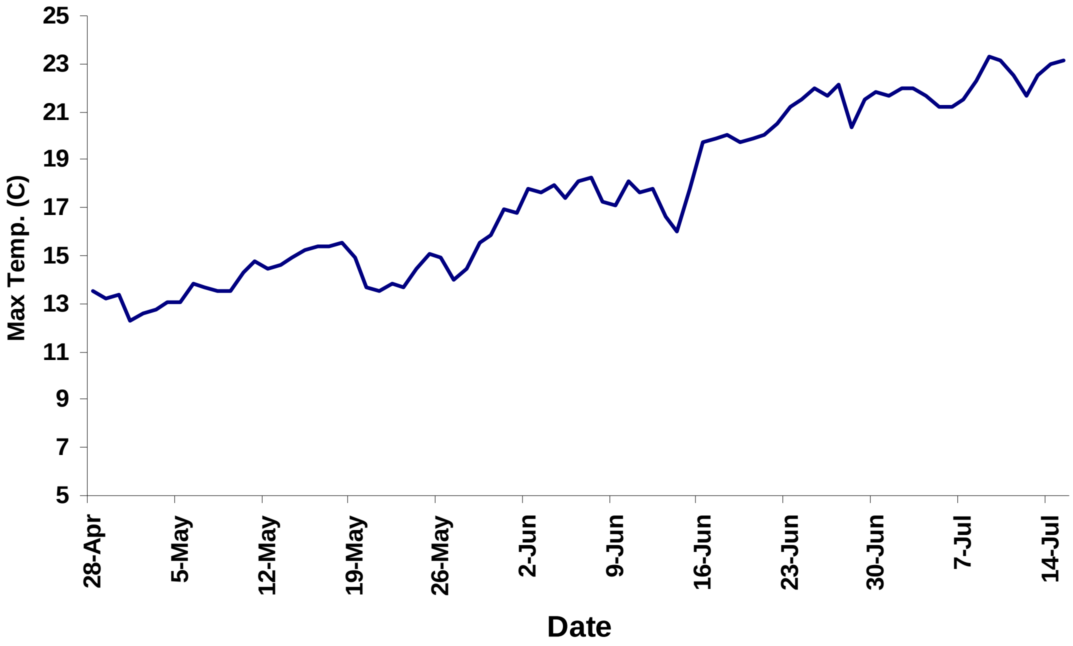

Figure 11. Water temperature at the Sherwood Bridge study site on Mill Creek for the period 28 April through 15 July.

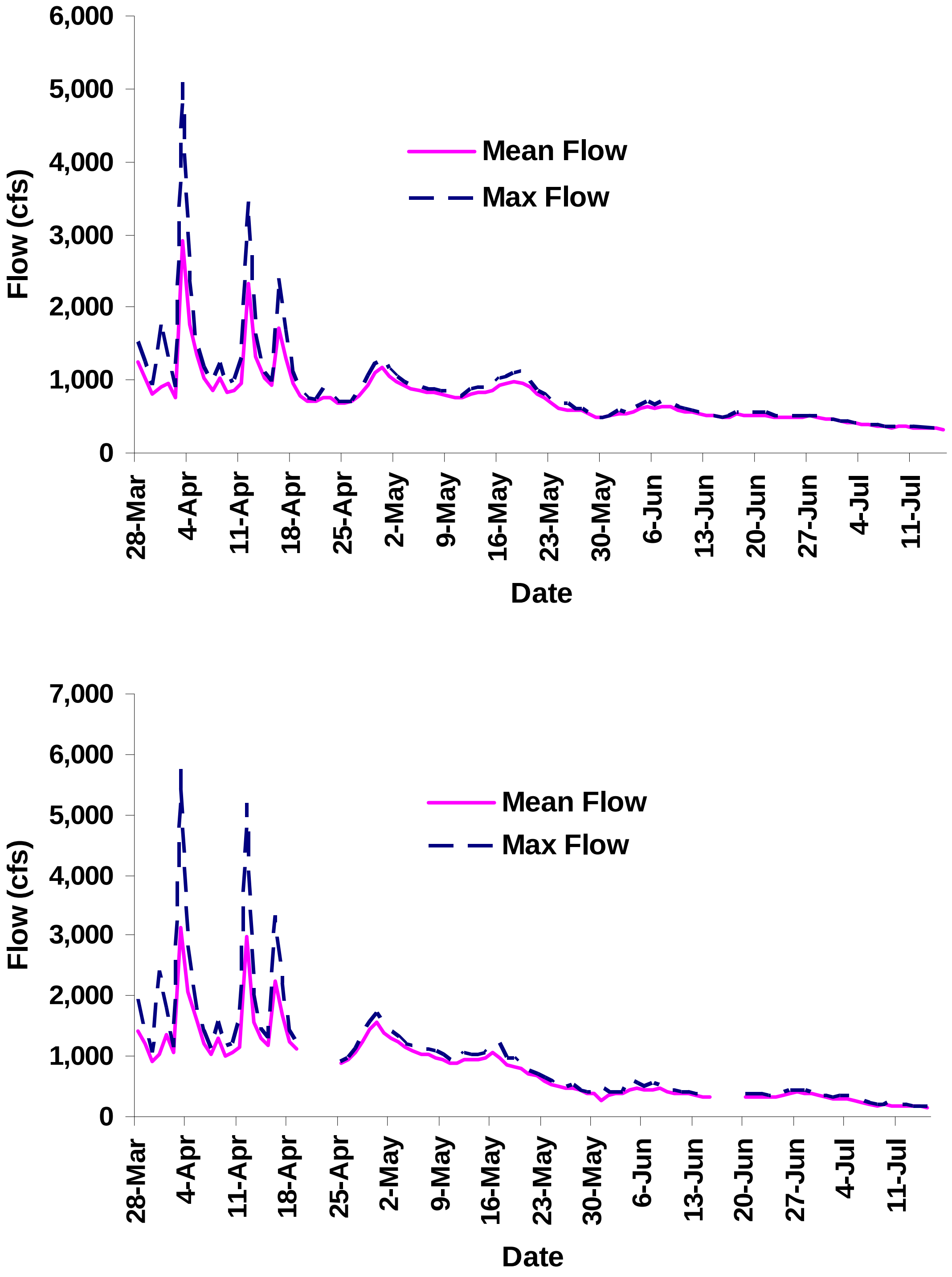

Figure 12. Daily mean and maximum flows of Mill Creek in 2006 for Upper Dam (top) and Highway 99 (bottom) stream gauges. The Upper Dam gauge is located about 4 miles upstream from the Sherwood Bridge study site and the Highway 99 gauge is located about 1 mile downstream of the study site.

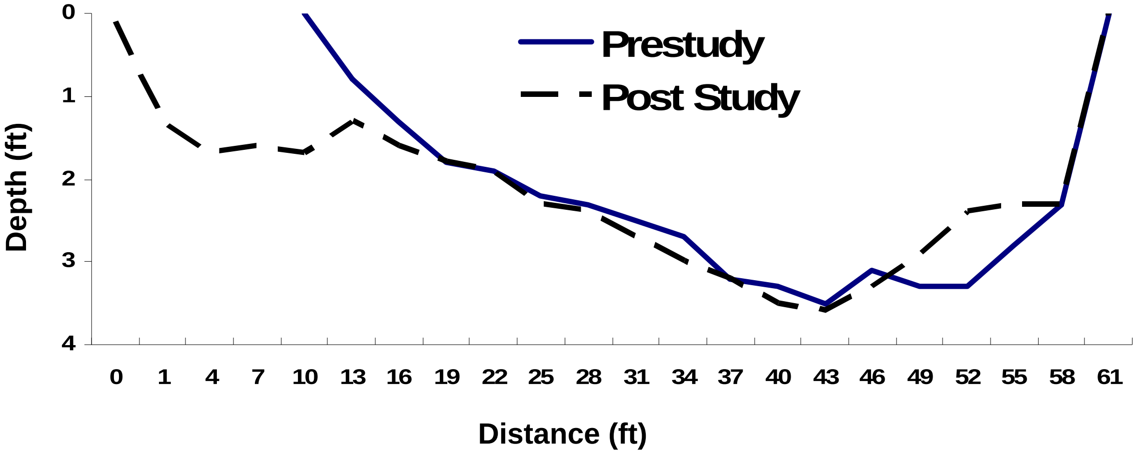

Figure 13. Cross-sectional profiles of Sherwood Bridge site on Mill Creek measured prior to conducting the study and after the study was completed. The majority of the scouring occurred on the river right bank. The figure perspective is looking upstream.

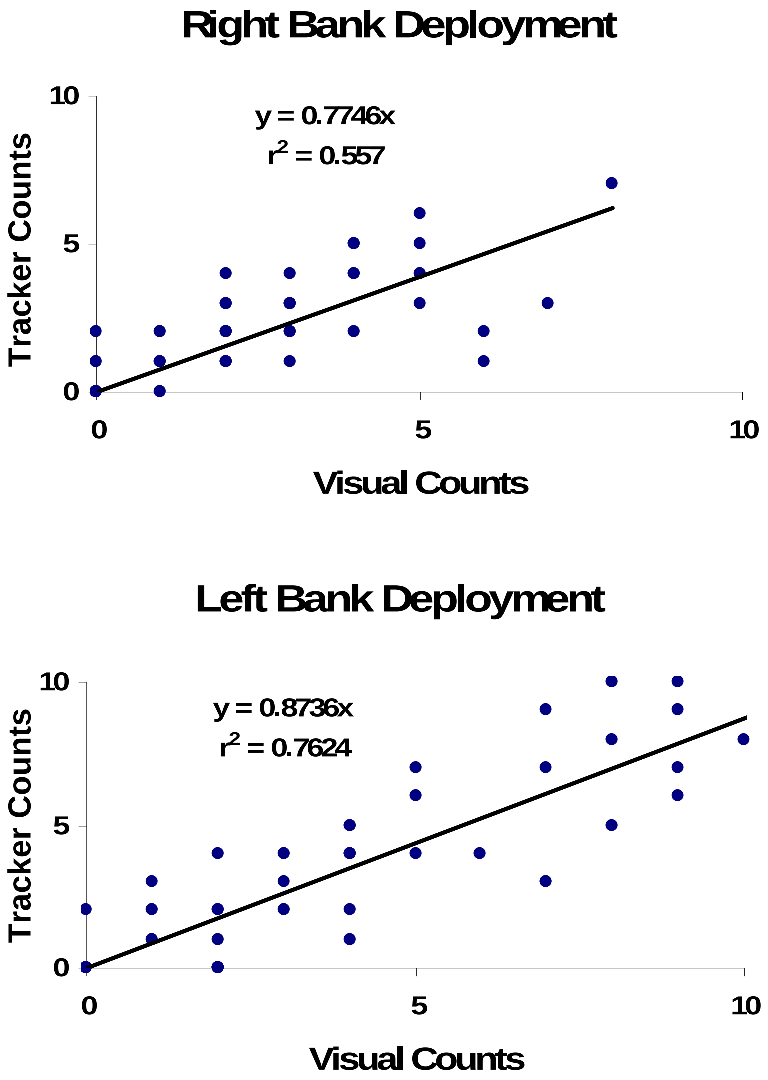

Figure 14. Scatter plots of the relationship between tracker counts and visual counts for the river right bank (top) and river left bank DIDSON deployments. Each data point represents one hour of data (n = 51 and 52 for right and left bank, respectively) that was both autotracked and manually counted.

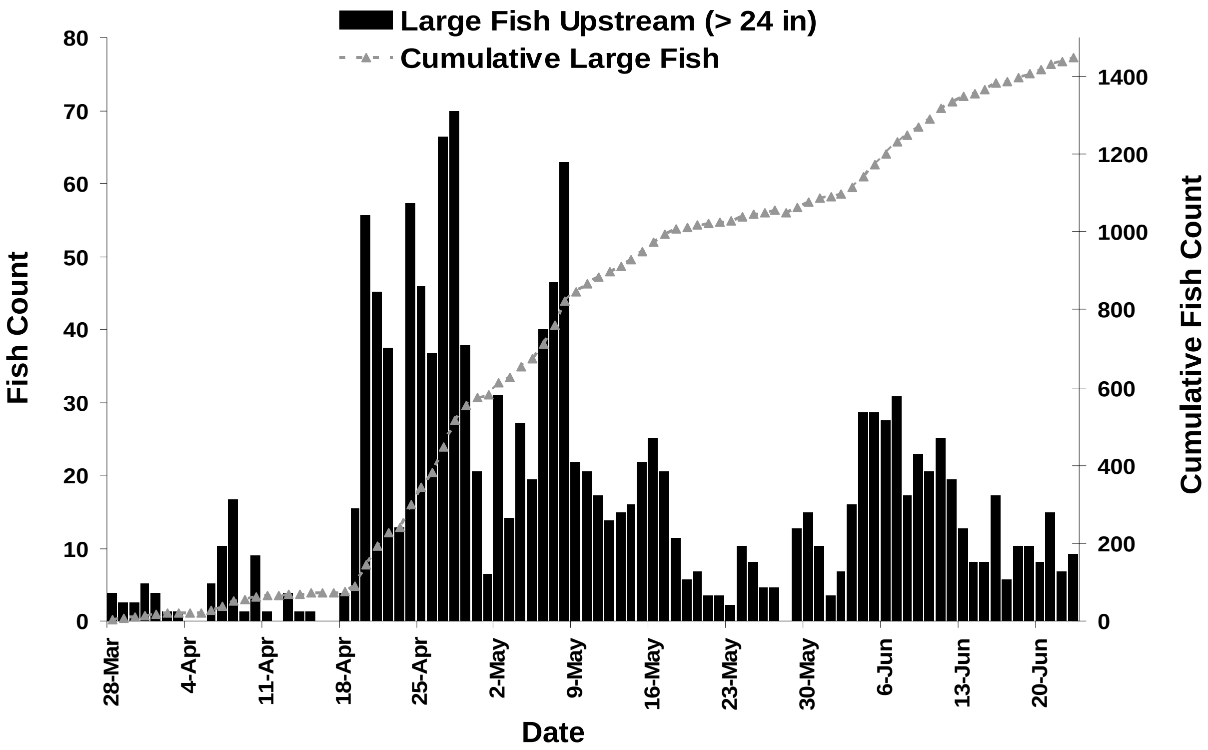

Figure 15. Run timing plot of spring Chinook salmon at the Sherwood Bridge site on Mill Creek for 2006 based on DIDSON sampling.

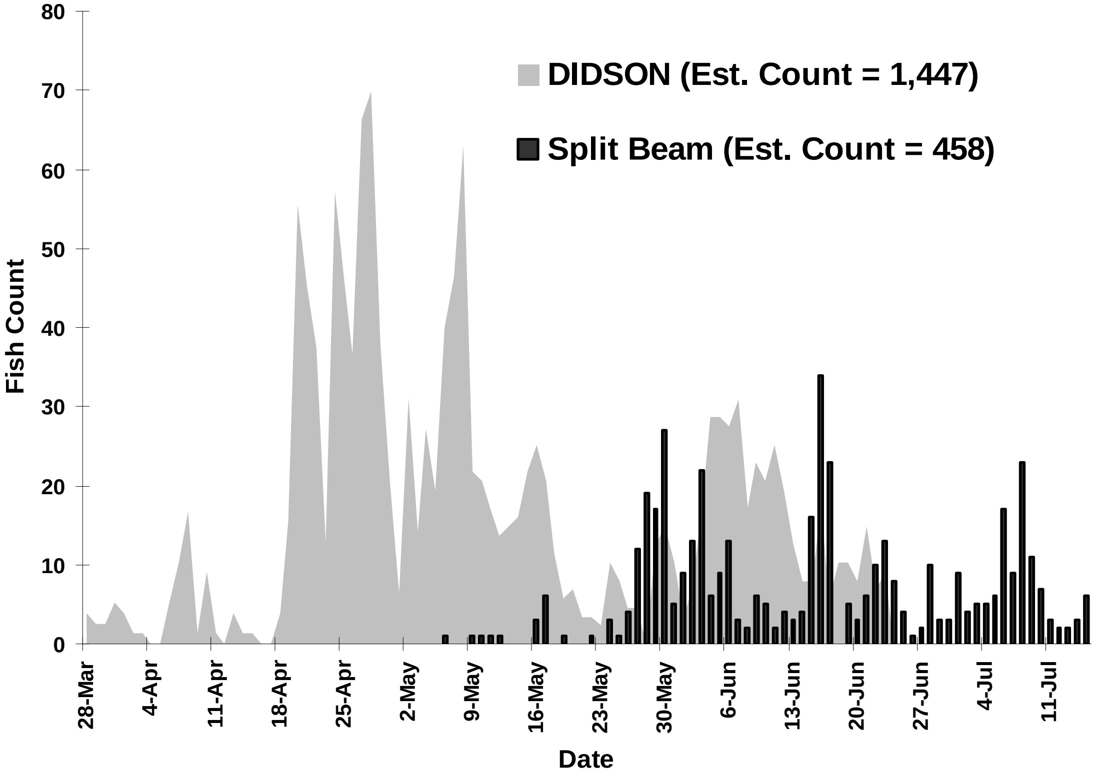

Figure 16. Run timing of spring Chinook salmon at the Sherwood Bridge site on Mill Creek in 2006 based on both DIDSON and split-beam sampling.

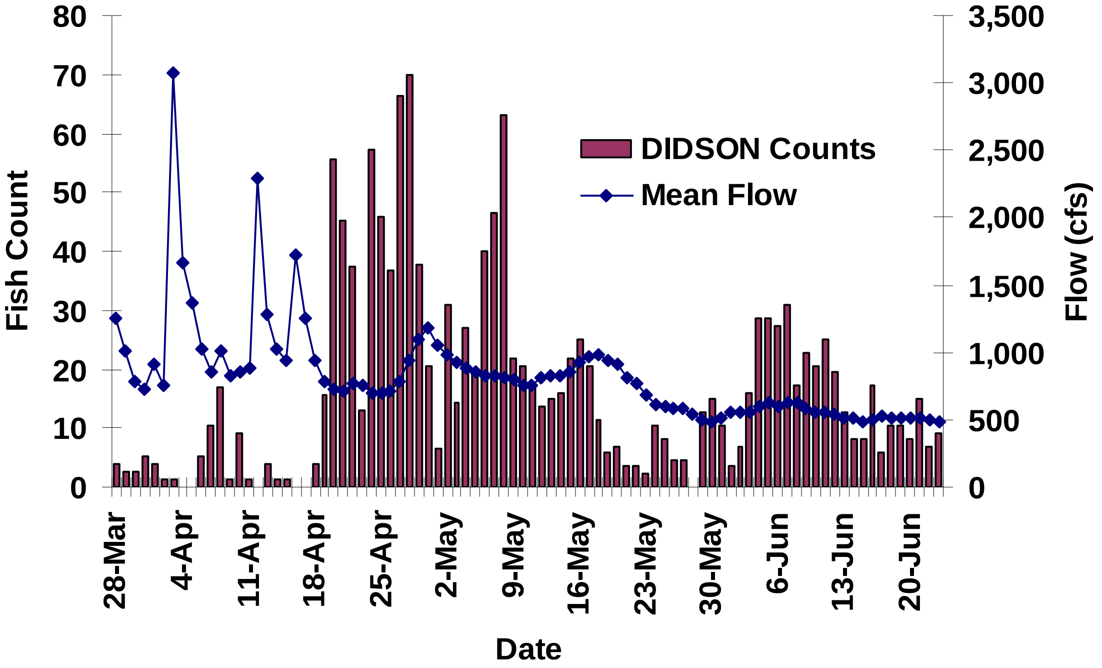

Figure 17. Daily fish counts based on DIDSON sampling and mean discharge from the Upper Dam stream gauge (the Upper Dam gauge is located about 4 miles upstream of the Sherwood Bridge study site).

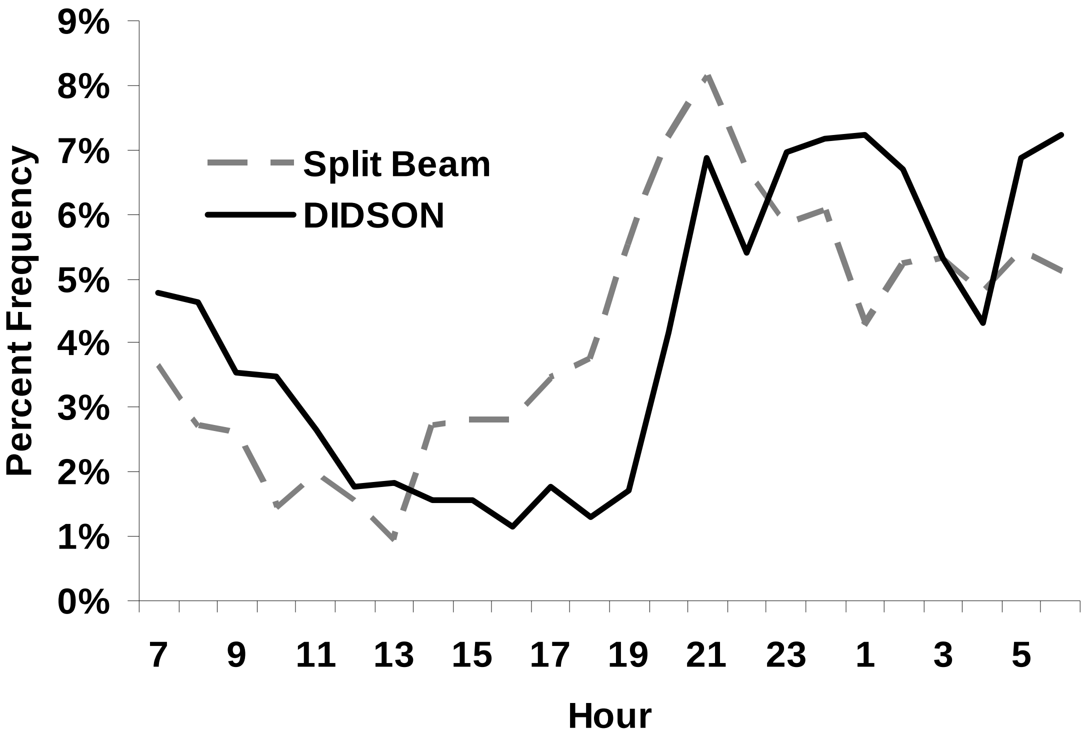

Figure 18. Hourly passage of spring Chinook salmon at the Sherwood Bridge site on Mill Creek in 2006 based on DIDSON and split-beam sampling.

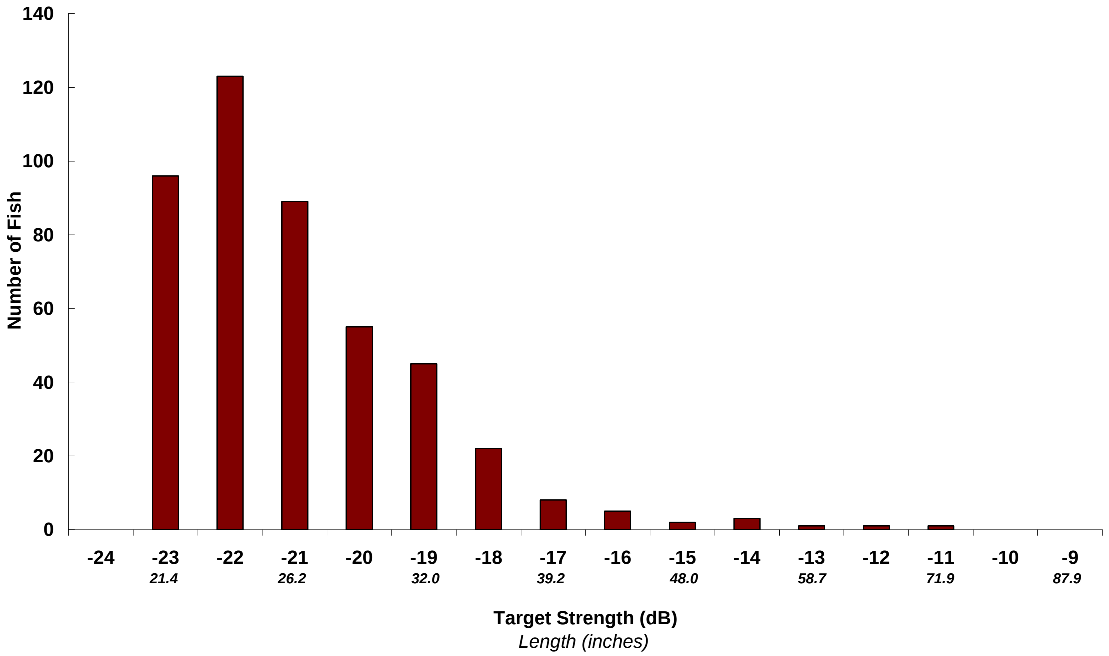

Figure 19. Target strength distribution of detected fish using split-beam sampling at the Sherwood Bridge site on Mill Creek in 2006. Total lengths of fish that correlate with target strengths were calculated using Love's equation (1971).

APPENDICES

APPENDIX A. Operational protocol for long-term monitoring of Chinook salmon escapement in Mill Creek.

The operational protocol used should consist of the following:

- For sampling Mill Creek, use the Sherwood Bridge site as this location proved to be suitable for acoustic sampling in 2006.
- If acoustic sampling were proposed for a different waterway, then we recommend evaluation of several sites using the site suitability criteria used in 2006 (Table 1). Site suitability should be evaluated in the winter months to ensure enough setup time prior to the onset of spring Chinook migration.
- Apply for appropriate state and federal permits as required in the winter months prior to data collection to guarantee permits are in place prior to data collection start date.
- Install acoustic gear and fish fence at the site during the last week in March to ensure detection of the initial pulse of up-migrating spring Chinook salmon.
- Measure bathymetry across study site prior to start of data collection.
- Map the sample volumes for both sampling methods to ensure optimal coverage.
- Engineer stream reach by removing large boulders that may limit effective sampling ranges.
- Acquire data 24 hours per day from late March through mid-July.
- Monitor data collection systems daily both on-site and remotely through DSL link to ensure functionality.
- Establish data backup and archiving routine with external hard drives and optical media storage.
- Automate data processing to allow for quick turnaround of preliminary escapement counts and trends in migration run timing. Automation would occur in future years once data processing parameters are determined.
- Implement quality control process on DIDSON data by manually reviewing a subset of data and comparing the manual count data to those estimated with the auto tracking software. The relationship between the manual and auto counts should then be used to refine escapement estimates as done in 2006.
- Deploy temperature sensors at the study site to allow for inferences into the relationship between water temperature and fish passage.
- Download flow data from both the Highway 99 Bridge and Upper Dam gauges via the internet (http://cdec.water.ca.gov/cgi-progs/histPlot; http://waterdata.usgs.gov/ca/nwis/uv?format=gif&period=31&site_no=11381500) on a weekly basis to track discharge in Mill Creek throughout the study period.
- Deploy a stage elevation gauge at the study site to gain understanding of the water level / discharge relationship and insight into variable stage effects on sampling effectiveness.
- Conduct snorkel surveys to assess species composition near the sampling beams on a weekly basis, depending upon water clarity.
- Produce periodic progress reports highlighting trends in physical variables (flow and temperature) and escapement results.

- Measure bathymetry after data collection is completed and compare results with cross-sectional profile measured prior to start of data collection.
- Report results of estimated escapement and compare with redd count population estimates and previous years' escapement results.

Information gathered during each subsequent study should be utilized to further refine the process with the eventual goal of completely automating data acquisition and processing.

APPENDIX B. Costs for operating an acoustic counting program on Mill Creek.

Besides the purchase costs for the split-beam and DIDSON systems and the software programs, the costs below are rough order-of-magnitude estimates. Actual costs will vary depending upon yearly labor rates, specific material costs and study duration. Annual costs assume a 3-month study period.

First Year Setup Costs:

BioSonics 120 kHz Split Beam System	$39,440 (purchase) $18,000 (lease)
EchoView Software	$16,000
DIDSON	$80,000 (purchase) $43,000 (lease)
DIDSON Processing Software	$3,500
Total First Year Costs	$138,940 (purchase option) $80,500 (lease option)

Annual Costs:

BioSonics 120 kHz Split Beam System	$18,000 lease (if not purchased)
DIDSON	$43,000 lease (if not purchased)
Total Annual Lease Cost	$61,000

Labor for:	DIDSON	Split-Beam
Planning	$ 2,400	$ 1,600
Deployment / Testing Acoustic Systems	$ 7,500	$ 7,500
System Operation	$ 9,000	$ 7,000
Data Management and Transfer	$ 2,000	$ 6,000
Data Analysis	$20,000	$16,000
Reporting	$12,000	$ 5,000
Project Management	$ 3,000	$ 4,000
Labor Subtotal	$55,900	$47,100

	All
Travel	$7,000
Office / Communications / Shipping	$5,000
Materials and Field Supplies	$3,000
Total Annual Labor/Travel/Other Cost	$118,000
Grand Total Annual Cost	$179,000