OPERATION OF DUAL FREQUENCY IDENTIFICATION SONAR (DIDSON) TO MONITOR ADULT ANADROMOUS FISH MIGRATIONS IN THE SMITH RIVER, CALIFORNIA: 2-YEAR PILOT STUDY

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ABSTRACT

We investigated the use of Long Range Dual Frequency Identification Sonar (DIDSON) for enumerating adult salmon and steelhead migrating past river mile 6 in the Smith River, Del Norte County, California. Two Long Range DIDSON units operated continuously at the fixed location to record anadromous fish passage 24 hours per day from 25 Oct 2010 to 04 Apr 2011 in Year 1 and from 01 Oct 2011 to 29 Mar 2012 in Year 2. The percentage of actual sonar recording time out of the total possible recording time in Years 1 and 2 was 86% and 95%, respectively. The net totals of adult fish counted migrating upstream in Years 1 and 2, without removing steelhead trout kelts, were 31,977 fish and 32,143 fish, respectively. Peak migration times of Chinook salmon and steelhead at the Rowdy Creek Fish Hatchery weir were similar to peak upstream fish passage times at the Smith River DIDSON facility. Based on DIDSON fish counts and available fisheries data, our preliminary estimates of basin-wide escapement of Chinook salmon and steelhead to the Smith River was 22,500 Chinook salmon and 16,000 Steelhead in Year 1, and 20,000 Chinook salmon and 15,000 steelhead, in year 2. We did not consider coho salmon in our estimates due to the lack of available information and suspected low abundance. Results from our pilot study show promise for the use of fixed location DIDSON systems to aid in monitoring the status and trends of anadromous fish populations in the coastal rivers of California.

ACKNOWLEDGEMENTS

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INTRODUCTION

Monitoring the abundance of Pacific salmon returning to rivers to spawn is critical for evaluating the status and trends of populations, managing fisheries and identifying conservation needs. The raw data upon which salmon and steelhead spawning abundance estimates are developed for northern California rivers are based on spawning ground surveys, dam counts, and angler-use information (Good et al. 2005, Ford et al. 2010). While this information is extremely useful for resource managers it does not provide a complete measure of anadromous salmonid abundance or escapement for individual rivers and streams, and in most cases the data represents only a fraction of spawning grounds in a basin or region.

Anadromous fish escapement information for the West Coast is often limited by the financial, physical and technological constraints involved with collecting continuous anadromous fish information in dynamic, relatively large and often turbid stream conditions inherent of coastal anadromous streams. New adult abundance monitoring approaches and techniques are needed to help evaluate the status and trends of all anadromous fish populations. In this pilot study, we investigated the utility of a fixed location, DIDSON fish counting system for collecting basin wide salmon and steelhead abundance information in the Smith River, California's fourth largest coastal river (Figure 1).

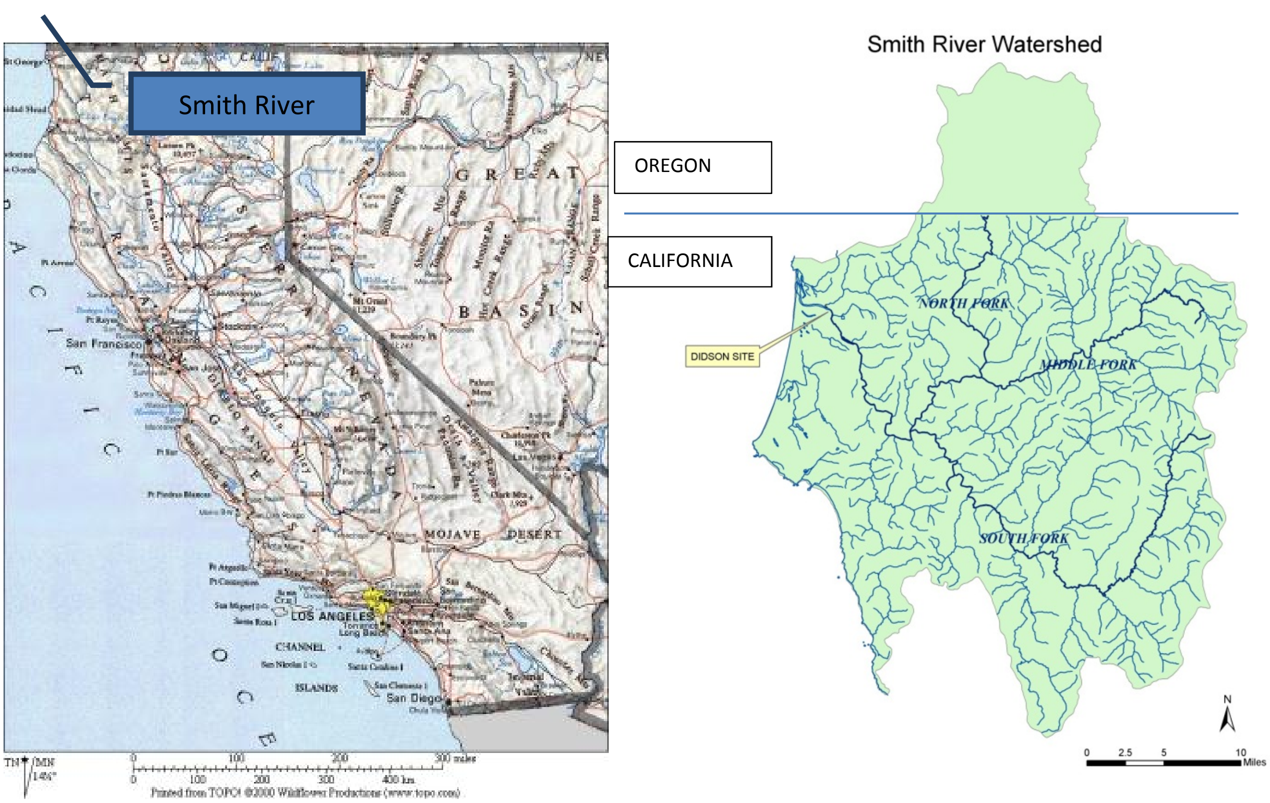

Figure 1. Location of the Smith River Basin, Del Norte County, California.

DIDSON is a multi-beam, high-definition imaging sonar that can detect and identify fish in dark and turbid aquatic conditions to a range of at least 40 meters. The technology produces images of fish in real time that can be recorded like video, analyzed with software, and the data can be archived. DIDSON can be deployed in large rivers or small streams and does not require handling fish, modifications to the environment or State and Federal permits to operate. DIDSON units are the size of a car battery and can be deployed from a submerged, stationary position near the water's edge to ensonify a subsection or an entire cross-section of a submerged channel. Fish can be imaged, counted and measured as they pass through the sonar beams. Unbiased fish counts and reasonably accurate length measurements can be manually derived or semi-automated with software provided by the manufacturer.

Fixed location DIDSON fish counting stations are becoming more widespread to estimate basin-wide salmon and steelhead escapement (Galbreath and Barber 2005; Holmes et al. 2006; Burwen et al. 2007; Johnson et al. 2006; Maxwell and Gove 2007; Methany 2012; Mueller et al. 2008, Pipal et al. 2010, Pipal et al. 2012). The use of DIDSON is proposed by the California Coastal Salmonid Monitoring Plan (CMP) (Adams et al. 2011) for Southern California steelhead populations and currently is used in Santa Cruz County (Pipal et al. 2011, Pipal et al. 2012), Santa Barbara and Ventura Counties (S. Howard pers. comm., D. McCanne pers. comm). In the CMP Northern Region, regional sample-based spawner survey methods described in Gallagher (2005) are included in the CMP for targeting adult coho salmon abundance (Adams et al. 2011). Studies like ours are being conducted in Northern Region, including Redwood Creek (Metheny 2012) and the Mad River (CDFW), for investigating the usefulness of DIDSON for estimating total anadromous fish escapement to moderately large streams. The advantages of using DIDSON to help monitor the status and trends of anadromous fish in the Northern Region of California include the ability of the technology to;

- Operate in rivers too wide or powerful for barrier weirs or too turbid for visual observations.
- Collect protected species data without handling fish or affecting critical habitat;
- Monitor anadromous fish migrations 24 hours per day;
- Validate spawning ground surveys
- Observe behavioral patterns of anadromous fish;
- Detect rare events (e.g. sturgeon);

Using DIDSON or other side looking sonar systems alone to estimate anadromous fish run-size has disadvantages with respect to apportioning species with overlapping run times (Burwen et al. 2011, Pipal et al. 2012). Pipal (2012) reported that the differentiation between steelhead and coho salmon with DIDSON was not possible because fish were too similar in size, body morphology, and run timing. In Alaska, gill netting or fish wheels aid in species apportionment but is costly to implement and subject to biases (Burwen 2011). Most recently ADF&G evaluated the potential for dual-frequency identification sonar (DIDSON) to provide improved discrimination of larger

Chinook from smaller species of salmon based on size measurements taken directly from high-resolution images of migrating salmon (Burwen et al. 2007).

The presence of multiple fish species with overlapping run times in a river can complicate escapement estimates made using hydroacoustics. Species apportionment can be achieved through analysis of hydroacoustic images and physical sampling means such as spawning ground surveys and angler and outfitter data where relevant. Physical, behavioral and temporal similarities of observations can potentially be used to determine species frequency distributions or probability of species presence (Metheny 2012). Length frequency analysis is a promising approach to determining target species when there is minor overlap in individual lengths, or when length frequency distributions can be calibrated with sampling data. A semi-automated length measurement procedure is widely used to measure lengths. However, manual edits of hydroacoustic images made by different technicians can lead to bias in results. Data processing can also be time consuming, necessitating a sub-sampling procedure for efficient analysis.

Investigators have observed a positive bias in DIDSON length measurements. Johnson et al. (2009) compared fork lengths of Chinook salmon carcasses with manual measurements of DIDSON fish images during the same year. After converting fork lengths to total length and subtracting 6 cm from DIDSON lengths they found a reasonable comparison of DIDSON length frequency distribution to the distribution of Chinook carcass lengths. Burwen et al. (2007) further investigated the length exaggeration using a long range DIDSON in high frequency mode fitted with a high resolution lens. Researchers tethered 10 salmon near the center of the DIDSON's beam array and compared manual DIDSON measurements using the Sound Metrics DIDSON software with measurements of 130 free swimming fish, also of known length. Sonar settings were 20 meters, and measurements were made 4-8 meters from the transducer for free swimming fish and 4-13 meters from the transducer for tethered fish.

At higher passage rates, individual fish could be measured with confidence when they were within 1.5 to 20 meters from the transducer. Error in manual measurements was mostly associated with the position and shape of the fish's body in relation to the transducer. As the fish arched their bodies while swimming, measurement error was often approximately 5.1 to 6.8 cm. Interestingly, length bias was only observed in the tethered fish. Measurements of free-swimming fish were relatively accurate, while tethered fish measurements displayed a length exaggeration of approximately 1.3 cm/m. Researchers suspected this error was a result of the position that the measurements were taken within the sonar array, as the sensitivity of DIDSON sub-beams depends on their distance from the acoustic axis. Tethered fish were measured close to or along the array axis, whereas free swimming fish were measured throughout the array; thus, tethered fish lengths were more likely to suffer bias with an increase in range. This bias is likely a result of the decrease in down-range resolution of the images. Burwen et al. (2007) recommended that tethered fish experiments be replicated at each sonar site to determine the magnitude of the bias with range. However, given that measurements of free swimming fish made on and off axis did not display much of a length exaggeration, reasonable estimates of fish length can likely be obtained at close ranges (<12 m) and using the high frequency mode (1.8 MHz). Length may also be significantly affected at close ranges by the focus range (Hanot 2012, pers. comm.).

Sampling continuously to enumerate fish can be inefficient. Lilja et al (2008) used auto and cross correlation analysis to investigate the appropriate sampling frequency for estimating escapement of Sockeye Salmon (*O. nerka*) in the Horsefly river in British Columbia with a DIDSON. They sampled 20 minutes per hour and then used a subset of the data to evaluate the efficiency of their sampling protocol. Researchers split 20 minute sequences into 10 minute periods and salmon escapement was estimated during each period, finding that the estimates were similar and that variation within the hour was random. They recommended a minimum sampling schedule of 10 min per hour and a maximum of 20 min per hour. They also suggested that sampling occur more frequently during high passage events to further increase sampling efficiency.

PILOT STUDY OBJECTIVES

The objectives of the Smith River DIDSON Pilot Study were to:

1. Develop and operate a DIDSON fish counting station in the lower Smith River for two seasonal migrations of fall-run Chinook salmon, coho salmon and steelhead.
2. Investigate the usefulness of DIDSON fish counting stations for achieving California Coastal Salmonid Monitoring Plan Objectives.
3. Compare DIDSON count data with Rowdy Creek Fish Hatchery Weir data.
4. Develop a regional model for DIDSON station design and operation.
5. Provide a baseline for monitoring the status and trends of Smith River salmon and steelhead.

SITE DESCRIPTION

The Smith River is the fourth largest coastal river in California and has the unique status as the State's last major free flowing river that drains directly into the Pacific Ocean. The Smith River is famous for water clarity, its world-class salmon and steelhead fishing and its ancient redwood forest groves (SRAC 2002). The watershed exists within Redwood National and State Park and National Forest boundaries, is designated a Key Watershed under the Pacific Northwest Forest Plan and has National Recreation Area and Wild and Scenic River status. The Smith River is a Salmon Stronghold Basin under the North American Salmon Stronghold Partnership.

The Smith River originates in the Siskiyou Mountains of the Klamath Geologic Province and enters the Pacific Ocean 4 miles south of the Oregon Border in Del Norte County, California. The total watershed area is approximately 1,862 km^2 (720 mi^2) with 236 km^2 in Oregon in the North Fork sub-basin. The elevation ranges from sea level to 1,958 m. The total length of stream channel is 5,000 km of which about 483 km is available for anadromous fish (McCain et al. 1995). Annual rainfall amounts range from approximately 1778 mm (70 in.) at the coast to over 3800 mm (150 in.)

in the interior. The precipitous terrain and elevation drop creates a fast response time of stream flow to rainfall events. The Smith River has the largest mean annual runoff per area of any major watershed in California (Rantz, 1969) and is prone to periodic large scale flooding, particularly during rain-on-snow events. Mean monthly flow values in the Smith River, based on USGS gauging station data, range from about 8.5 cubic meters per second (cms) or 300 cubic feet per second (cfs) in August and September, to around 230 cms or 8,000 cfs in December and January (Figure 2).

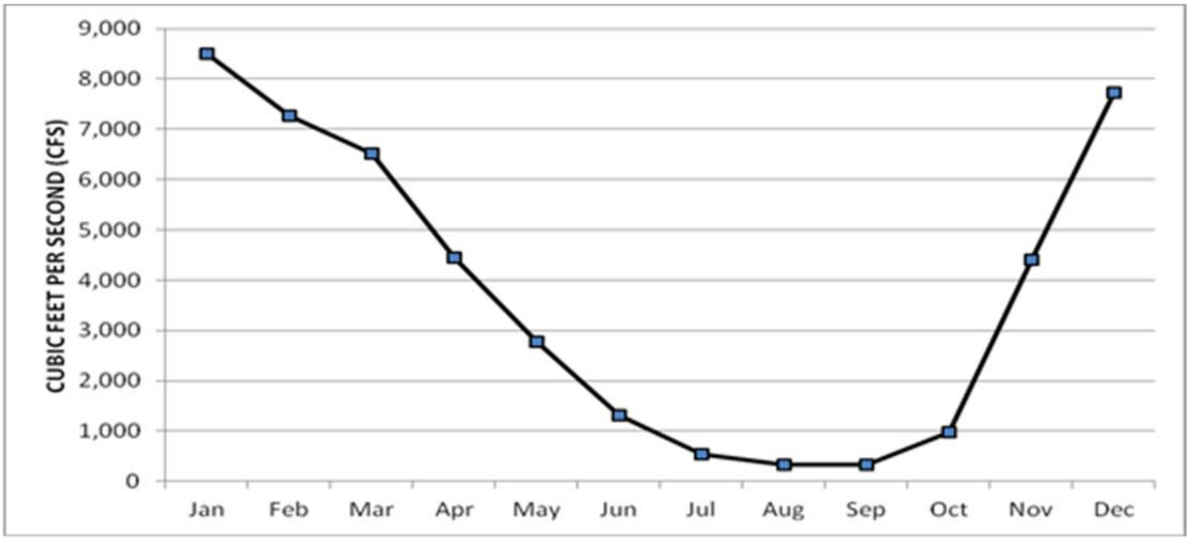

Figure 2. Mean monthly discharge values in the Smith River from 1931 to 2012 (USGS 11532500, Smith River near Crescent City)

This pilot study focused on salmon and steelhead in the Smith River. The Smith River supports four principal species of anadromous salmonids: fall-run Chinook salmon (*Oncorhynchus tshawytscha*), coho salmon (*O. kisutch*), winter-run steelhead trout (*O. mykiss irideus*) and coastal cutthroat trout (*O. clarki clarki*). Small numbers of chum salmon (O. keta), spring-run Chinook and summer steelhead have been observed in the Smith River but their past and present status is poorly understood (Moyle 2002).

The status of Smith River Chinook salmon, coho salmon and steelhead trout and their associated Evolutionary Significant Units (ESU's) are included in Table 1. For a list of all anadromous fish in the Smith River and their status descriptions see Appendix A. Only coho salmon are listed under the Endangered Species Act (1973) as a Threatened Species in the Southern Oregon and Northern California Coast ESU. Otherwise fall Chinook salmon and steelhead populations in the Smith River are considered healthy and continue to support popular recreational fishing opportunities. There is no evidence of a long term decline in the fall-run Chinook population, but data are limited (Moyle 2002). In 1997 the California Department of Fish and Wildlife recognized the Smith River as being California's most robust steelhead population but overall there was widespread concern that Klamath Mountains Province (KMP) steelhead populations were in general depressed from historic levels (CDFG 1997).

Table 4. Status of Chinook salmon, coho salmon and steelhead trout in the Smith River Basin.

Species	Evolutionary Significant Unit (ESU) and description	ESA/CESA Status
Chinook salmon	Southern Oregon Northern California Coast (Cape Blanco to Klamath River)	Not Warranted
Coho salmon	Southern Oregon Northern California Coast (Cape Blanco, OR to Punta Gorda, CA)	Threatened
Steelhead	Klamath Mountains Province (Cape Blanco, OR to Klamath River, CA)	Not Warranted

In 1960 the US Fish and Wildlife Service provided a survey report, at the request of the Department of the Interior, to establish a baseline of fish and wildlife resources in northern California (USFWS 1960, 1965) (Table 2). However, “estimates given here which are based on little or no data should be used only in outlining the major and critical factors of the resource” (CDFW 1965). The basin-wide estimates of spawning abundance, exclusive of catch, were: King (Chinook) salmon, 15,000 fish; Silver (coho) salmon, 5,000 fish; and steelhead trout, 30,000 fish. Except for the Trinity River, recent estimates of steelhead run sizes are not available for any of the major runs in the KMP (CDFW 1997). Moyle (2002) described the Smith River as a relatively unaltered stream that never supported a large Chinook population. He reported annual estimates of Chinook salmon in the Smith River are generally 15,000-30,000 fish.

The run times of Smith River salmon and steelhead have been documented primarily by angler surveys, Rowdy Creek Fish Hatchery weir counts, and tributary spawning ground surveys. Waldvogel (2006) monitored a productive reach of the Mill Creek watershed over a 23-year period and reported three distinct Chinook salmon runs. Table 3 provides a broad description of fall-run Chinook salmon, coho salmon and winter steelhead run times in the Smith River (SRAC 2002). Angler surveys may provide the best available information regarding timing of entry of Chinook salmon, coho salmon and steelhead in the Smith River. The California Department of Fish and Wildlife Steelhead Catch Report Restoration Card program was established in 1992 to analyze California steelhead catch and provide an indication of steelhead population size based on catch per unit effort. On-the-ground angler surveys by the Department of Fish and Wildlife were conducted in the Smith River in 1984, 1997, 1998, 1999, 2000, 2001, 2004, and 2005 (Figure 3).

The Smith River DIDSON Station is located 1.8 river miles upstream from the mouth of Rowdy Creek (RM 4), a lower Smith River tributary. In 1970, the governor signed Senate Bill #1047, which authorized the Kiwanis Club of Crescent City to build the first privately owned fish hatchery in California. The hatchery facilities included a barrier weir fish trap that provides one of the longest set of annual anadromous abundance data for the Smith River. In general, peak counts of Chinook salmon at the hatchery facility occur during November and typically cease around 15 December (A. Van Scoyk pers. comm.). Coho salmon, though very few are observed at the weir, have passed through the facility in October and again in late December. It is thought that coho appearing in October are strays from the Klamath River (A. Van Scoyk, pers. comm.). Although over-lap of Rowdy Creek salmon and steelhead run times exists, peak numbers of steelhead at the hatchery are observed in mid-January. The weir data provides opportunities for species run timing comparisons and additions of weir counts to basin-wide escapement counts or estimates.

Table 5. Salmon and steelhead run-size estimates for northern California rivers (USFWS, 1960).

River Basin	Chinook salmon	Coho salmon	Steelhead
Smith River	15,000	5,000	30,000
Klamath River	100,000	20,000	400,000
Redwood Creek	5,000	2,000	10,000
Mad River	5,000	2,000	6,000
Eel River	25,000	15,000	100,000
Mattole River	5,000	2,000	12,000

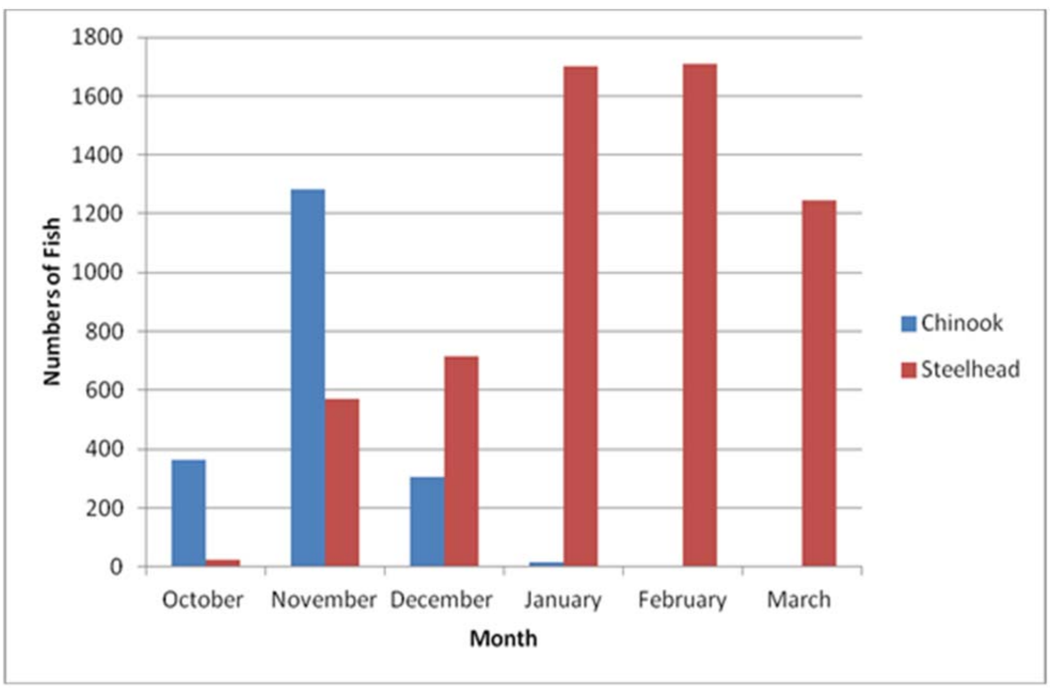

Figure 3. Mean annual estimates of angler caught Chinook and steelhead by month in the Smith River, 1997-2006 (CDFG 1997-2006).

Table 6. Adult migration times for salmon and steelhead in the Smith River.

Species	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct	Nov	Dec
Chinook salmon												
Coho salmon												
Winter steelhead												

The Smith River DIDSON Pilot Study site is located in the lower Smith River at the Public Boat Launch facility, one river mile downstream from the Highway 101 Bridge and 6 river miles (RM) upstream from the mouth of the river (Pacific Ocean) (Figure 4). The site includes the State of California 3-acre parcel (APN# 105-02-002) managed by Del Norte County for boat launch and river access. Alexandre EcoDairy Farms, owners of land on the opposite side of the river, granted access for the study so the two DIDSON units could operate between the opposing river banks. A biological assessment was prepared for the construction of utilities infrastructure and a 10 feet by 14 feet building, built above the 100 year flood elevation (California Coastal Development Permit 1-DNC-10-119, County Use Permit UP1101C, County Building Permit B31369).

Site selection for the Smith River DIDSON Station was based both on its location upstream from tidal influence and downstream from major spawning grounds in the mainstem Smith River and numerous tributaries. We considered channel geometry, the availability of grid power, ownership vehicular access and security for appropriately siting the station for obtaining basin-wide anadromous salmonid escapement information.

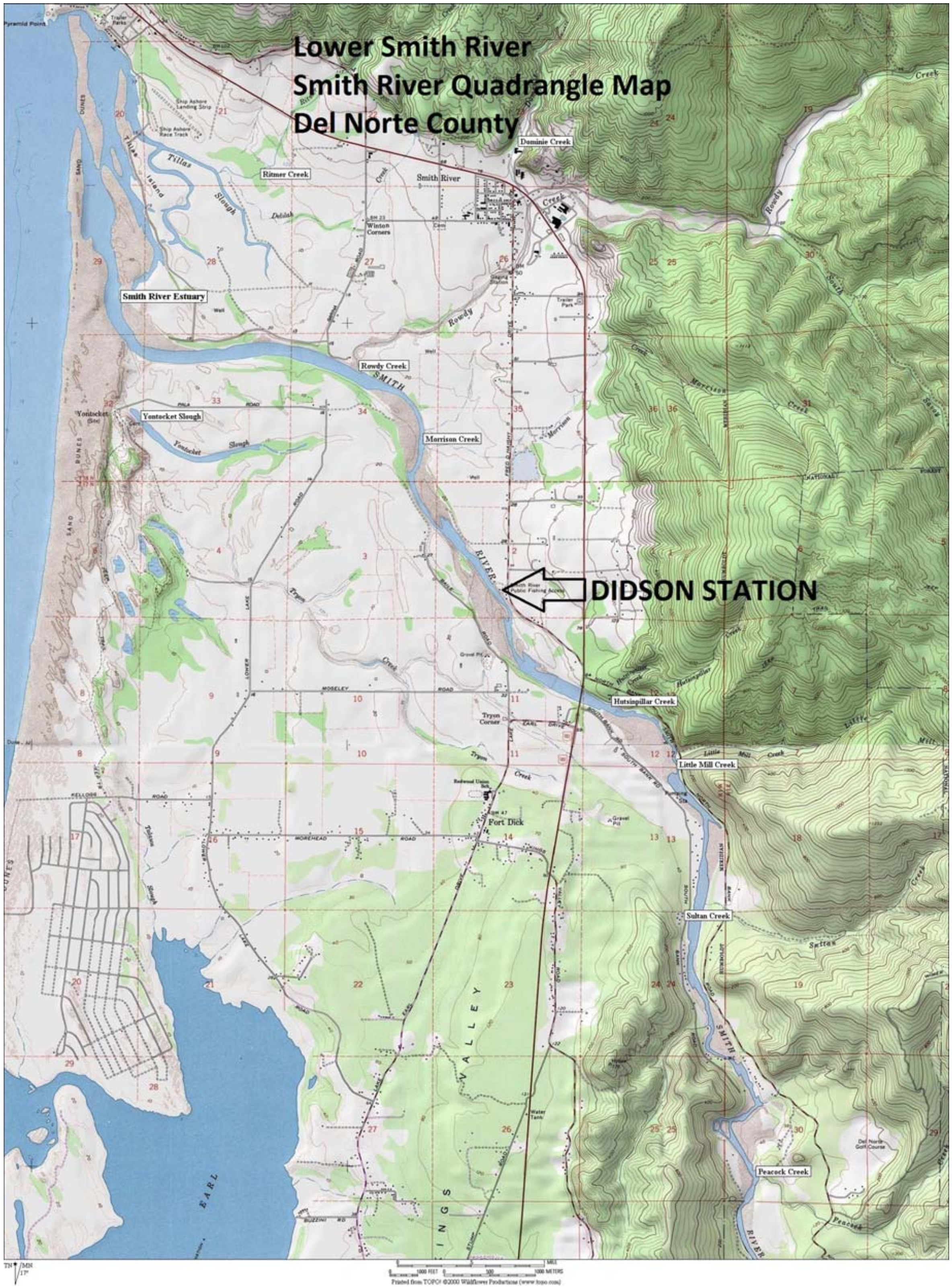

Figure 4. Location of the Smith River DIDSON Pilot Study facility location at river mile 6 near the town of Smith River, Del Norte County, California.

MATERIALS AND METHODS

Smith River DIDSON Station Operation

The Smith River DIDSON Station included small building connected to grid power, two Long Range DIDSON packages, 200-feet device communication cables, two laptop computers, point-to-point wireless bridge network components, a bank of 12v deep cycle batteries, and a motorized boat to maintain units. DIDSON units were deployed with “H” mounts submerged near river banks and positioned facing each other from opposite sides of the river to ensonify a cross section of the river channel (Figure 5).

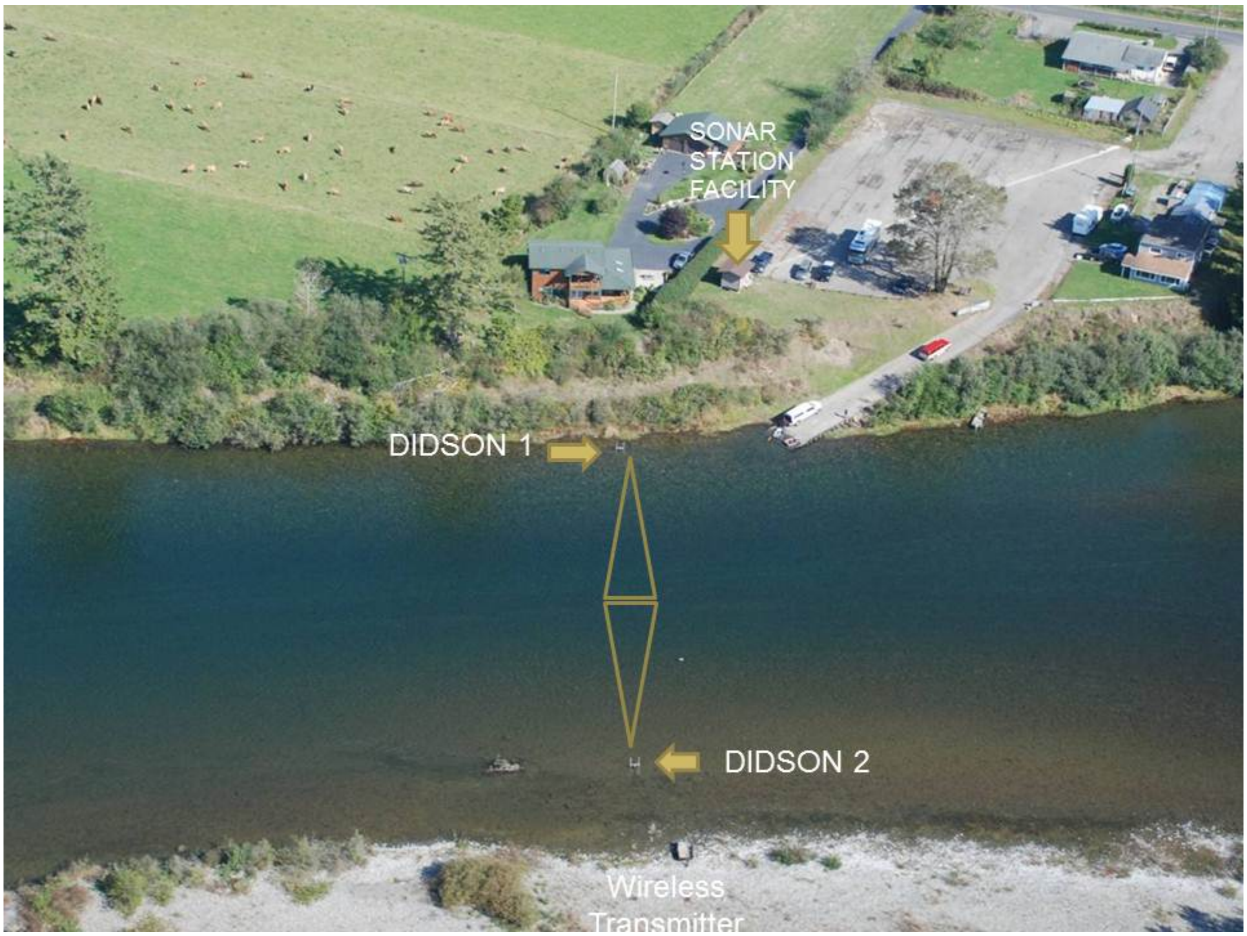

Figure 5. Aerial view of the Smith River DIDSON Pilot Study site and facilities at the public boat launch facility located at river mile 6. DIDSON 1 is located on the right bank and DIDSON 2 is located on the left bank. (Photo by Justin Garwood, CDFW)

The building was located on the right bank (downstream view) of the river above the 100-year flood elevation level and was connected to local power through 300 feet of conduit buried under the Public Boat Launch Facility asphalt parking lot. A battery back-up system was connected to the computers, sonar and network components to provide uninterrupted data collection and system protection during power surge events or outages. On the left bank of the river, a bank of 3, 12-volt batteries connected in parallel to a 400w inverter powered the left bank DIDSON, topside box and wireless router (Figure 6). While 3 batteries powered the left bank components in a rainproof steel box, 3 additional batteries were charged with a 3-bank charger plugged into the office. Batteries were swapped every 24 hours to maximize battery life.

The right bank sonar and components were hardwired into the computer network. The remotely operated left bank sonar was connected to the network with the point-to-point wireless bridge (Appendix B). Right bank and left bank DIDSON units were operated simultaneously with one laptop computer (Dell Latitude E5510). A 17-inch laptop computer was used for data analyses. Data was recorded 24 hours per day, stored in 30 minute files in 2010/2011 and 20 minute files in 2012/2013. Data recorded from each DIDSON was saved to different 2-terrabyte (TB) and 3-TB external hard drives and backed-up to a second set of hard drives through a computer to computer network. Data was saved in weekly file folders and analyzed onsite with Sound Metrics DIDSON software version 5.23.

Figure 6. Left bank DIDSON power and communication box showing configuration of the batteries, inverter, topside box and wireless router (right) and antenna (left).

DIDSON Deployment

Many options exist for the deployment of DIDSON units. We chose the simple and inexpensive H-mount design, made of schedule 40, 2-inch aluminum pipe with fittings that allow for easy assembly and adjustment with Allan head set screws (Figure 7, Appendix C). A 6-inch square mounting plate was cut out of ¼-inch thick aluminum was welded to the cross-bar of the H-mount to accept RAM double socket ball joints. Aluminum H-Mounts were assembled out of the water at deployment sites and 200 feet device communication cables were attached to DIDSON units. Units were attached to H-mounts using RAM double socket parts for easy sonar adjustment. Although a pan and tilt motor was budgeted for the project it was not deemed necessary for the application. The Ram double socket ball joints allowed for efficient manual adjustments of pan, tilt and roll. The H-Mount, with DIDSON and communication cable attached, was carried into the wetted channel.

Figure 7. DIDSON H-Mount design constructed from aluminum pipe and fittings. The aluminum plate was fabricated and welded to the crossbar and attached to a RAM double socket ball joint to accept the DIDSON unit**.**

When submerged, the hollow aluminum pipes filled with water and sufficiently stabilized the units even during moderate flow velocities. The units were oriented lens down with a vertical distance of approximately 25-50 cm from the bottom substrate. The units were aimed approximately 5-10 degrees downward, depending on bottom profile and image output. DIDSON units were moved perpendicularly to the channel, in or out, according to river stage. DIDSON was operated at high or low frequency settings depending on river stage and wetted channel widths. Twenty four hour staffing was needed to maintain optimum instrument position and aiming, particularly during rapid changes in river stage.

The average wetted channel width during the study was approximately 90 meters. During low river stage the ensonified channel cross sectional coverage was close to 100% based on comparisons of field measurements of actual distance from H-mount to H-mount and the associated window length settings in the software application. The ensonified channel cross section coverage ranged from 100% during low flow periods to less than 50% during large winter flow events.

The two DIDSON units aimed at each other resulted in interference, or crosstalk while operating at the same frequency settings. The image noise from crosstalk reduced image quality and affected CSOT and echogram processing functions. Substantial amounts of crosstalk rendered echograms of files useless and created challenges for technicians to process and analyze files. In 2010-2011 both units were operated at low frequency settings and we minimized crosstalk by slightly off-setting the directional aim of the units. In 2011-2012 we eliminated crosstalk by operating the left bank DIDSON at high frequency and the right bank at the low frequency. The different frequencies did not create interference. From mid-December throughout the remainder of the season, fish (steelhead) exhibited a high fidelity to the left bank. Due to high water, tsunami warning, equipment failure and human error, there were periods of hours and days when units were not recording.

Limited maintenance of sonar equipment was required during the field seasons. However, after extended periods of high flows sediment accumulated in the lens resulting in target resolution. During warmer water temperatures and a longer photoperiod in late winter and early spring, algae accumulated on the outer portion of the lens and inside the housing and also reduced resolution. Soft bristle brushes were sufficient for cleaning lenses and this occurred in the field and required brief periods of interrupted operation. Air formed within the fluid filled lens Infrequently and the issue was remediated with materials and instructions provided with the package.

Counting Fish with DIDSON

DIDSON data was recorded 24 hours per day and stored in 30 minute files in 2010/2011 and 20 minute files in 2012/2013. Every file recorded was processed for a complete census and fish counts were organized into a database for future systematic sampling investigations. A copy of the data was created each week for data processing, quality control and archiving. We used the free software, Karen’s Directory Printer, to copy entire file name directories and information was pasted the into Microsoft Excel spreadsheets for manual data entry. This enabled the efficient transfer of file information to spreadsheets including the date, time and frequency settings. DIDSON files

(DDF) and Excel spreadsheets files (XLS) were stored in weekly file folders. Within each worksheet, count data was separated into rows according to the DDF file and corresponding data. In addition to count data, each row contained the initials of the data reviewer, file start time, file end time, total file time (rounded to the nearest minute), file name and any comments (e.g. pinnipeds, small fish, birds, possible sturgeon). Count data from a single data collection week from both banks were combined to form weekly count data Master file workbooks. Within each master workbook, count data was organized by the bank and day of collection. The total time per day *fished* by bank was recorded for the calculation of fishing efficiency, or how many hours and minutes of data was actually recorded with two sonars per day.

Fish were counted and recorded as Upstream Migrants or Downstream Migrants if they passed completely through the sonar beam array. Fish were not counted if they entered or exited the sonar beam array without completely passing the upstream and downstream boundaries of the sonar beam array. We used this method to avoid counting fish again with the other DIDSON or double counting fish swimming in and out of the sonar beam array. We used the Background Subtraction (display of moving targets only) software function and manipulated the frame rate in order to count fish during high rates of passage. Only fish measuring greater than approximately 50 cm were counted as adults. Files containing more than 50 fish were counted several times and the average count was recorded. The Zoom and Measure tools in the software were used to distinguish small fish from larger fish (>50cm), and fish from mammals and birds. During low fish passage rate periods, files were processed with the Convolved Samples Over Threshold (CSOT) function to remove *blank* file portions before counting. The CSOT function abbreviates files by exporting only segments of a file a decibel threshold. The semi-automated counting approach using echograms was used for comparing manual counting methods on a limited scale and primarily was used for length frequency analysis in Year 2.

We used the following simple flux model described by Xie et al. (2002) to estimate total upstream movement of adult anadromous fish observed with DIDSON (*in* Cronkite et al. 2006).

$$N = U - D \tag{1}$$

where N = the net upstream flux, U = the upstream actively migrating fish and D = the downstream actively migrating fish. Milling fish, or fish that are not actively migrating, can also be accounted for in this model, provided these fish eventually move upstream through the ensonified area (Cronkite et al. 2006). Since steelhead are iteroparous, spawned-out fish, or kelts, have to be removed from the downstream estimate since the model relates only to actively migrating fish, and kelts would have been included in the spawning population as upstream fish. Summed over 24 hours, this model produces daily escapement estimates that are compiled to estimate the total spawning population entering a river.

We calculated the efficiency of the DIDSON station operation (Fishing Efficiency) with respect to the actual time data was recorded per day versus total possible time data could be recorded. Fishing efficiency was calculated for each unit as follows.

$$E = \frac{\mathrm{R+B}}{T} \tag{2}$$

Where E = fishing efficiency, R = total right bank sonar file time recorded, B = total left bank sonar file time recorded, and T = 48 hours.

The unseasonably low flow period during November and December 2011 and associated milling behavior of fish required large amounts of staff time to analyze files. Frame rates needed to be slowed down and files were reviewed multiple times in order to keep track and count individual fish milling within the sonar beam array. This was difficult using the semi-automated approach. The CSOT function that abbreviates files by exporting only segments of target detection above a decibel (dB) threshold, was not practical for processing files with abundant or milling fish. The automated counting function was effective beyond mid-December (steelhead trout run-time) on the Smith River. Most files were not abbreviated using the CSOT function during peak Chinook abundance and, but the method used almost exclusively during the steelhead run-time.

Comparing Rowdy Creek Fish Hatchery Weir Counts to DIDSON Fish Counts

The Rowdy Creek Fish Hatchery provided all of the daily data collected from their barrier weir on Rowdy Creek for the two year pilot study period. Their Chinook and coho salmon and steelhead trout data were organized in spreadsheets and compared with daily data from the Smith River DIDSON Station.

Estimating Escapement of Smith River Chinook Salmon and Steelhead

On October 24, 2010, the day before deploying the DIDSON units in the Smith River, a pre-project snorkel fish count was conducted by 13 experienced volunteer divers to enumerate anadromous fish in the mainstem before the DIDSON station was deployed. The information was added to Rowdy Creek Fish Hatchery weir counts and estimates of salmon and steelhead escapement from DIDSON counts described below. The dive survey covered 4 consecutive reaches from RM 9 (Ruby Van Deventer Park) to RM 17 (South Fork Confluence) in the Smith River mainstem.

We attempted to estimate Chinook salmon and steelhead escapement to the Smith River using angler data collected by the Department of Fish and Wildlife from 1997 through 2006. Attempts were made to include coho salmon but due to the paucity of available adult data, the negative bias in the recreational catch data (no recreational coho salmon fishery) and suspected low number of returning adults we did not include coho salmon in the estimate. We believe our estimates for Chinook salmon and steelhead to be flawed and should be considered preliminary. Nevertheless we averaged the ratios of species caught by month over the years and applied them to the Year 1 and Year 2 DIDSON anadromous fish census data. We removed downstream passage numbers from the simple flux model after 01 January for both years to account for downstream steelhead presumably already spawned (kelts). We then applied ratios of species caught per month to the modified monthly DIDSON data set. Additions of Rowdy Creek weir counts and diver survey data were included.

Measuring Fish with DIDSON

Length measurements of fish were made using two methods available in the DIDSON software application. We used the basic Measure and Zoom tools during adult fish enumeration for determining whether a fish was classified as an adult. The basic Measure tool allows the user to create a rectangle around a target and determine the height, width and diagonal distances. Length measurements for length frequency analysis were made using the echogram function in the DIDSON software package. This method allows a line to be drawn to through a target. The echogram analysis allows the user to quickly scan each file. Three length measurements were taken as close to the center beam as possible. The grid tool was used first for coarse image centering adjustments. The zoom tool was used to focus on the fish image. The frame advance tool was used to find the frame where the fish was closest to the center beam and this image was measured using the measuring tool. The frame was then reversed so that the previous frame could be viewed, and a length measurement was taken. Then the frame was advanced twice and another measurement was taken. If the images closest to the center beam were not clear (few frames were above threshold, excessive flare was observed etc.) then measurements were taken from adjacent frames. The angle and range were recorded along with each measurement. Length measurements were taken for the first twenty minutes of each hour, two days per week.

A quality control procedure was instituted to catch errors in processing parameters and file length. All original DIDSON files, before CSOT processing, were investigated for length; if a file was less than twenty minutes then another file was chosen from within the hour. If any of the processing parameters deviated from the standard settings then a spreadsheet containing notes about problematic files was consulted to see if there was some reason that the settings had been altered. Often processing parameters such as min cluster size, min threshold, and Factor A were changed in order to prevent CSOTS and echograms from crashing with images of poor quality. If there was no reason that the defaults had been altered then it was assumed that operator error was involved and the files were re-analyzed using the defaults.

RESULTS

Counting Fish with DIDSON

We operated the DIDSON fish counting station facilities from 25 October 2010 to 15 April 2011 and from 01 October 2011 to 29 March 2012 (Figure 8, Table 4, 5). In 2010/2011, the total count of adult fish passing upstream by the DIDSON station was 43,065. The total count of downstream adult fish was 11,088 fish. The net total using the simple flux model was 31,977 fish passing upstream and the Fishing Efficiency for the 2010/2011 season was 84.3%. The total 2011/2012 count of adult fish passing upstream by the DIDSON station was 76,707 fish. The total count of downstream adult fish was 44,564. The net total, using the simple flux model, was 32,143 fish passing upstream and the fishing efficiency for the 2011/2012 season was 94.7% .

Fish Passage Patterns and Behavior

Diel patterns of fish passage were very similar between the two years of study. Temporal changes in diel fish passage occurred between October and March and these changes were similar for each season (Figure 9,10). Fish passing the DIDSON site during the fall Chinook salmon run time from October to mid-December, exhibited the highest levels of activity just before dusk followed by a spike of activity at dawn. Fish observed during late December and January exhibited the highest levels of activity during mid-day while nighttime activity decreased into February. Our observations lead us to believe that, in general, most Chinook tend to migrate from dusk until dawn and most steelhead tend to migrate from dawn until dusk.

Fish observed from October to early December travelled in large groups or schools. Files analyzed during this period frequently included over 100 fish moving upstream over a 20 minute period. Milling behavior was exhibited throughout this period particularly during low flows. Fish during the early season were observed using the entire channel with a tendency to travel up the channel thalweg nearest the right bank, even during moderately high flow events. In mid-December milling behavior diminished and the lowest percent of fish travelling downstream was observed in January, regardless of flow. Fish during this period and throughout the steelhead season were observed generally from 5 to 20 meters from the sonar lens and fish clearly favored the shallow (<2m) left bank gravel bar side of the channel, by as much as 80%. These late season fish were observed migrating in small groups, often as singles or in pairs, and were occasionally observed in groups as large as 15 fish.

When river stage increased even slightly during the Chinook run time passage rates increased dramatically and milling behavior waned (Figure 11, 12). Beginning in mid-December for Year 1 and Year 2, we observed less milling and fewer fish using the deeper part of the channel and by the late December fish travelled almost exclusively upstream and within 25 meters from the bank.

Comparing Rowdy Creek Fish Hatchery Weir Counts to DIDSON Fish Counts

Rowdy Creek Fish Hatchery weir counts provided species specific run time data that was compared to DIDSON data from 2010 to 2012. During the two year pilot study peak net upstream counts of adult fish from DIDSON data closely mimicked peaks of Chinook and steelhead counts at the Rowdy Creek weir (Figures 13, 14). Less than 10 coho were counted at the Rowdy Creek Fish Hatchery in 2010 and 2011 and we did not make any comparisons regarding coho salmon. After the first significant rise in river stage on 25 October 2010 large numbers of fish were counted at the DIDSON station as well as at the hatchery weir. Fish continued to pass the DIDSON site and the Rowdy Creek weir until late November when Rowdy Creek weir counts of Chinook, and DIDSON fish counts decreased rapidly around 15 December 2010. Small, but consistent numbers of steelhead were counted at the Rowdy Creek weir beginning the last week of November until counts increased rapidly in mid-January. DIDSON fish counts also spiked during the same time frame. Another spike of steelhead counted at the Rowdy Creek weir occurred during mid-February and DIDSON count data displayed a similar spike. Temporal overlap of adult Chinook and steelhead counted at the weir occurred between late November and the end of December and this overlap is also apparent in angler survey data (Figure 3).

The DIDSON station began operating on 01 October 2011 immediately before the first major storm and flow event of the 2011/2012 season (Figure 15). Over 10,000 fish were counted passing the DIDSON station before the first Chinook salmon were recorded at the Rowdy Creek weir. During the week of 18 November 2011 the Rowdy Creek weir recorded 483 Chinook salmon and 6 steelhead trout while the net upstream fish count from DIDSON was 5,464 fish. The Smith River dropped to unseasonably low flow conditions shortly thereafter and counts at both facilities waned. Flows increased in late December and Chinook counts at the Rowdy Creek weir rose as did upstream fish counts at the DIDSON station. Steelhead comprised approximately one third of fish captured during the final spike of Chinook salmon migration at the Rowdy Creek weir. Similar to the 2010/2011 results, DIDSON fish counts increased during the second week of January and steelhead counted at the Rowdy Creek weir increased. Finally in March 2012, Rowdy Creek experienced another spike of steelhead passing the weir while DIDSON counts waned. The DIDSON station ceased operation on 29 March 2012.

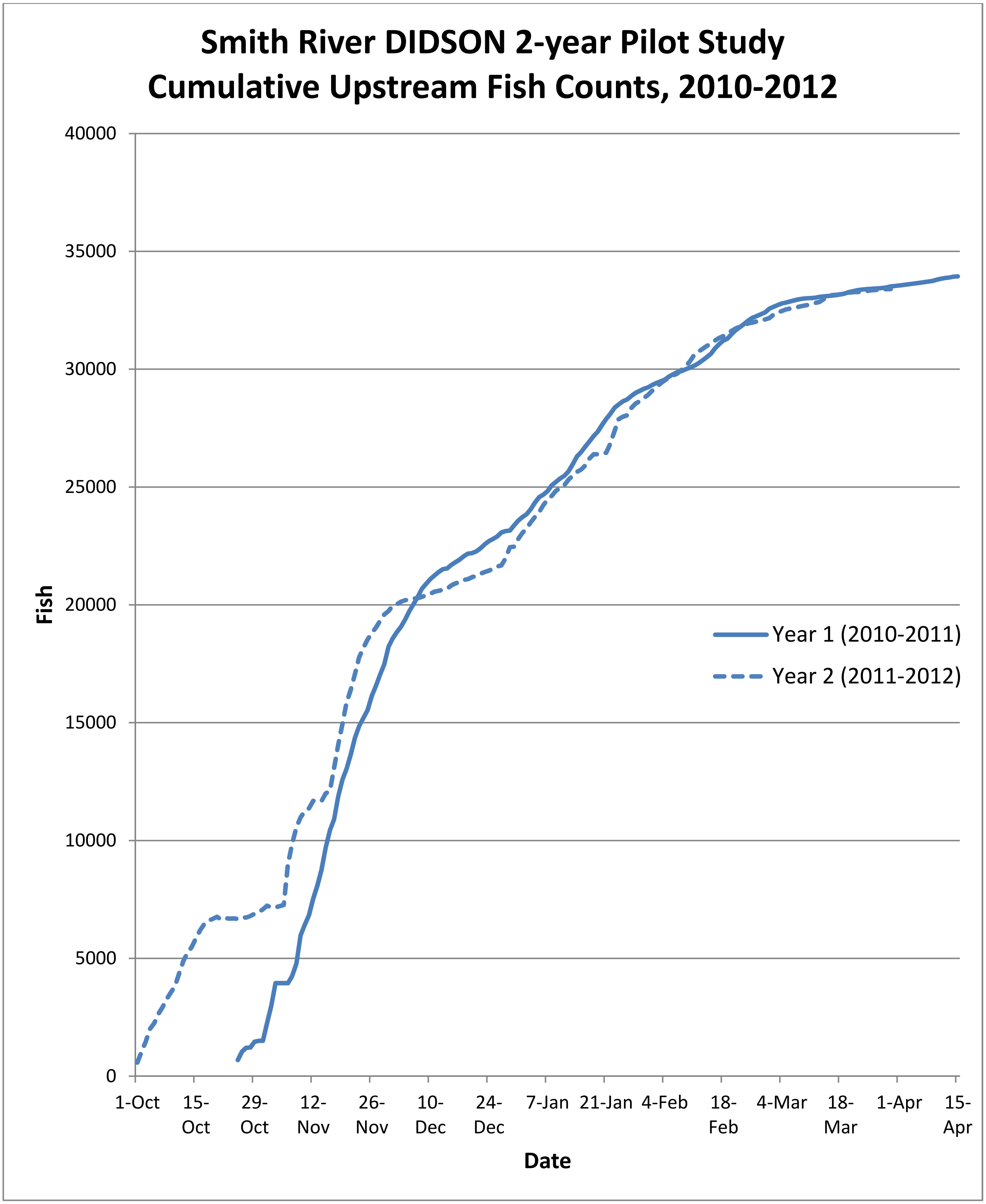

Figure 8. Cumulative fish counts from the Smith River DIDSON Station 2010-2012**.**

Table 4. 2010-2011 Weekly counts of fish passing the DIDSON station and efficiency of operation.

Week	Adults Upstream	Adults Downstream	Total Upstream Adults	Fishing Efficiency
Oct. 25 - 30	2304	801	1503	42.4%
Nov. 1 - 7	3831	1075	2756	49.6%
Nov. 8 - 15	7441	2013	5428	78.2%
Nov. 16 - 23	7820	2652	5168	85.9%
Nov. 24 - Dec. 1	5203	1490	3713	88.6%
Dec. 2 - Dec. 9	3071	741	2330	92.6%
Dec. 10 - Dec. 17	1209	189	1020	88.5%
Dec. 18 - Dec. 25	986	104	882	82.6%
Dec. 26 - Jan. 2	1121	93	1028	79.2%
Jan. 3 - Jan. 10	1507	141	1366	97.2%
Jan. 11 - Jan. 18	1798	92	1706	97.8%
Jan. 19 - Jan. 26	1556	78	1478	97.8%
Jan. 27 - Feb. 3	769	132	637	96.9%
Feb. 4 - Feb. 11	655	193	462	98.2%
Feb. 12 - Feb. 19	1159	167	992	97.5%
Feb. 20 - Feb. 27	1033	233	800	97.0%
Feb. 28 - Mar. 7	592	156	436	80.0%
Mar. 8 - Mar. 15	182	66	116	38.4%
Mar. 16 - Mar. 23	269	132	137	87.3%
Mar. 24 - Mar. 31	159	100	59	80.3%
Apr. 1 - Apr. 8	183	126	57	99.2%
Apr. 9 - Apr. 15	217	314	-97	99.6%
Season Totals	43065	11088	31977	84.3%

Table 5. 2011-2012 Weekly counts of fish passing the DIDSON station and efficiency of operation**.**

Week	**Adults Upstream**	**Adults Downstream**	**Total Upstream Adults**	**Fishing Efficiency**
Oct. 1-8	6647	3378	3269	86.3%
Oct. 9-16	6080	3158	2922	98.7%
Oct. 17-24	6453	5956	497	99.0%
Oct. 25-Nov.1	6191	5646	545	98.7%
Nov. 2-9	13470	9727	3743	99.0%
Nov. 10-17	10703	8613	2090	99.6%
Nov. 18-25	7953	2489	5464	94.9%
Nov. 26-Dec.3	4771	3167	1604	99.5%
Dec. 4 - 11	862	434	428	99.6%
Dec. 12-19	804	272	532	99.6%
Dec. 20-27	859	277	582	98.7%
Dec. 28-Jan.4	2248	294	1954	89.1%
Jan. 5-12	1570	143	1427	99.7%
Jan. 13-20	1104	67	1037	74.0%
Jan. 21-28	2128	137	1991	80.4%
Jan. 29-Feb. 5	1095	65	1030	99.1%
Feb. 6-13	1227	151	1076	99.6%
Feb. 14-21	878	121	757	99.7%
Feb. 22-29	435	76	359	99.4%
Mar. 1-8	517	139	378	99.7%
Mar. 9-16	468	171	297	91.2%
Mar. 17-24	179	31	148	73.8%
Mar. 25-29	65	52	13	99.7%
Running Total	76707	44564	32143	94.73319%

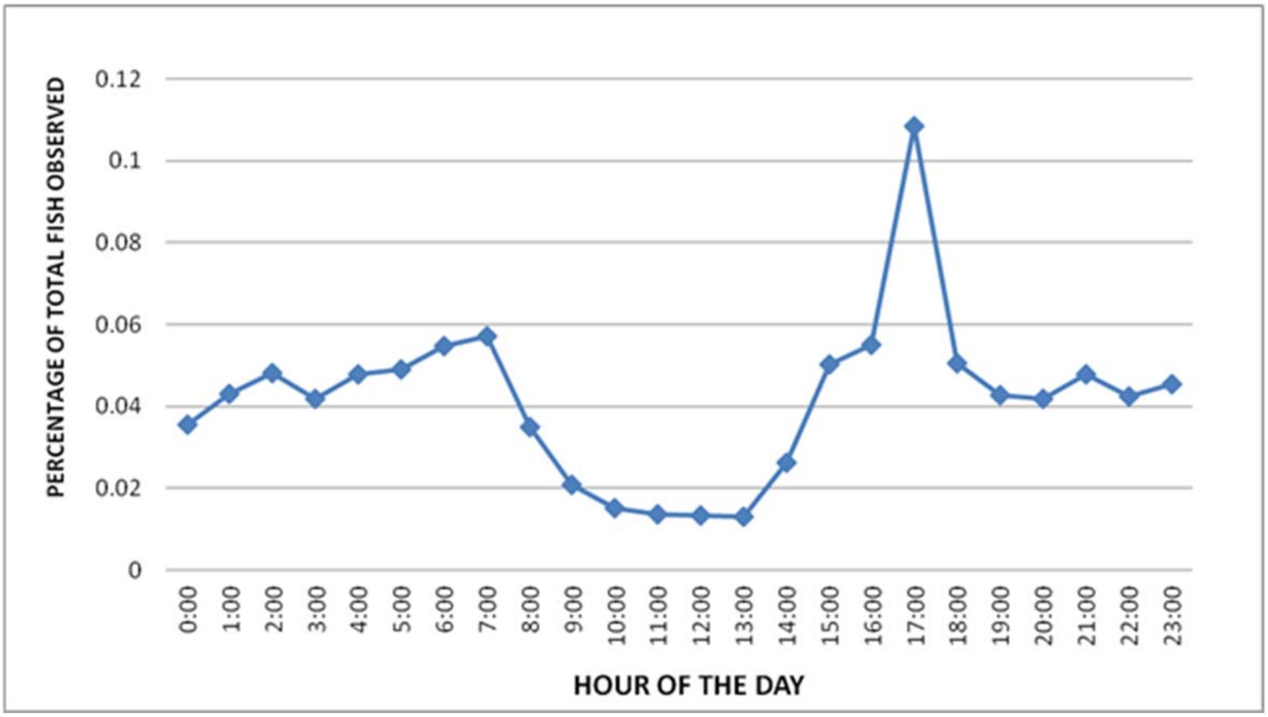

Figure 9. The percentage of fish passing the DIDSON site per hour during November, 2010. This period of time is almost exclusively the Chinook salmon run time in the Smith River.

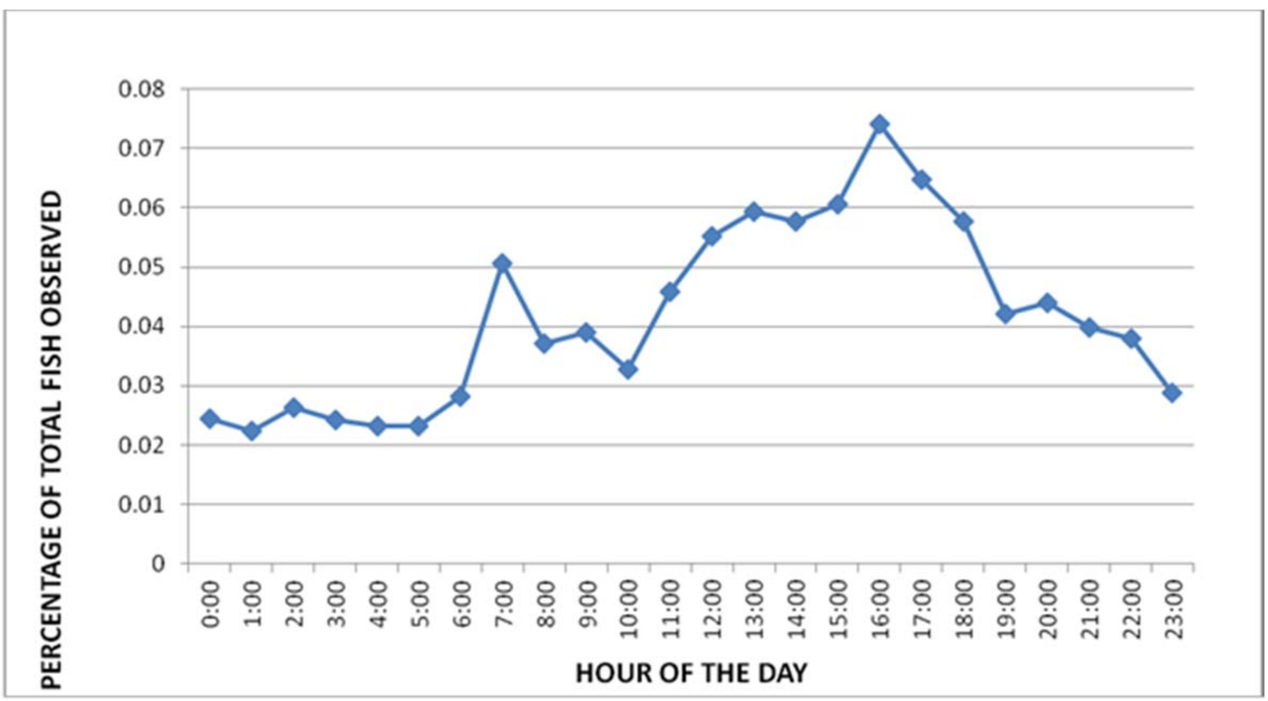

Figure 10. The percentage of fish passing the DIDSON site per hour during February, 2011. This period of time is almost exclusively the steelhead run in the Smith River.

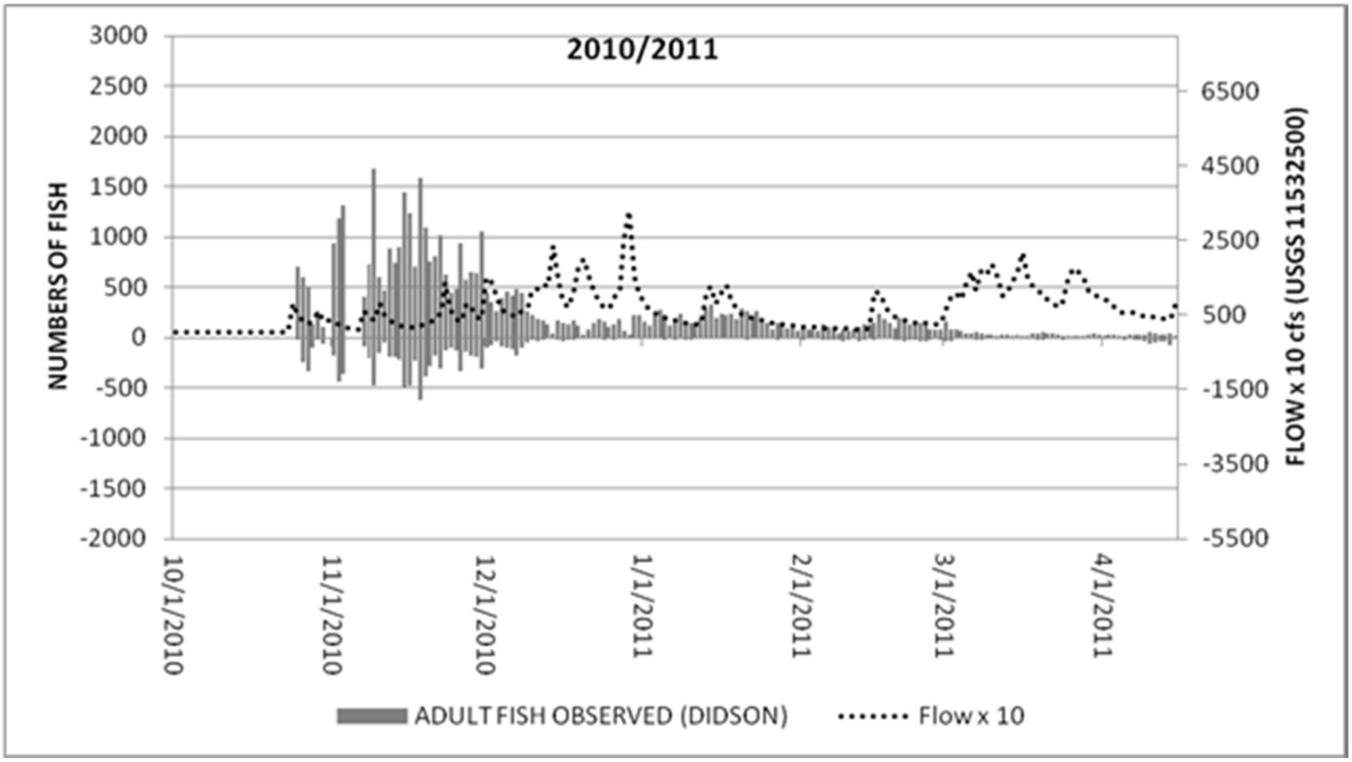

Figure 11. Smith River flows (in c.f.s.) and upstream and downstream adult fish passage at the Smith River DIDSON Pilot Study site, 2010/2011.

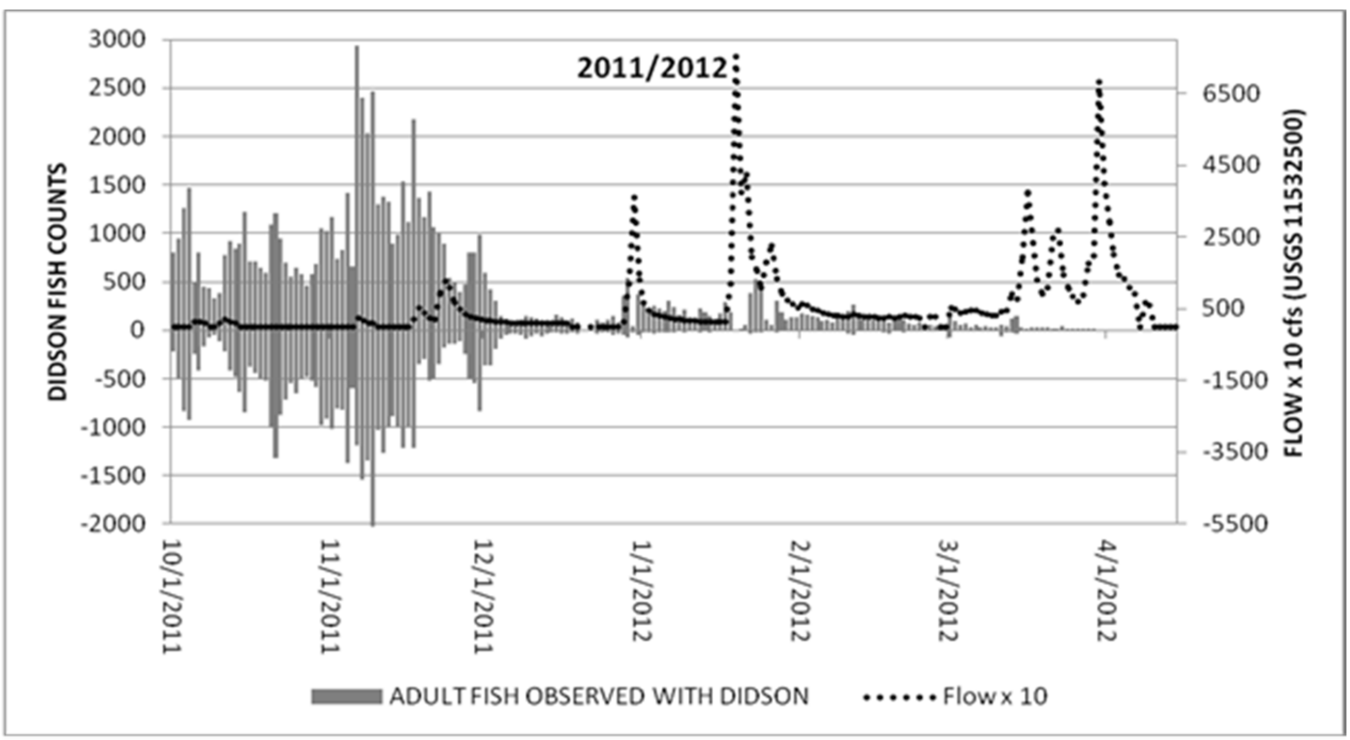

Figure 12. Smith River flows (in c.f.s.) and upstream and downstream adult fish passage at the Smith River DIDSON Pilot Study site, 2011/2012.

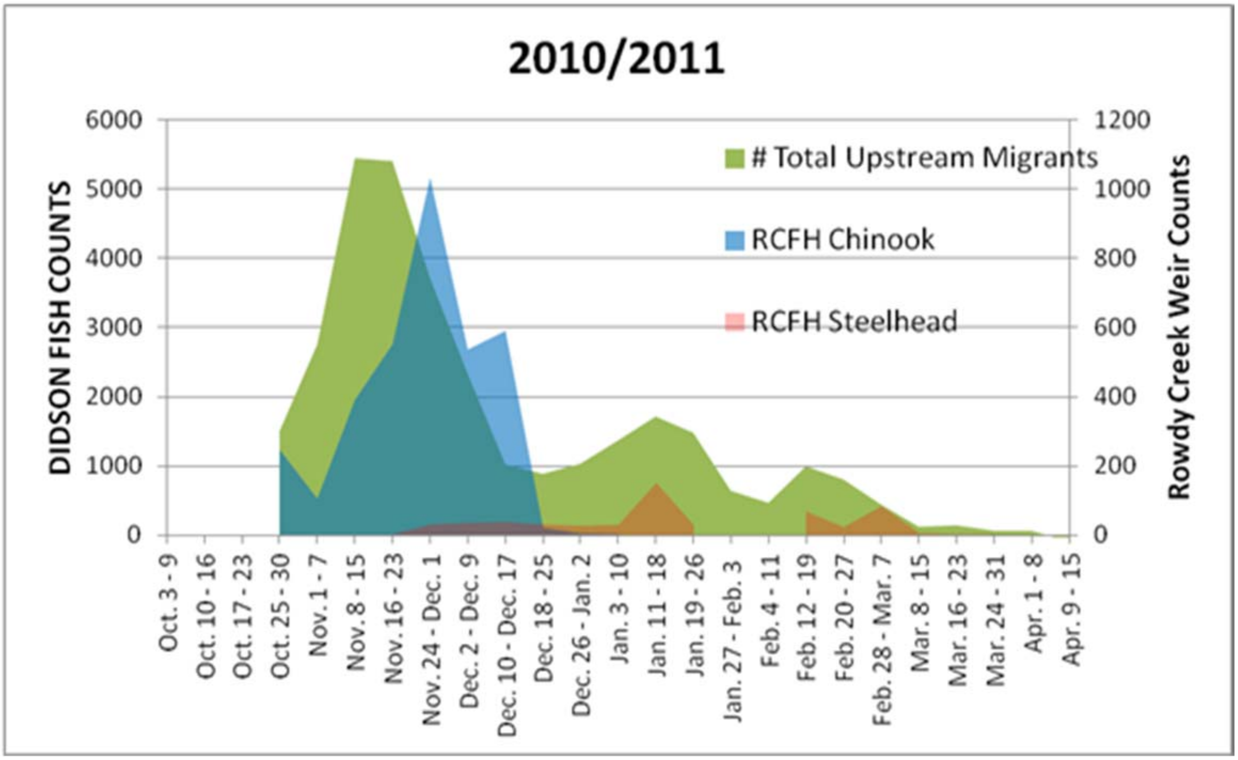

Figure 13. Run Timing: Rowdy Creek Fish Hatchery weir counts of Chinook and steelhead compared to Smith River DIDSON Pilot Study Data, 2010/2011.

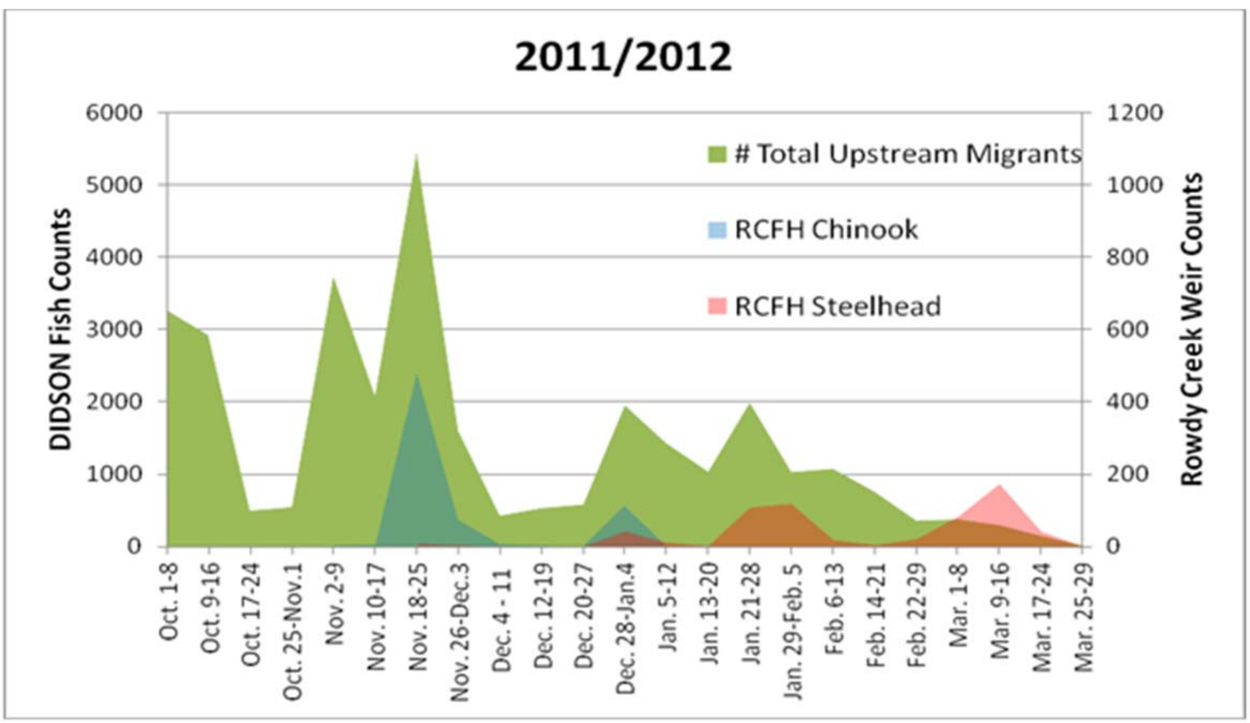

Figure 14. Run Timing: Rowdy Creek Fish Hatchery weir counts of Chinook and steelhead compared to Smith River DIDSON Pilot Study Data, 2011/2012

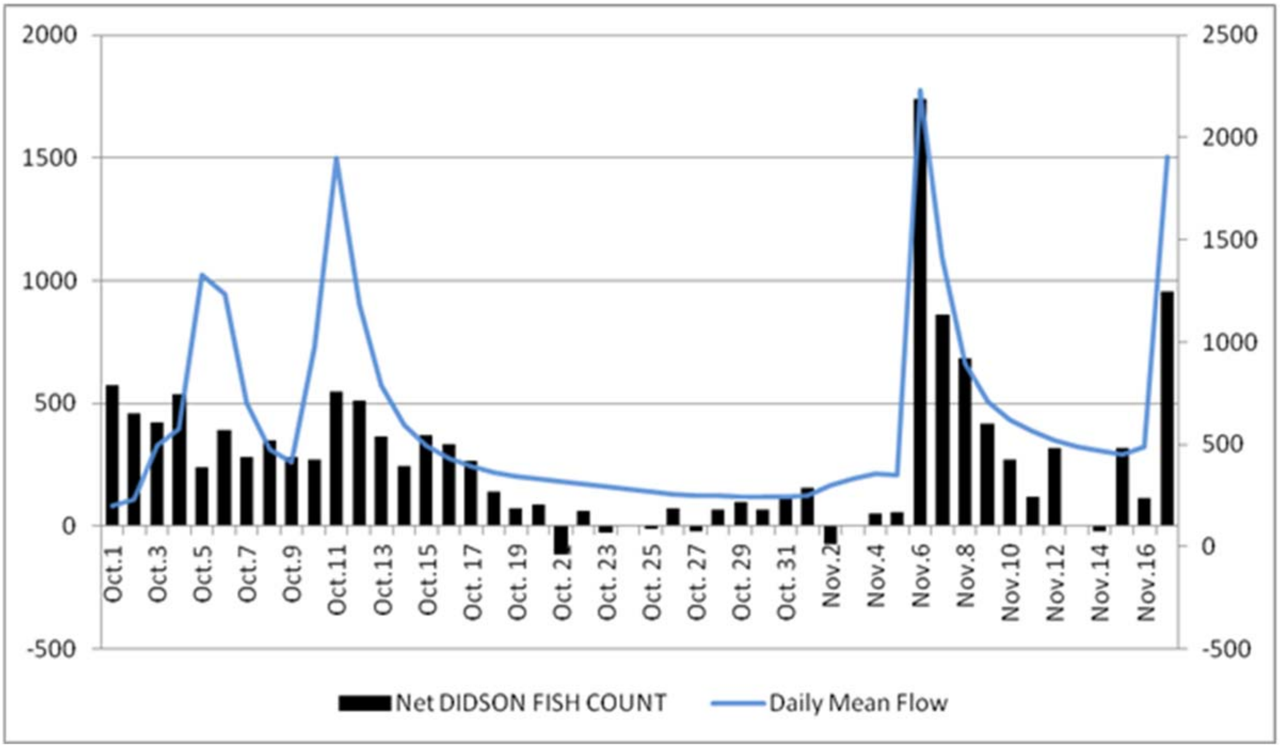

Figure 15. River stage and net counts from the Smith River DIDSON Pilot Study during the fall-run Chinook salmon run-time in the Smith River, 2011.

Estimating Escapement of Smith River Chinook Salmon and Steelhead

In 2010, a pre-project diver based fish count was conducted upstream from the DIDSON station in the Mainstem Smith River from river mile 9 (Ruby Van Deventer Park) to river mile 17 (South Fork Confluence). Approximately 1,100 adult Chinook, 20 adult steelhead, 60 half pounder steelhead and 60 adult cutthroat trout were observed. No diver based counts were conducted in 2012.

We removed downstream passage numbers from the flux model after 01 January for both years to account for steelhead kelts and applied the ratios of species caught per month to the modified monthly DIDSON data set (Table 6). Additions of Rowdy Creek weir counts and snorkel counts data were included. The preliminary estimates of Chinook and steelhead escapement for the 2010/2011 season were 22,559 fish and 16,202 fish, respectively. The preliminary estimates of Chinook and steelhead escapement for the 2011/2012 season were 19,197 fish and 14,768 fish, respectively (Table 7).

Table 6. DIDSON based Chinook and Steelhead estimates based on historic angler survey data.

Month	Angler Chinook Ration	Angler Steelhead Ration	2010/2011 DIDSON Counts	2011/2012 DIDSON Counts	2010/2011 Estimated Chinook	2010/2011 Estimated Steelhead	2011/2012 Estimated Chinook	2011/2012 Estimated Steelhead
October	0.977	0.023	1503	7078	1469	34	6916	162
November	0.906	0.094	16717	12659	15138	1579	11463	1196
December	0.242	0.758	5353	3058	1294	4059	739	2319
January	0.012	0.988	5656	6112	67	5589	73	6039
February	0.001	0.999	3183	3204	5	3178	5	3199
March	0.001	0.999	1122	1287	1	1121	1	1286
TOTAL			**33534**	**33398**	**17973**	**15561**	**19197**	**14201**

Table 7. 2011-2011 and 2011-2012 Smith River Chinook and steelhead escapement estimates based on DIDSON data with steelhead kelts (downstream count) removed after January, Rowdy Creek Fish Hatchery weir counts and a pre season dive survey (2010).

Year	Species	Apportioned DIDSON Counts	Rowdy Creek Weir Count	Pre-project Dive survey	Escapement Estimate
2010	Chinook	17,973	3,486	1,100	22,500
2010	Steelhead	15,561	641	20	16,000
2011	Chinook	19,197	696	n/a	20,000
2011	Steelhead	14,201	567	n/a	15,000

Measuring Fish With DIDSON

Results from this portion of the study are questionable and should be considered inadequate for assessing length frequencies beyond comparing approximate lengths between fall Chinook salmon run times and steelhead trout run times during the 2011-2012 season. We believe the data to be highly biased due to observer error in measuring mammals or debris, automated measuring of debris and mammals or both. Please see the Discussion section for more information.

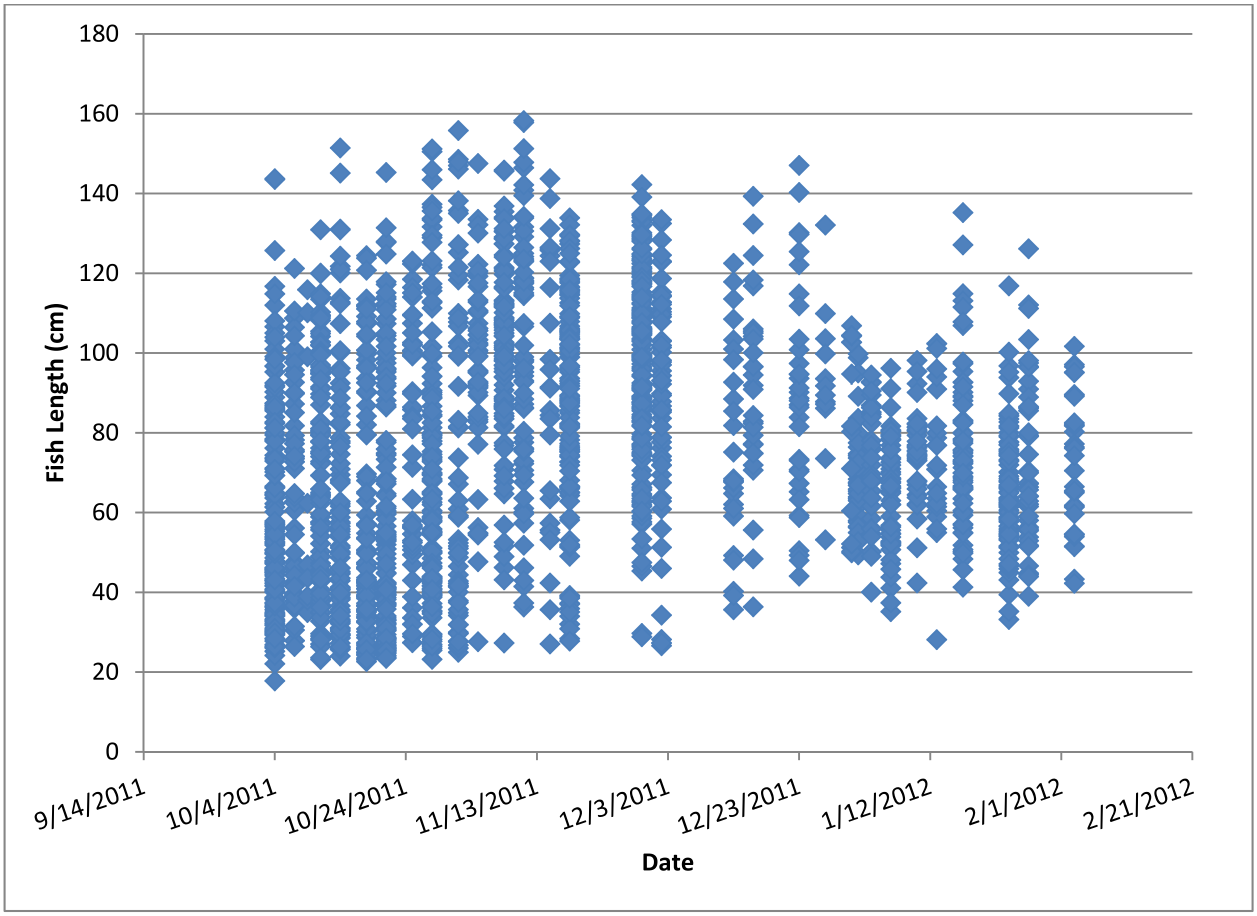

Figure 16. Fish lengths from a Long Range DIDSON fitted with standard lens measured and automeasured during the 2011-2012 season after subtracting out 1.3 cm/m range exaggeration observed by Burwen et al. (2007).

DISCUSSION

We fulfilled our pilot study objectives to develop and operate a fixed-location DIDSON fish counting station in the lower Smith River mainstem during two seasonal migrations of fall-Chinook salmon, coho salmon and steelhead trout migrations from 2010 to 2012. The pilot study confirmed that the technology can operate continuously and effectively in the Smith River over a wide range of flows. The efficiency of the Smith River DIDSON Station operation during the 2-year study, due largely to the adequate staffing, was high (84-95%) considering the challenges of operating 24 hours per day in a relatively large and *flashy* river system. The anadromous fish census data set allows for investigations of sampling strategies, similar to Reynolds et al. (2007), for attention to cost-effective operation of DIDSON in northern California rivers. Preliminary unreported investigations of nonreplicated systematic sampling indicate that sampling error varies throughout the season.

DIDSON Observations of Animal Behavior Predators and Rare Events

Chinook salmon utilized the entire channel, exhibited crepuscular and nighttime movement, milled and traveled in large schools. Steelhead exhibited fidelity to channel margins, predominately travelled during daylight hours, and traveled in small groups. Marine mammals, Pacific harbor seals (*Phoca vitulina richardsi*), were frequently detected with DIDSON and visually during both study seasons and most observations occurred between 18:00 to 10:00.

Seals were most often detected by the right bank sonar and observed using the channel thalweg. It is unclear whether California sea lions were present though a series of targets, measured during the questionable length frequency analysis, were greater than 2.5 meters. We also observed probable seal predation attempts on fish. Approximately 575 detections of marine mammals were recorded during the study period however observations were not always noted particularly during high fish passage rates. Other aquatic mammals, beavers and otters, were observed and were easily distinguishable from fish. Waterfowl, mostly common mergansers (*Mergus merganser*), were easily distinguishable from mammals and fish and frequently appeared in DIDSON files.

DIDSON detected a possible 2.1 m sturgeon on April 6, 2011. Clips of the data were sent to Southwest Region of the National Marine Fisheries Service (NMFS) for further analysis. A NMFS DIDSON user stated the fish was too large to be anything but a sturgeon but the species could not be determined (D. Woodbury, NMFS, pers. comm.). The timing of the observation is similar to typical green sturgeon (*Acipenser medirostris*) entry in the Klamath River. An echogram of the file displayed clear tail beat patterns described in Mueller et al. (2010) that were different from echogram files of suspected marine mammals. In general, mammals observed with DIDSON did not display these tail beat patterns in the echograms (Figure 17).

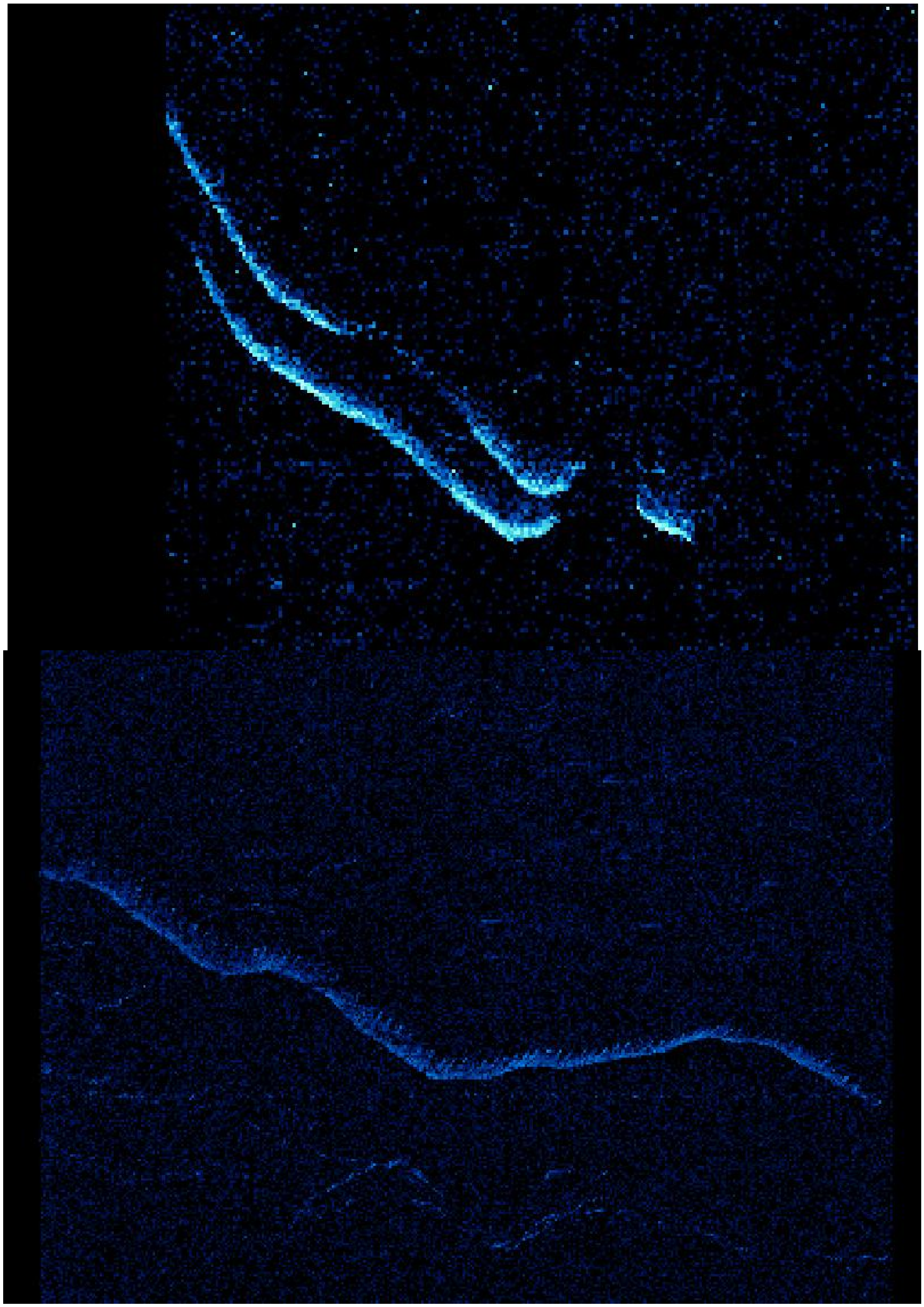

Figure 17. Echogram images of harbor seals (top) and a 2 meter sturgeon (bottom) sturgeon identified during the Smith River DIDSON Pilot Study (Low Frequency Standard Lens).

Measuring Fish with DIDSON

Our study failed to deliver appropriate length frequency information due to either errors by observers or use of the Long Range DIDSON with a standard lens. There is a high likelihood that seals were measured, debris was measured, and perhaps two or even three fish together were measured. The issues are uncertain though we had reasonable success manually measuring individual fish without the reported level of positive bias. Attempts were made to correct the matter but further investigation surrounding the high bias, even after applying correction factors, needs to be conducted. Additionally, tethered fish experiments may shed light on any effects our local environment may have on the Long Range DIDSON performance in producing more accurate lengths of fish. A large lens (high resolution lens) was purchased for the Smith River DIDSON Pilot Study and hopefully funding can be available to improve fish length measurements by DIDSON in the region.

Estimating Escapement of Smith River Chinook Salmon and Steelhead

No reasonable data sets were available for apportioning Smith River DIDSON fish counts. The generation of escapement estimates based on the cursory use of past Smith River angler data is flawed. We express the need for some mechanism to apportion DIDSON data into individual estimates of Chinook salmon, coho salmon, steelhead trout and potentially cutthroat trout. Due to the constraints of gill netting or using other physical means of obtaining relevant species composition information in the presence of protected Southern Oregon and Northern California Coast coho salmon, we may not have the ability to accurately and precisely apportion species during known overlapping run times. However alternative means of apportioning DIDSON counts or estimates may be possible through video sampling or intensive angler and redd survey data that include the entire Chinook salmon, coho salmon and steelhead trout seasonal run times. Species apportionment of DIDSON data is a viable in Native American tribal fisheries such as in the nearby Klamath River.

CONCLUSION

Monitoring anadromous fish escapement to moderately large coastal rivers with DIDSON is a promising approach for assessing the status and trends of salmonid populations. Although the technology has limitations with respect to discriminating between salmonid species and identifying fish of hatchery origin, DIDSON can provide unprecedented and accurate information about the magnitude of salmonid escapement in the Smith River. When used in conjunction conventional fisheries sampling techniques, DIDSON can reduce the uncertainty associated with current status assessments of imperiled species and improve the management of existing fisheries.

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APPENDICES

APPENDIX A

Status of fish species occurring or potentially occurring in the Smith River watershed.

SPECIES	ESU	STATUS[1]	
		Federal	State
Coho salmon (*Oncorhynchus kisutch)*	Southern Oregon/Northern California Coasts	T	T
Chinook salmon *Oncorhynchus tshawytscha*	Southern Oregon/Northern California Coasts	NW	CSC
Steelhead *Oncorhynchus mykiss irideus*	Klamath Mountains Province	NW	None
Coastal cutthroat trout Oncorhynchus clarki clarki	Southern Oregon/California Coastal	NW	CSC
Chum salmon *Oncorhynchus keta*	Pacific Coast	NW	None
Green sturgeon *Acipenser medirostris*	N/A	C2	None
River lamprey Lampetra ayresi	N/A	C2	CSC
Pacific Lamprey *Lampetra tridentata*	N/A	C2	None

T Threatened
NW Not warranted for listing
CSC CDFG and/or California Board of Forestry Species of Concern
C2 Species formerly classified as Category 2 candidates by the USFWS; these species no longer have a legal federal status
CE Candidate to be listed as endangered pursuant to the California Endangered Species Act.

APPENDIX B

Remote Operation of DIDSON

The following information describes the Smith River DIDSON Pilot Study point-to-point wireless network bridge connection design. The design allows for the simultaneous operation of multiple DIDSON units one computer.

Network Materials:

- (2) Radiolabs- High Power Router –o2link (item RL54GXP)
- (2) RL 1000 Wall Mount Wireless Antenna (item RL1000)
- (2) LMR-400 WiFi Cable RP-SMA

Procedure:

1. Routers bridged together using Radiolabs supplied documentation.
2. Set-up encryption for both routers (optional)
3. Antennas mounted to allow a direct line of sight between antennas.
4. For one PC and one DIDSON, default settings are sufficient.
5. For one or more PCs and/or multiple DIDSON units refer to .pdf file

"Multiple DIDSONs on an Ethernet" supplied on by Sound Metrics Corporation.

Components and IP Addresses used on the Smith River DIDSON Pilot Study network:

Component	IP Address
Office Router	192.168.1.1
Remote Router	192.168.1.2
Dell Latitude 5115	192.168.1.101
RB Sonar	192.168.1.102
LB Sonar	192.168.1.103

APPENDIX C

DIDSON H-Mount Parts List

FRAME: McMaster-Carr Supply Company:

Quantity	*Item*	*Description*
(4)	#4699T222	Aluminum, 2” pipe size, 6’ length
(4)	#4699T26	Aluminum, 2” pipe size, 5’ length.
(8)	#4698T109	Aluminum slip-on rail fittings Tee w/through hole, fits 2” pipe size.

RAM Mounting Systems, Inc.

Quantity	*Item*	*Description*
(2)	Ram-D-101U-C:	Double Socket D Short Arm
(2)	Ram-D-25-254U:	Ram 2 7/16” diameter Base with 2 ¼ ball.

APPENDIX D. Smith River DIDSON Pilot Study site survey, February 2011.