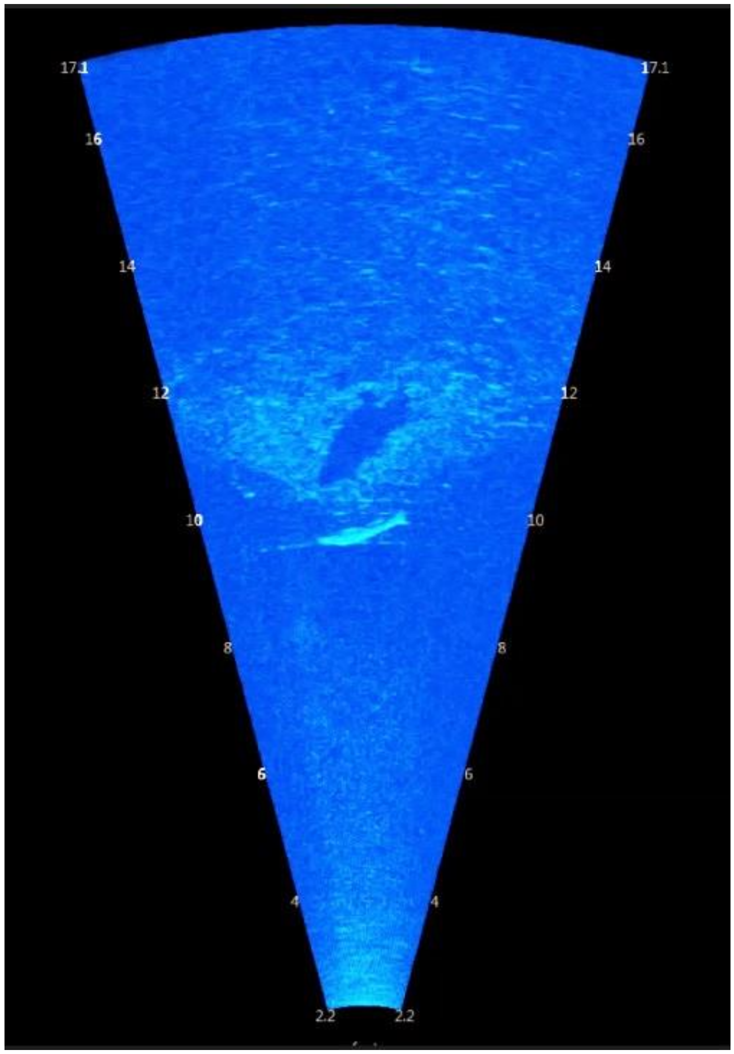
DUAL FREQUENCY IDENTIFICATION SONAR (DIDSON) DEPLOYMENT AND PRELIMINARY PERFORMANCE AS PART OF THE CALIFORNIA COASTAL SALMONID MONITORING PLAN



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NOTE TO READERS

This DiDSON deployment report is a documentation of one of the procedures and methodologies for executing Salmonid monitoring described in Fish Bulletin 180 entitled California Coastal Salmonid Population Monitoring: Strategy, Design, and Methods (Adams et al. 2011).

California's salmon and steelhead populations have experienced drastic declines leadingto both federal and State Endangered Species Act listings of many coastal stocks (Good et al. 2005, Williams et al. 2011, CDFG 2002, CDFG 2004). California has experienced pressure from the federal government, other Pacific States, fisheries organizations, and communities to improve status and trend monitoring of coastal salmon and steelhead. Of the four National Marine Fisheries Service's Viable Salmonid Population (VSP; McElhany et al. 2000) parameters (abundance, spatial distribution, productivity, and diversity), adult abundance is the most fundamental. Establishment of DIDSON counting stations under California's Coastal Salmonid Monitoring Plan (CMP) (Adams et al. 2011) in key locations will enable the Department to obtain vital adult return data to inform State, Trans-State, and federal management and recovery decisions.

Since 2006, Dual frequency identification sonar cameras (DIDSONs) have been installed in numerous California streams to enumerate adult salmon and steelhead during upstream migration. We report on the initial operational and biological results of deployments across California for the primary purpose of counting returning anadromous salmonids. Principally this work has been undertaken as part of CMP but DIDSONs have also been deployed within several Central Valley watersheds. Additionally, we report on the laboratory experimental results conducted on DIDSON units at the University of California, Davis, and the sturgeon work performed in the Central Valley. This is the first comprehensive report of the use of DIDSON devices in California's watersheds. This report provides information to future partners, current users, and a reporting structure to build the knowledge base in an iterative scientific fashion.

As with all of its products, Fisheries Branch is very interested in ascertaining the utility of this document in other programs, particularly regarding its application to the fisheries research and management decision process. Therefore, we encourage you to provide us with your comments. Please be assured that they will help us direct future efforts. Comments should be directed to Dr. Russell Bellmer, Fisheries Branch, 830 S Street, Sacramento, CA 95814, 916 327-8840, russ.bellmer@wildlife.ca.gov.

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Dual frequency identification sonar (DIDSON) Deployment and Preliminary Performance as part of the California Coastal Salmonid Monitoring Plan

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Abstract: Anthropogenic landscape alteration has negatively affected riverine habitat and hydrologic processes, which in turn has reduced the viability of salmonid species that depend on healthy watersheds for spawning, migration, rearing, growth, and survival. As society increasingly demands more water and other natural resources, the ability of managers to conserve these resources will be based, in part, on their ability to maintain and restore watershed processes. California's salmon and steelhead trout populations have experienced drastic declines leading to both federal and State Endangered Species Act listings of many coastal stocks (Good et al. 2005, Williams et al. 2011, CDFG 2002, CDFG 2004). California has experienced pressure from the federal government, other Pacific States, fisheries organizations, and communities to improve status and trend monitoring of coastal salmon and steelhead trout. Of the four National Marine Fisheries Service's Viable Salmonid Population (VSP; McElhany et al. 2000) parameters (abundance, spatial distribution, productivity, and diversity), adult abundance is the most fundamental. Establishment of DIDSON counting stations under California's Coastal Salmonid Monitoring Plan (CMP) (Adams et al. 2011) in key locations will enable the Department to obtain vital adult return data to inform State, Trans-State, and federal management and recovery actions. Since 2006, dual frequency identification sonar cameras (DIDSONs) have been installed in California streams to enumerate adult salmon and steelhead trout during upstream migration. We report on the operational and biological results of initial deployments of DIDSON units across California for the primary purpose of counting returning anadromous salmonids. Principally, this work has been undertaken as part of CMP, but DIDSONs have also been deployed in several Central Valley watersheds. Additionally, we report on the laboratory experimental results conducted on a DIDSON unit at the University of California, Davis, and the sturgeon work performed in the Central Valley. This is the first comprehensive report of the use of DIDSON devices in California's watersheds.

INTRODUCTION AND BACKGROUND

The California Coastal Salmonid Monitoring Plan:

California's salmon and steelhead trout populations have experienced drastic declines leading to both federal and State Endangered Species Act (ESA) listings of many coastal stocks (Good et al. 2005, Williams et al. 2011, CDFG 2002). These listings require development of federal and State recovery strategies designed to conserve, protect, restore, and enhance listed species. Federal guidelines require that recovery planning include objective, measurable criteria that will result in delisting (16 USC 1531, Endangered Species Act 1973). California law also requires that listed salmon be returned to sufficient numbers to support reinstating commercial use (California Fish and Game Code Sections 2050 to 2097).

California has experienced pressure from the federal government, other Pacific States, fisheries organizations, and communities to improve status and trend monitoring of coastal salmon and steelhead trout. In addition, recent declines of Klamath River Chinook salmon (2006) and Central Valley Chinook salmon (2008-09), lack of adequate data on California Coastal Chinook salmon, and the severe decline of coho salmon along the central and north coasts stimulated the Department to expand and intensify anadromous salmonid monitoring in many watersheds. Of the four Viable Salmonid Population (VSP; McElhany et al. 2000) parameters (abundance, spatial distribution, productivity, and diversity), adult abundance is the most fundamental. Establishment of sonar camera counting stations in key locations will enable the Department to obtain vital adult return data to inform State, trans-State, andfederal management and recovery decisions.

The Coastal Salmonid Monitoring Plan (CMP; Adams et al. 2011) was developed to address broad scale VSP-based status and trend monitoring of coho salmon, Chinook salmon, and steelhead trout populations in streams across the entire California coast. The CMP also meets the need for monitoring progress toward recovery. Prior to implementation of the CMP, California's coastal anadromous adult monitoring was restricted to a few adult counting stations, localized carcass surveys of fall-run Chinook salmon in scattered reaches of the Klamath, Mad, and Eel rivers, snorkel surveys in the major spring Chinook salmon and summer-run steelhead streams, production and harvest monitoring of Klamath- Trinity fall-run Chinook salmon, and limited monitoring of winter-run steelhead in Mendocino County (Boydstun and McDonald 2005). Recent CMP adult monitoring, including Generalized Random Tessellation Stratified (GRTS)-based redd surveys and DIDSON stations, is underway in coastal streams inthe counties of Del Norte, Humboldt, Siskiyou, Mendocino, Sonoma, Marin, Santa Cruz, and Monterey. Redd-based surveys that will soon become GRTS-based are being conducted in the counties of Santa Barbara, Ventura, and Los Angeles.

The CMP (Adams et al. 2011) describes the use of Sound Metrics Corporation's dual frequency identification sonar (DIDSON) systems primarily to directly enumerate steelhead trout in the Southern Area (from the Pajaro River, Monterey County, south). The CMP also notes that DIDSONs could be usefulfor counting adults at Life Cycle Monitoring (LCM) stations. DIDSON is thought to be ideal for enumerating adult steelhead trout in central and southern California streams because only one species of salmonid inhabits these streams and adults are rare and patchily distributed, making other methods (e.g., redd surveys as applied in the Northern Area) potentially inefficient. Although mainly envisioned asa technology for directly counting steelhead trout in southern area streams, DIDSONs have also been installed in some northern area streams at potential LCM stations and for other purposes. DIDSONs at LCM stations may also provide data to correlate adult returns (direct fish counts) to redd estimates and to monitor ocean survival at selected LCM stations without the need to handle or trap fish.

Utility of DIDSON for adult monitoring:

DIDSON (Sound Metrics Corp.) is an acoustic camera originally developed by the U.S. Navy for use in harbor surveillance and to detect underwater mines under low-visibility conditions (Belcher et al. 2001). DIDSON sonar creates images using a lens that focuses sound waves onto a high-resolution sensor array. DIDSONs produce what are said to be "near video-quality images" of fish at ranges up to 15 m in high- frequency mode (1.8 MHz) and up to 40 m in low-frequency mode (1.1 MHz). DIDSONs can produce good images in highly turbid water and during the darkness of night where and when traditional methods that rely either on visual techniques or capture and handling of fish are limited.

DIDSON technology was identified by the Department as a potential non-intrusive survey method for meeting the adult counting station requirements as identified in Adams et al. (2011). Before purchasing DIDSON units, the Department reviewed its application, utility, and use for more than four years. The Department consulted with the National Marine Fisheries Service, the U.S. Navy, and states of Alaska, Oregon, and Washington, all of which use DIDSON for underwater imaging. In fisheries applications, DIDSON has been successfully used to count fish and evaluate salmon behavior (Morsund, et al. 2003, Holmes, et al. 2006, Mueller, et al. 2006), to count salmon redds (Tiffan et al. 2004), to estimate fish size (Burwen et al. 2007), for fishery monitoring (Maxwell and Gove 2004), and to estimate escapement (Duffy 2011). Specific to California, Pipal et al. (2010, 2012) evaluated the use of DIDSON to count steelhead trout in the San Lorenzo River, Santa Cruz County, and this information is presented in this document along with that done by other California researchers.

Obtaining reliable DIDSON data relies heavily on proper site selection (e.g., Maxwell 2007). Deployment sites should be selected to meet specific management needs of the project as well as the operational requirements of the DIDSON equipment (Enzenhofer and Cronkite 2000). Ideally, DIDSONs should be deployed at a secure site, downstream of spawning areas of interest at a natural constriction of the river, having medium velocity that minimizes milling behavior, with sloped and/or steep sides, and with minimum amount of air (bubbles) in the water column (Cronkite et al. 2006), and suitable power supply (Pipal et al. 2010). Table 1 shows additional site selection guidelines for DIDSON Fish-counting stations (Enzenhofer and Cronkite 2000).

Table 1. General site selection criteria for location of DIDSON fish-counting stations (from Enzenhofer and Cronkite 2000, with modification).

Site Selection Criteria
1. The river should have a straight single channel, not meandering, with laminar water flow. Laminar flow will produce less acoustic background noise than turbulent flow, resulting in a greater signal-to noise ratio and hence, a greater ability to detect targets. River stretches that exhibit back-eddies and pools may cause milling behavior that can result in fish being repeatedly counted.
2. The river bottom profile should be planar, rather than shelved or scalloped. A shelved bank creates zones of the riverbed that are inaccessible to the acoustic beam.
3. The bottom substrate size should be moderate and free of large boulders. Boulders can interfere with the path of the acoustic beam or create turbulent flow.
4. Activity on the river should be minimal because such things as propeller wash entrains air bubbles, which create background noise. Activities that may alter fish migration behavior should be avoided as this may affect the acoustic count.
5. It is advisable to survey potential sites to determine the bank and bottom profile.
6. Fish should be actively migrating past the site and not holding or milling. Fish that tend to remain in the sampling area may be counted several times which results in overestimates.
7. Sites with white-water, cliffs on one bank, or that have more than one channel should be avoided.

DIDSON Alternatives:

Alternatives to DIDSON for adult monitoring include trap and handling methods (weirs and other interception techniques), visual cameras, and traditional acoustic cameras. The Department chose DIDSON over other methods because it is relatively simple to install, does not require trapping, handling and marking, is usable in turbid and dark water, and images are relatively easy to interpret. Additionally, DIDSON images are often good enough to allow measurement of fish size. Use of DIDSONs in places with more than one salmonid species presents substantial challenges, and is still under development. However, research on identifying different species using DIDSON images is encouraging (Fleischman and Burwen 2003, Muller et al. 2010, Burwen et al. 2010).

Here we report on the results of initial deployments of DIDSON units across California for the purpose of counting returning anadromous salmonids, and we describe the progress to date toward CMP and other project goals. This is the first comprehensive report of the use of DIDSON devices employed as part of the CMP and for other uses.

METHODS

A. Equipment

The DIDSON system consisted of the DIDSON camera, camera cable, topside box, Ethernet cable, mount, laptop computer, and external hard drive(s) (Figure 1). Researchers (Department unpublished data, Pipal et al. 2010, Metheny 2012, Seesholtz and Manuel 2013, SCWA 2013, and Atencio and Reichmuth 2014) deployed standard DIDSON (DIDSON-S) model, created by Sound Metrics, at all locations except at the Smith River, where Zack Larson and Associates (2013) deployed two long range DIDSONs (DIDSON-LR). After finding poor imaging results during testing of their two long range DIDSONs on the Russian River, SCWA (2012) swapped them out with the standard range units that use higher scanning and shorter range imaging.

B. Deployment

i. Site Description:

Department (unpublished data), Pipal et al. (2010), Metheny (2012), SCWA (2013), and Atencio and Reichmuth (2014) deployed DIDSON units at fixed locations in 14 coastal watersheds, six Central Valley watersheds, and in one laboratory setting (Figure 2). A total of 20 DIDSONs were deployed at fixed stations on rivers to count individual salmonids during their migration. The deployment at the laboratory setting consisted of one DIDSON which was subjected to tests at the J. Armorocho Hydraulics Laboratory at University of California, Davis, aimed at documenting juvenile Chinook salmon movementrates and locations where entrainment occurred in a river simulation with an unscreened water diversion (Timothy Mussen, January 27, 2012). The two mobile stations consisted of DIDSONs mounted to boats to evaluate sturgeon habitat use (Seesholtz and Manuel 2013, Steve Tsao, June 05, 2014) (Figure 3).

The watersheds where DIDSONs were operated ranged substantially in physical characteristics including watershed size, channel morphology, turbidity (biological and suspended sediment), and flow discharge as well as in biological characteristics, including terrestrial and aquatic flora and fauna. Land-use practices varied greatly between watersheds where DIDSONs were deployed and included protected land, forested land with timber practices, farmed land, urbanized land, etc.

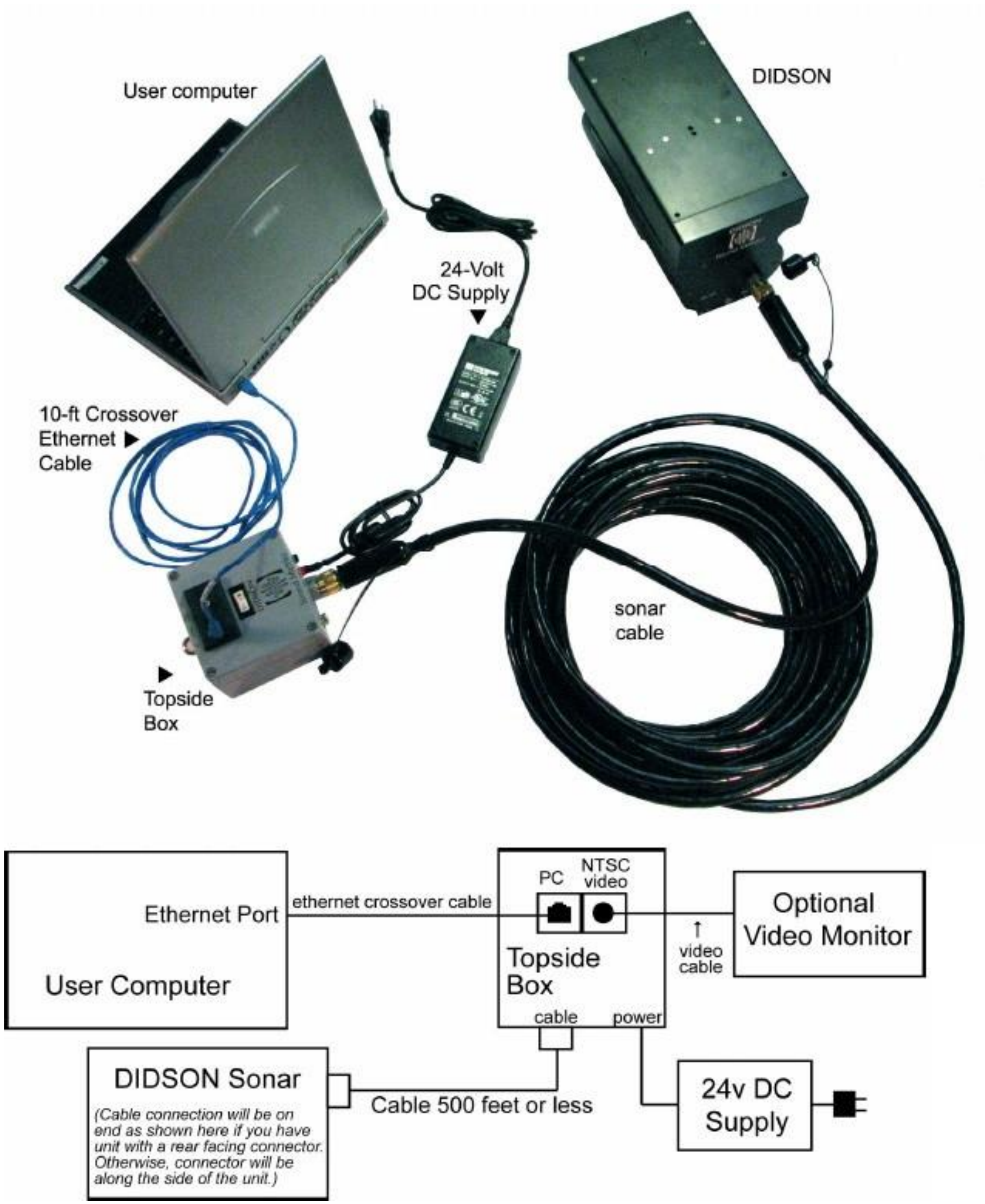
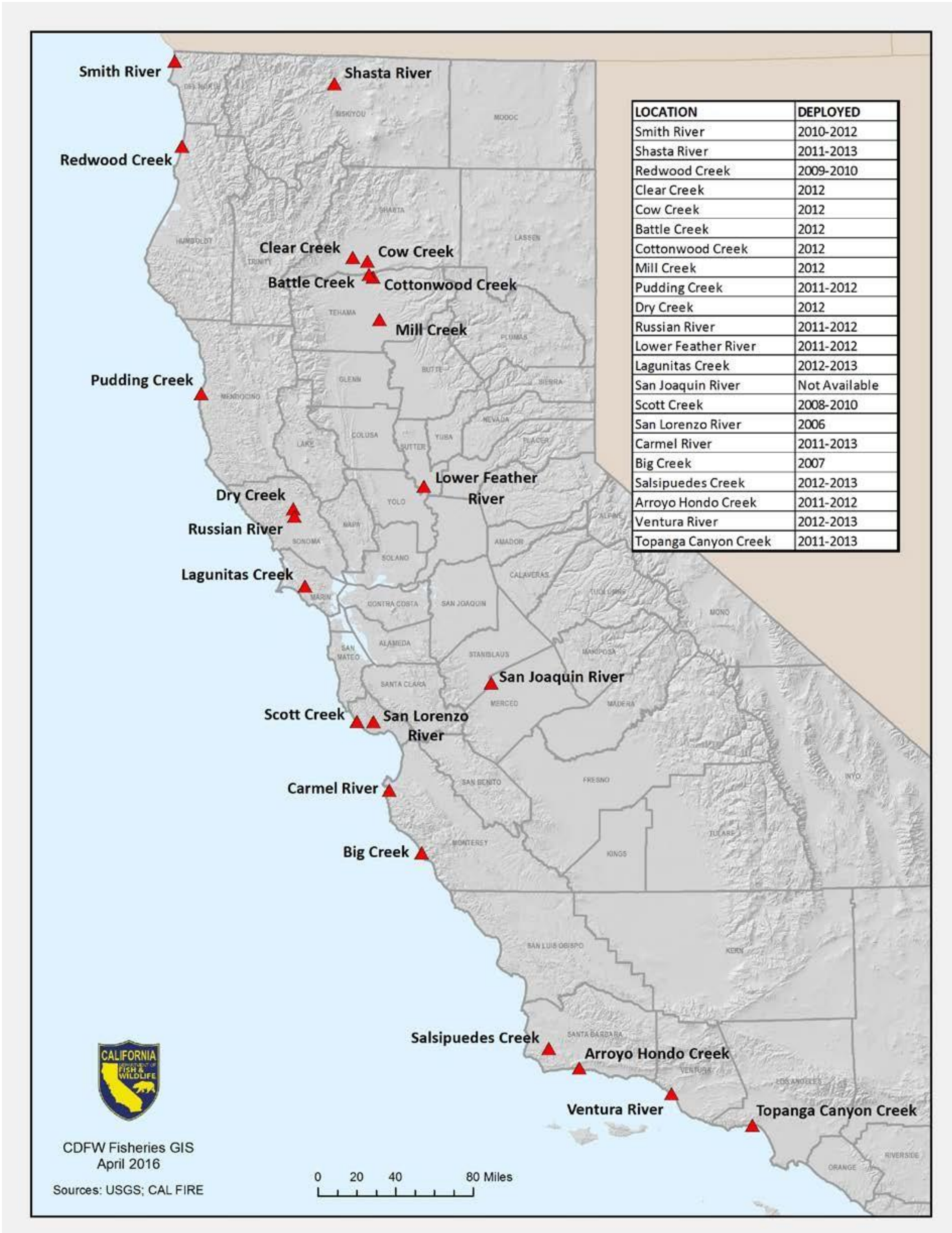


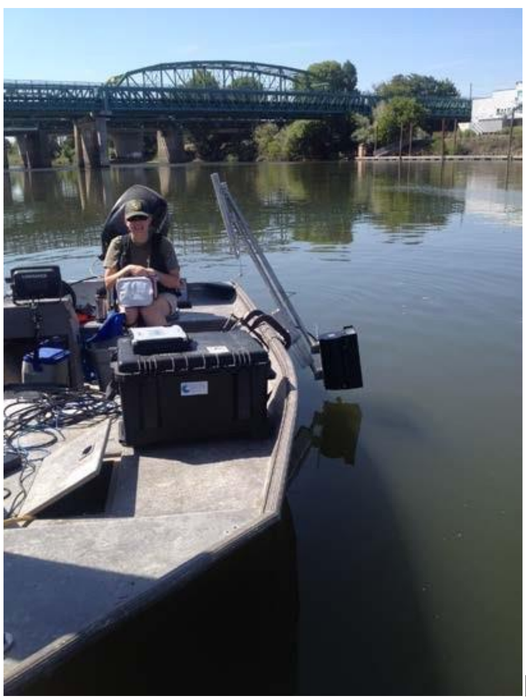
Figure 1. The DIDSON system consists of the DIDSON camera, sonar cable, topside box, Ethernet cable,mount (not pictured), laptop computer, and external hard drive (not pictured). Image obtained from www.soundmetrics.com.



LOCATION	DEPLOYED
Smith River	2010-2012
Shasta River	2011-2013
Redwood Creek	2009-2010
Clear Creek	2012
Cow Creek	2012
Battle Creek	2012
Cottonwood Creek	2012
Mill Creek	2012
Pudding Creek	2011-2012
Dry Creek	2012
Russian River	2011-2012
Lower Feather River	2011-2012
Lagunitas Creek	2012-2013
San Joaquin River	Not Available
Scott Creek	2008-2010
San Lorenzo River	2006
Carmel River	2011-2013
Big Creek	2007
Salsipuedes Creek	2012-2013
Arroyo Hondo Creek	2011-2012
Ventura River	2012-2013
Topanga Canyon Creek	2011-2013

Figure 2. DIDSON monitoring locations in California.

a)



b)

c)

Figure 2. Examples of DIDSON deployments at (a) fixed station at Deer Creek on February 14, 2013 andat (b) (c) roving stations in the San Joaquin River on June 05, 2014.

ii. Site-Selection Description

All sites where DIDSONs were deployed were carefully selected based on the goals and objectives of the particular study, the availability of an adequate power supply, and security. For CMP, these studies were primarily intended to obtain adult return counts or to calibrate redd surveys. Thus, the Department (unpublished data), Pipal et al. (2010), Metheny (2012), Zack Larson and Associates (2013), SCWA (2013), Atencio and Reichmuth (2014), and Hamilton (2014) deployed DIDSONs in coastal watersheds at fixed locations upstream of tidal influence and as low in the watershed as feasible to maximize the number of fish that passed by the camera. In the Central Valley, Killam and Johnson (2013) paired DIDSON units with video cameras at existing video locations to count Chinook salmon. To evaluate sturgeon life history patterns, including distribution and habitat in the Lower Feather River, Seesholtz and Manuel (2013) operated a DIDSON from a jet boat.

For salmon escapement estimates, the habitat type was selected to encourage fish passage in one direction (e.g. habitat types included “runs” and shallow “glides”) as opposed to enhancing milling behavior (e.g. “pools” and deep “glides”). Riffles and other habitat types with substantial turbulence / bubble curtain were generally avoided to prevent image interference. When assessing sturgeon behavior at water pumping facilities on the Lower Feather River, Seesholtz and Manuel (2013) had no choice but to operate the DIDSON in locations that characteristically had high turbulence. Channel morphology was also considered in site selection to ensure that ensonification was maximized by minimizing obstructions, and researchers attempted to choose cross sections that had gradual contours and small substrate (grain size ranging from sand to large cobble). For ensonification at the Smith River, a wide river (ranged in width from 279 to 326 ft as a function of flow during 2011/2012), Zack Larson and Associates (2013) deployed two DIDSONs at opposite banks so that the entire cross section could be viewed. The authors were careful to minimize or avoid interference or “cross talk” between the two facing DIDSONs by operating them at different frequencies (one high and the other low) and by slightly off-setting the ensonification zones. At the Russian River and in Central Valley rivers, DIDSONs were deployed side-by-side with video cameras to allow for fish counts during periods of low visibility, at night and during high turbidity after storms (SCWA 2013, Killam and Johnson 2012).

iii. Installations

In coastal Northern California streams, Department (unpublished data), Pipal et al. (2010), Metheny (2012), Zack Larson and Associates (2013), SCWA (2013), Atencio and Reichmuth (2014), and Hamilton (2014) deployed and maintained their DIDSONs on-site throughout the salmonid migration seasons. In southern California streams, where there was intermittent hydrological connectivity with the ocean as well as security issues associated with close proximity to urbanized areas, Department (unpublished data) deployed DIDSONs only during times of hydrological connectivity, and they staffed each DIDSON throughout the duration of deployment. Likewise, Killam (personal communication, February 2014) reported that the Department deployed DIDSONs at Central Valley stream locations only during times of low visibility when the video camera (with which the DIDSONs were paired) was ineffective. To evaluate sturgeon life history patterns in the Central Valley, Seesholtz and Manuel (2013) conducted presence/absence surveys for 15 minutes to an hour per site, followed by transect surveys using a DIDSON from a jet boat.

Department (unpublished data), Pipal et al. (2010), Metheny (2012), Zack Larson and Associates (2013), SCWA (2013), and Atencio and Reichmuth (2014) reported that they tested and made adjustments of DIDSONs in the field to ensure the units were properly oriented and channel ensonification was optimized. Metheny (2012) reported that the angling of the camera off the river bottom was typically between -2 and -6 degrees at Redwood creek, and Zack Larson and Associates (2013) reported it to be approximately -5 to -10 degrees at the Smith River.

Department (unpublished data), SCWA (2012), and Metheny (2012), and Zack Larson and Associates (2013) reported that they mounted DIDSON units on H-Frames in a manner that allowed angling and adjustment of the camera. At Pudding Creek and the Smith River, Department (unpublished data) and Zack Larson and Associates (2013) reported attaching the DIDSON to the H-Frame mount by a ball joint that allowed the user to adjust the direction of the camera. The center bar of the H-frame mount was set up so that it could be raised or lowered depending on water depth, and sandbags were placed on the feet of the mounting frame to hold it in place. Zack Larson and Associates (2013) reported that the hollow aluminum frames of their H-Frame filled with water, stabilizing the frame enough that no additional anchoring mechanism was needed. Killam and Johnson (2013) deployed their DIDSONs by clamping each unit to T-posts mounted on the banks. For the sturgeon boat surveys on the lower Feather River, Seesholtz and Manuel (2013) mounted the DIDSON on a hinged pole system that allowed recording video in either a fixed position for running transects or in a dynamic position for presence / absence surveys, allowing for manual rotation on three axes to adjust for height, rotation, and pitch.

Additionally, Seesholtz and Manuel (2013) recorded GPS coordinates in the video using a Trimble GeoXH connected to the DIDSON.

Pipal et al. (2010) and Atencio and Reichmuth (2014) used tripod-style mounts with sled-like feet that could be moved into position by dragging the unit and / or by moving the adjustable arm from which the camera was mounted. To prevent fish from swimming behind the camera, Pipal et al. (2010) installed deflector fencing from the camera to the closest stream bank. The fencing consisted of panels of T-posts and 5-cm chicken wire that allowed for individual panels to be added or removed as flows levels fluctuated. Atencio and Reichmuth (2014) installed a Sound Metrics X2 pan-and-tilt motor to remotely aim the camera and a deflection fence upstream of the DIDSON to protect the unit from floating debris. A second fence located downstream of the DIDSON was installed to direct fish to swim upstream through the center of the channel, providing optimal footage and to discourage them from taking cover at the undercut bank. For study sites that were too steep and / or unsafe to allow for adjustment of DIDSON locations up and down bank during high flow fluctuations, Pipal et al. (2010) constructed a crank-pulley system that consisted of cables, pulleys, and a boat-trailer style crank. Likewise, on the steep banks of Salsipuedes Creek, Department (unpublished data) designed and installed a “track- mounting system.” To maximize image quality for their DIDSON on the Shasta River, Department (unpublished data) installed metal panels spanning the river, leaving a 9.5 m opening for fish passage and deployed the DIDSON immediately upstream in a protective steel box.

C. POWER SUPPLY

Department (unpublished data), Pipal et al. (2010), SCWA (2012), and Metheny (2012), and Zack Larsonand Associates (2013) reported that they considered access to power supply as part of their site selection procedure. Having consistent power helped ensure that data would not be lost and was moreconvenient than continuously replacing batteries. Pipal et al. (2010) used 110-V, AC power at all three sites, requiring power lines to be extended to DIDSONs. Likewise, Department (unpublished data) at Pudding and Salsipuedes Creeks and the Ventura River used the existing facilities' AC power supply, as did Metheny (2012) at Redwood Creek, SCWA (2012) at the Russian River sites, and Atencio and Reichmuth (2014) at Lagunitas Creek. Having AC power at Salsipuedes Creeks, however, did not completely ward off power outages. An electrician had to be called in to fix an electrical problem, and afterward the DIDSON was reported to operate smoothly. Uninterrupted Power Supply (UPS) devices were used to protect the data and equipment from power outages and surges.

At their facility on the Smith River, Zack Larson and Associates (2013) used existing AC power for one DIDSON, and for their second DIDSON on the opposite bank that lacked an AC power source, they used three 12 volt batteries connected in parallel to a 400 W inverter. They replaced the three batteries every24 hours to avoid disruptions due to power loss.

Due to the lack of access to power at one of the three southern California streams (e.g.,Topanga Creek), Department (unpublished data) used a solar panel mounted on a mobile trailer. This mobile unit allowedpower supply to the DIDSONs during periods when there was adequate stream flow and depth for operating the sonar units.

D. SECURITY / PROTECTING GEAR

All researchers reported that security of equipment was an important factor for determining deployment sites. At Pudding Creek, Department (unpublished data) secured DIDSON equipment on private property behind two locked gates from the road. For additional security, the DIDSON's cable wasrun through PVC and under mats of vegetation, and the H-Frame and other equipment was secured withcables and padlocks to permanent structures. Electronic equipment (laptop, power box and external hard drives) was secured in a pump house located in close proximity (approximately 100 ft) to the DIDSON.

For security at Redwood Creek, Metheny (2012) cabled gear to T-Posts that were anchored on shore, and he used PVC conduit and vinyl tubing to protect cables against abrasion. At the Smith River, a 10 ft by 14 ft building located on private property just outside of the 100 year flood plain was used to secureelectronic equipment, and Zack Larson and Associates (2013) reported that "24 hour staffing was needed" to provide security, protect equipment, and to ensure proper angling and functioning of the DIDSON. At study sites on the Central California coast, Pipal et al. (2010) used cables and padlocks to secure DIDSON equipment to permanent structures (e.g., trees) and used a weather proof storage box to protect electronic equipment (laptop, back-up battery system, DIDSON topside box, and external hard drives) from the elements as well as for security.

Due to the close proximity of Southern California streams to urban areas (and due to the flashiness of flows), the Department (unpublished data) was on-site during the entire time that DIDSONs were being operated for sites with security concerns. Additionally, the flashy nature of Southern California streams and the potential to leave DIDSON units out of water (potentially over-heating and damaging the units) after storms necessitated that researchers maintain a regular presence at three of four sites during deployment. The unit deployed at Salsipuedes Creek did not require a regular presence because it had continuous streamflow and was securely located on property with a caretaker and behind a gate.

To protect image quality and prevent fouling of the lens, Department (unpublished data) enclosed the DIDSON camera in a thick plastic bag at Pudding Creek. The Department (unpublished data) on the Shasta River and Metheny (2012) on Redwood Creek protected their respective DIDSON cameras by placing the units in an aluminum enclosure and steel box with only the lens and camera cable exposed, for protection. Zack Larson and Associates (2013) reported that they cleaned the lens regularly with a soft bristle brush to remove algae and sediment. In several sampling locations, researchers use Sound Metrics Corporation silt boxes to reduce silt infiltration of the sonar camera. Department (unpublished data) in southern California employed a combination of the two by first placing the camera in a plastic silt box before placing it inside a protective aluminum housing referred to as a “debris box”. The aluminum housing had the added benefit of allowing for the attachment of a security tether as an added precaution.

E. FIELD OPERATIONS

At all fixed stations, Department (unpublished data) , Pipal et al. (2010), Metheny (2012), Zack Larson and Associates (2013), SCWA (2013), Killam and Johnson (2013), and Atencio and Reichmuth (2014) reported that DIDSON camera orientation and positioning had to be adjusted throughout deployment due to changing stream stage. Department (unpublished data) at Pudding Creek reported that two technicians were required to operate the deployment of equipment for the remainder of the season, replacing external hard drives (2-3 TB) once per week and making DIDSON adjustments in the field (taking approximately 2-3 hours per week), as well as reviewing DIDSON video and recording fish passage data in the office (taking approximately eight hours per day for 24 hours of video recording).

Zack Larson and Associates (2013) safe-guarded against data loss by setting up wireless networks for the two opposite bank DIDSONs to view real-time video as a way to check for any problems that needed to be addressed on site, safe-guarding against data loss.

F. DATA ANALYSIS

i. Software Operations

Department (unpublished data), Pipal et al. (2010), Metheny (2012), Zack Larson and Associates (2013), SCWA (2013), and Atencio and Reichmuth (2014) reported that they installed and tested the software package (V5.23) provided by Sound Metrics, Inc. to see if the software worked for their local applications. The *Convoluted Samples OverThreshold* (*CSOT*) Program was included in the DIDSON software package and is designed to reduce file size and thus save review time. Instructions and tutorials for use of this software can be found on the DIDSON CD software and at the Sound Metrics FTP site(ftp://soundmetrics.com).

Department (unpublished data) at Pudding Creek reported that once the hardware was connected and the software was loaded, boot-up took about a minute. They recommended that if the connection takeslonger then several minutes and the Ethernet fails, one should try increasing the Ethernet speed in the “Local Area Connection.” Additionally, they reported that cable lengths in excess of 60 m require Ethernet speed to be set to 10 Mbits/sec. Furthermore, they reported that to run a DIDSON and its software, computers must have a minimum processor speed of 2 GHz and 1 GB of RAM.

Zack Larson and Associates (2013) reported that they used a single lap top computer to simultaneousconnect as a network to the two DIDSONS operated on both sides of the Smith River.

SCWA (2013) reported that although the software set up was a “simple” process that included connecting the equipment and booting up the software, configuring the software for one’s particularneeds require a lot of “trial and error” based on the many ways the software can be configured.

ii. Recording and Storage

Department (unpublished data), Pipal et al. (2010), Metheny (2012), Zack Larson and Associates (2013), SCWA (2013), Atencio and Reichmuth (2014), and Hamilton (2014) reported that they recorded the entire salmonid run rather than subsampling (e.g., running the camera for X minutes per hour). In order to minimize the potential for data loss (e.g., file corruption) and to ease file transfer, all researchers saved data in files of 10-60 minute increments in duration. All files were stored on hard drives (300 GB-3TB) that were regularly swapped out and backed-up.

Department (unpublished data) at Pudding Creek (unpublished data) and Zack Larson and Associates (2013) at the Smith River, reported using the “Brute force” (continuous recording) option provided by the Sound Metrics, Inc., software, instead of “timed” or “motion detection” options, because they felt itgave a more accurate count of salmonids. Except in several southern California streams where stream flow was intermittent, researchers recorded data 24 hours per day, seven days per week, during the period of migration to protect data quality in case of power outages or other failures.

iii. Post-Processing Data

Pipal et al. (2010) reported that parameters needed to be modified during the monitoring season as image quality changed under varying environmental conditions (e.g., flow, debris, turbidity). Zack Larsonand Associates (2013) reported that they used the software to count steelhead trout, but they had to count Chinook salmon manually due to excessive milling of salmon at the study site, especially under low flow conditions.

Department (unpublished data) in southern California streams and in Pudding Creek reported using*CSOT* first to locate the moving objects then they used *Echogram*, another tool in DIDSON software package, to automatically count fish. For data generated from southern California streams, the researchers used *Echogram* function with background subtraction which enabled them to quickly highlight potential fish passage events. The associated raw footage was then toggled to and manually reviewed to obtain species identification and sizing data. In addition, they left parameters in default values and that they were "adequately" able to detect and count steelhead trout. At Pudding Creek, researchers reported that due to the large quantity of moving plant matter at their site, they were unable to determine the correct parameters to get the software to only count fish. They found that viewing the raw data in the "fast-playback" mode was most effective for identifying and counting only fish given the noise. Metheny (2012) attempted to use the *CSOT* and *Echogram* software and found that there was too much noise to accurately estimate escapement; *CSOT* did not substantially reduce file size and *Echogram* counted all drifting matter including vegetative debris . Instead, he reviewed the raw files and tallied the fish.

Atencio and Reichmuth (2014) reported using the standard *CSOT* settings with the exceptions of turning on "insert prequel" and setting "persistence" to eight. Atencio and Reichmuth (2014) organized the *CSOT* files by deleting those that contained no net fish movement and replacing them with a text file to minimize file size and to indicate the respective files had been analyzed. Video from each day was reviewed by a single reviewer then counts were entered into a Microsoft Excel spreadsheet.

Pipal et al. (2010) reported that after processing the raw files using *CSOT*, the files were batched into 24 hour periods to be reviewed by a single reviewer and that *background subtraction* was used to improve the review of the moving fish. Zack Larson and Associates (2013) also used the background subtraction feature to help them distinguish between large and small fish, mammals, and birds.

To facilitate transfer of data from DIDSON files (.ddt) to Excel spreadsheets, Zack Larson and Associates (2013) used the free software *Karens Directory Printer* to copy and paste entire file name directories.

Zack Larson and Associates (2013) processed data from each of the two opposite-bank DIDSONs separately utilizing the Sound Metrics, Inc., software. After weekly video reviews, fish count data collected from each bank were entered into separate Microsoft *Excel* spreadsheets and then compiled into one master fish count data file.

In order to get best estimates possible and to account for days when equipment was not in use, Killam and Johnson (2013) used R software developed by a statistician at WEST, Inc. to smooth out the daily counts from video camera /DIDSON station footage.

iv. Species Identification

All researchers reported that they used a combination of their familiarity with the watershed, knowledge of which species were present, and supplemental sampling techniques (e.g., trapping, video cameras, hook and line, spawner survey information) were used to aid in species identification in DIDSON images (Department unpublished data, Pipal et al. 2010, Metheny 2012, Zack Larson and Associates 2013, and SCWA 2013, Atencio and Reichmuth

2014). Coho salmon and steelhead trout were reported by Pipal et al. (2010) and by Department (unpublished data)at Pudding Creek and the Shasta River to be particularly difficult to distinguish from steelhead troutdue to overlap in migration timing and similarity in size and morphological characteristics. Pipal et al. (2010) and Department (unpublished data) was able to apportion species based on a combination of runtiming and data obtained at adjacent traps (Scott and Pudding Creeks) and at a video monitoring station (Shasta River). Zack Larson and Associates (2013) averaged monthly catch per species from the Department's angler survey reports from 1997 to 2007 at the Smith River to apportion estimates of escapement of Chinook salmon and steelhead trout. SCWA (2013) used video cameras at the Russian River to differentiate steelhead trout and Chinook salmon, and when visibility was poor, they made estimates from DIDSON video total counts and apportioned by species based on the proportion of each species in the previous 24 hour period of video camera images. At Redwood Creek, Metheny (2012) used four methods to distinguish salmonid species: regression models using individual and summed probabilities; species' ratios obtained from spawning survey observations; and normalized distribution of species' run times. Spawning survey data at Lagunitas Creek was used to differentiate between adult anadromous salmonids and those that were likely jacks or resident rainbow trout (Atencio and Reichmuth 2014).

To classify steelhead trout as either resident or anadromous, Pipal et al. (2010) used the maximum size of resident trout captured (30 cm) during electrofishing surveys to set the cut-off (40 cm) between resident and anadromous fish. Metheny (2012) and Department (unpublished data) at the Shasta River used a 16 inch (40.6 cm) anadromous-resident cutoff, the same used by the California Department of Fish and Game Steelhead Report Card for differentiation. At southern California streams, Department (unpublished data) differentiated species based on size, direction of movement, and whether there hadbeen hydrologic connectivity with the ocean. Atencio and Reichmuth (2014) were able to rule out common carp (*Cyprinus carpio*), a species known to be present in the Lagunitas Creek watershed, basedon knowledge that this species was not likely to be present in the vicinity of the DIDSON location. In southern California streams which contain common carp, Department (unpublished data) evaluated swimming behavior and morphological characteristics to differentiate carp from steelhead trout.

At Lagunitas Creek, salmonids were differentiated from several fishes and other wildlife. Salmonids weredistinguished from catfish (*Ictalurus punctatus*) by evaluating differences in body shape and swimming behavior, from Sacramento suckers (*Ictalurus punctatus*) by differences in swimming pattern, and from California roach (*Lavinia symmetricus*) by differences in size (Atencio and Reichmuth 2014). Additionally,differentiation between salmonids and sunfish species (*Lepomis spp.*) at Lagunitas Creek was accomplished using differences in size, morphology, and swimming behavior. Differentiation from green sturgeon (*Acipsenser medirostris*) was based on differences in size and morphology. Surprisingly, discrimination from North American river otters (*Lontra canadensis*) was challenging at first and was done by looking for presence of bubbles produced by swimming otters as well as by the otters' large size and swimming style of undulating on a vertical plane (Atencio and Reichmuth 2014).

v. Measurement and Enumeration Techniques

Department (unpublished data), Pipal et al. (2010), Metheny (2012), Zack Larson and

Associates (2013), SCWA (2013), Atencio and Reichmuth (2014), and Hamilton (2014) reported that they used the DIDSON software's size measuring tools to measure every individual salmonid's total length. Pipal et al. (2010) and Atencio and Reichmuth (2014) specifically reported that they used the box measuring method. This involved drawing a box that extends from snout to end of the tail and the software providing a length total calculation.

To enumerate salmonids, Pipal et al. (2010) employed a couple of techniques including the "Best Guess Approach" and "Decision Support Tools (DST)". The Best Guess Approach required experienced reviewers, who made determinations on how to classify the net upstream and downstream travel and whether fish were milling. These expert determinations, coupled with direction of travel of each fish, were based on the four following factors: pairing of fish with other fish; the timing of the last fish observation; fish size; and swimming pattern. Pipal et al. (2010) further developed and implemented DST methodology to standardize the decision process and make it more objective in systems on the San Lorenzo River where passage was complicated due to milling, pauses in migration, and spawning behavior. Using this tool, a point system was applied to the previously mentioned four factors to determine the likelihood of multiple observations of a fish being the same fish.

Atencio and Reichmuth (2014) at Lagunitas Creek and Department (unpublished data) on Pudding Creek reported that they tried using the DST but due to extensive milling, the technique became too cumbersome to use. Instead, these researchers and Department (unpublished data) on the Shasta River enumerated salmon manually. Zack Larson and Associates (2013) and Metheny (2012) reported that they estimated escapement using the model described in Xie et al. (2002) that determines the net upstream flux of fish by subtracting the number of fish moving downstream from the number of fish moving upstream.

In addition to estimating adult escapement, only Department (unpublished data) on Pudding Creek reported that they investigated the feasibility of counting and measuring smolt length using DIDSON and its software.

On the Carmel River, Hamilton (2014) used two techniques to estimate steelhead escapement, "Approach #1" and "Approach #2", during 2011/2012 and 2012/2013 monitoring seasons. Approach #1 consisted of calculating the sum of the daily values of net number of upstream-moving steelhead trout (those greater than 35 cm total length) and not considering outmigrating kelts in the escapement estimates. Approach #2 took kelt outmigration in consideration. It consisted of calculating the sum of the daily, net upstream-moving fish (greater than 35 cm total length) until the number of fish peaked , and then for the remainder of the season, adding only the daily upstream counts.

RESULTS

The following text is based on reporting by watersheds of the first DIDSON programs. These are summaries of both data generated as well as operational results. Several programs are still in the experimental stages of deployment and researchers are resolving issues. The Fixed Stations are presented first from north to south, then roving stations, and lastly the laboratory uses

All of the units met the expectations of the principle investigators with the exception of the flume study conducted at UC Davis, where the DIDSON unit was unable to view movement of juvenile Chinook salmon through the bubble curtain generated by the flume's current (UC Davis Tim Mussen, January 27, 2012). Overall, field studies showed that the units are durable, reliable, and function well under the harsh and variable environmental conditions found in California's rivers, and that these units can be used to collect total adult salmonid counts as well as presence / absence and habitat utilization data for sturgeon. Although DIDSON are durable under harsh conditions, removal of units from rivers during highflow is necessary to protect equipment from being washed downstream or damaged by debris. Effectiveuse of DIDSONs required that the researchers have some training in their operation as well as a basic understanding of the channel morphology of the deployment location and the species present.

When multiple species of salmonids were present, no researcher was able to identify the species by video alone. Every researcher used a combination of the following: knowledge of the stream; the time ofyear; species present; life history characteristics of the fish species present; and species' size, morphology, and swimming behavior.

A. FIXED STATIONS

Smith River [Zack Larson and Associates (2013)]*:*

- In 2010/2011, Zack Larson and Associates (2013) enumerated 43,065 adult salmonids traveling upstream and 11,088 adult salmonids traveling downstream with an estimated "fishing efficiency" (percent of time the DIDSON was operated compared to actual time)of 84.3%. They estimated that there were 22,559 adult Chinook salmon, 16,202 adult steelhead trout, and they found that the number of coho salmon was too low to provide an estimate. In 2011/2012, they determined that 76,707 adult salmonids traveled upstream and 44,564 travelled downstream with a fishing efficiency of 94.7%. They estimated that there were 19,197 adult Chinook salmon, 14,768 adult steelhead trout, and they found again that the number of coho salmon was too lowto provide an estimate.
- Zack Larson and Associates (2013) reported that DIDSON video results show that the river stagehas the greatest influence on salmonid migration. Additionally, they reported that Chinook salmon exhibited a milling behavior at flows less than 500 cfs and that there was net downstream migration during "extreme" low flows.
- DIDSON video provided information about diel salmonid migration patterns. Zack Larson and Associates (2013) reported Chinook salmon tended to migrate "from dusk until dawn" and that steelhead trout "tended to migrate from dawn until dusk". Likewise, Zack Larson and Associates(2013) reported 575 detections of marine mammals and reported diel behavior patterns with observations occurring between 6pm and 10am.
- The DIDSON was used to report rare events such a potential sturgeon observation [Zack Larsonand Associates (2013)].

Redwood Creek [Metheny (2012)]*:*

- Metheny (2012) reported escapements of salmonids to be 3,000 (those greater than 40 cm totallength) and 900 (those less than 40cm) at Redwood Creek from November 17, 2009 to March 18, 2010. Of this total, the four models used predicted 2,318–2,500 to be Chinook salmon, 315- 490 to be coho salmon, and six to 12 to be steelhead trout up to the date of January 22, 2010. After January 22, all salmonids were assumed to be steelhead trout, bringing the steelhead troutescapement to approximately 560. Due to the high number of days the DIDSON was not operated during 2010-2011, only daily estimates and no escapement data are available. Down- time in 2010 included 40 days to repair the DIDSON after it was damaged and during times (39 days) of computer malfunction and high flows (greater than 3,000 cfs).

- At flows greater than 3,000 cfs, accumulated debris during conditions of fast current and rising water stage had the potential to pull-out T-posts that secured the DIDSON. In order to protect the DIDSON unit, equipment was removed from the stream and not operated at these high flows.
- Metheny (2012) reported that salmonids were consistently detected up to a distance of 27 m. Those within 27-35 m of the DIDSON appeared "intermittently as flickering objects". The sizes of salmonids detected typically were in the range of 15 cm to 2 m. High turbidity and large quantities of debris reduced the DIDSON's image quality.
- Metheny (2012) reported that he "…was unable to effectively use DIDSON software to automate the review process". *Echogram* counts (6,804) of upstream migration of salmonids were inconsistent with those by human reviewers (32,578). Counts between two human reviewers were highly correlated with a 0.94 Pearson correlation and regression with $R^{2}=0.889$. A 10 minute sample was determined to have a mean error of 9% when assuming constant background noise level.
- In 2009-2010, the distribution of salmonid counts peaked during 16-18 December and 15-25 February. Hourly escapement rates peaked (35%) at dusk (4-9pm) and were lowest (10%) during the mid-day (11am-4pm). Tide and date showed the strongest relationship to upstream passage than other parameters modeled.

Shasta River [Department (unpublished data)]:

- Department (unpublished data) reported that during the period DIDSON was deployed (Jan 10, 2012-March 29, 2012), 191 adult salmonids were observed moving upstream and 101 were observed moving downstream. They reported that differentiation of species was particularly difficult (and not achieved) in this watershed due to the overwhelmingly greater number of Chinook salmon compared to the number of coho salmon and steelhead trout. During the time period of deployment, the laptop crashed repeatedly but "successful" recording occurred for 69.5% of the time.
- After 2012, a Dell Latitude Laptop D800 was exchanged for the new ruggedized Dell Latitude XFR laptop, and deployment during the 2012 season occurred with minimal interruptions.

Pudding Creek [Department (unpublished data)]:

- Department (unpublished data) observed 123 adult salmonids in the period DIDSON was deployed (December 06, 2011 to April 22, 2012). No species specific counts were determined.
- The large quantity of floating aquatic vegetation made using *CSOT* and *Echogram* analysis tools impractical for making smaller files.
- Department (unpublished data) was able to use DIDSON images to improve operation of fish trapping and ladder facilities. They found that the bars on the top of the fish ladder prevented fish from freely moving downstream, thus delaying outmigration of post-spawned fish for days or weeks (and potentially leading to multiple counting of the same fish). Additionally, researchers documented from DIDSON video that river otters were active during the crepuscular hours and preyed upon the trapped fish. Department (unpublished data) officially documented this and now uses this as a tool to determine when to pull the trap.
- Department (unpublished data) found that although the resolution provided by the DIDSON allows for fish as small as smolts (120 mm) to be seen in the High Frequency Mode, it was too difficult to track individual fish due to substantial milling and schooling behavior. DIDSON footage allowed viewing of smolts moving down the

ladder but when the trap was in place, video became distorted by excessive cross-talk (noise).

Russian River [SCWA (2013)]:

- In their 2012 test trials (without total fish counts for the season) of operating DIDSON units paired with video cameras, SCWA (2013) reported that DIDSONs' detection rates far-exceed those of the paired visual system. DIDSON was able to record images of passing fish during times (e.g., night-time and during periods of high turbidity) when the video system could not.
- SCWA (2013) reported that determining salmonid versus non-salmonid "was not difficult" with the DIDSON although this was easier with the video camera during daylight hours when turbidity was low.
- By pairing with the video system, SCWA (2013) reported that they were able to apportion salmonids by species and to make counts, independent of time of day or water clarity.
- Determination of sex and life history stages of salmonids was more difficult with the DIDSON in comparison with their video cameras (SCWA 2013). SCWA (2013) reported that only mature adult males could be distinguished based on their relatively large size and their distinctive jaw outline.
- SCWA (2013) reported that although the DIDSON camera was set up in close proximity to view salmonids, it was problematic trying to determine whether the fish had an intact adipose fin and thus ad-clips rates could not be estimated. Additionally, they reported that DIDSON provided "sharper images" of the salmonids than did the video cameras, and that the DIDSON images were not affected by the lighting conditions.
- Salmonid behavior didn't seem to be affected by the presence of the DIDSON as it was with the video camera (SCWA 2013).
- SCWA (2013) reported that there was a "learning curve" when they began using the DIDSON software especially because minimal support documentation was available.

Lagunitas Creek [Atencio and Reichmuth (2014)]:

- Atencio and Reichmuth (2014) first deployed DIDSON on December 13, 2012, corrected issues with assembly and site selection (moved to a different site without the "noise" of active spawning activity) in January 2013, and continued DIDSON monitoring through April 29, 2013. The DIDSON operated 81% of the time during the December through April time period. Atencio and Reichmuth (2014) reported that the DIDSON was removed even though "activity" was still being observed.
- Although an escapement estimate of coho salmon could not be determined due to a late start of DIDSON deployment, this was the first time that total steelhead counts for Lagunitas Creek was determined. An estimate of 388 steelhead was determined based on species apportionment of live salmonid counts, and an estimate of 395 steelhead was determined based on species apportionment of redds.
- Peak upstream (192 counts) and downstream (212 counts) steelhead migration both occurred on March 28, 2013 and 68.7 percent of all salmonid passage events occurred at night. A total of 12,153 salmonid observations were recorded.
- Atencio and Reichmuth (2014) used the DIDSON software to measure lengths of salmonids and determined the average total length of steelhead to be 70 cm ±8 cm (median total length 71 cm) and coho salmon to be 67 cm±12 cm (median total length 70 cm).
- Most gaps in the DIDSON recording were reported to be due to temporary losses of power and due to the cables (Ethernet cable or USB Cable to external hard drive)

inadvertently being disconnected when working with the equipment.

Scott Creek [Pipal et al. (2010, 2012)]:

- Pipal et al. (2010, 2012) deployed the DIDSON over two seasons: (1) January 15 through April 30, 2008 and (2) from February 09 through March 24, 2009 and using the decision support tool, determined steelhead estimates of 153 and 57 for seasons 1 and 2, respectively.
- Pipal et al. (2012) reported that the placement of the downstream out-migrant traps caused increased milling of steelhead at the DIDSON location thereby affecting counts.
- Use of DIDSON was deemed to be a successful tool in determining steelhead escapement estimates at Scott Creek. To improve escapement accuracy, Pipal et al. (2012) recommended deploying DIDSON for the entire migration season, consider fish behavior, and be effective at species identification.

San Lorenzo River [Pipal et al. (2010)]:

- Pipal et al. (2010) determined that approximately 41 to 48 adult steelhead trout passed upstream of the DIDSON unit on the San Lorenzo River which was deployed for a total of 141 hours on March 14-17 and 21-24. Both the "Best Guess" method (41 steelhead trout) and "Decision Support Tool" (48 steelhead trout) were close to the count determined at the fish trap (46 steelhead trout).
- Although this deployment was deemed "successful" in counting salmonids, Pipal et al. (2010) determined that security issues made using it as a long term deployment location problematic.

Carmel River [Hamilton (2014)]*:*

- Both migration seasons surveyed (2011/2012 and 2012/2013) were characterized as "dry water year types" with low stream flows. Hamilton (2014) reported that the low flow conditions increased the milling behavior of adult steelhead due to impaired passage conditions at shallow riffles. He also reported that the low-flow conditions caused degraded DIDSON image quality due to "scattering" of the sonar beams in the very shallow (down to six inches) water. These conditions made determination of steelhead estimates during these two seasons unreliable.
- Hamilton (2014) reported substantially different estimates using the two analytical approaches. Using Approach #1 (where he did not consider kelt outmigration), Hamilton (2014) determined an escapement estimate of 654 steelhead during 2011/2012 migration season and 255 adult steelhead during 2012/2013. Using Approach #2 (where he considered kelt outmigration), he estimated 1,399 adults in 2011/2012 and 751 adults in 2012/2013. The San Clemente Fish Counter, located 15 miles upstream of the DIDSON deployment locations, had counts of 470 adult steelhead in 2011/2012 and 249 in 2012/2013.
- Hamilton (2014) reported that both Approach #1 and Approach #2 were biased. He reported that Approach #1 was likely an underestimate due to lack of a correction factor for outmigrating kelts. Additionally, he reported that Approach #2 was likely an overestimate due to lack of accounting for milling after the time recorded for peak migration.
- Hamilton (2014) recommended reducing bias by improving data analysis techniques. We, the authors of this paper, recommend that the DIDSON deployment location first

be re-evaluated and that either mechanisms be installed or a better location be chosen to reduce milling behavior. If milling cannot be reduced in this river, the value of using DIDSON for estimating escapement, especially during low flow conditions, should be reconsidered.

Big Creek [Pipal et al. (2010)]:

- Pipal et al. (2010) used the "Best Guess" method and determined that approximately 22-23 adult steelhead trout passed upstream of the DIDSON unit on Big Creek which was deployed from January 03 to May 08, 2007. They reported this deployment as "unsuccessful" due to extreme milling (990 fish observations) at the DIDSON location. Substantial milling and the lack of time for data processing made utilizing the "Decision Support Tool" for data analysis impractical, thus estimates were made using the "Best Guess" method.
- Pipal et al. (2010) reported that other DIDSON deployment locations were investigated but none were deemed appropriate for the application.

Salsipuedes Creek (tributary to Santa Ynez River) [Department (unpublished data)]:

- Department (unpublished data) reported that due to lack of hydrological connectivity and drought conditions when the DIDSON was to be deployed (2012/2013 season), the unit was deployed on four separate times at Salsipuedes Creek only during January to March 2013. Although this location has a dedicated power source, power outages affected the first two deployments and after an electrician repaired the problem, the DIDSON operated smoothly.
- Two steelhead trout (15 and 19 cm total length) were recorded by the DIDSON at this site, and both were believed to be residents by Department (unpublished data) based on their total lengths (15cm and 19cm) and the believed lack of access to the site from ocean (low stream flows and the presence of recently constructed beaver dams). The DIDSON recorded beaver activity throughout the night.

Arroyo Hondo Creek [Department (unpublished data)]:

- Department (unpublished data) reported that due to the lack of hydrological connectivity and drought conditions when the DIDSON was to be deployed (2011/2012 season), the unit was deployed at Arroyo Hondo Creek only during March and April 2012.
- During the deployment, four steelhead trout (total length ranged from 21 to 35 cm) were recorded milling at the site by the DIDSON. All four fish were believed to be residents based on their lengths. In addition to steelhead trout, a California red-legged frog (*Rana draytonii*) was observed in the DIDSON footage.

Ventura River [Department (unpublished data)]:

- Department (unpublished data) reported that due to lack of hydrological connectivity and drought conditions when the DIDSON was to be deployed (2012/2013 season), deployment was limited to three separate short periods at the Ventura River in 2013. The purpose of the first deployment (on March 4-5, 2013) was as a test to determine whether there were electrical problems or other issues at the site. Deployment on the next two dates occurred on March 30-April 01, 2013 and on April 15-17, 2013) when the flows were higher and steelhead trout more likely to access the site from the ocean.
- During the first deployment, Department (unpublished data) captured footage of two steelhead trout (17cm and 30 cm TL). Both fish were believed to be resident fish based on length. During both the second and third deployments, one 23 cm TL steelhead trout

was observed and it wassuspected to be the one of the previously observed fish based on size. No net-movement of steelhead trout was observed in any of the three deployments.

In addition to steelhead trout, researchers obtained footage of multiple common carp during allthree deployments. These were differentiated from trout based on differences in swimming behavior and the morphology of pectoral fins. Visual observations confirmed species identification using the DIDSON images. In addition to fish, researchers recorded DIDSON footage of turtles, chorus frogs, and swimming birds.

Topanga Creek [Department (unpublished data)]:

- Department (unpublished data) reported that due to lack of hydrological connectivity and drought conditions when the DIDSON was to be deployed (2011/2012 and 2012/2013 seasons),the unit was only deployed at Topanga Creek during short periods of time in April 2012 and in January 2013.
- During the deployment in April 2012, no adult anadromous steelhead trout were observed although several out-migrating steelhead trout smolts were recorded. Additionally, a total of five observations of "resident trout" (ranging from 19 to 23 cm TL) were documented from DIDSON. Both fish were believed to be resident fish based on length. Additionally, researchersrecorded images of chorus frogs, ducks, and unidentified species of small fish.
- During the deployment in January 2013, Department (unpublished data) reported that the water depth and flow was very low. Only crayfish, ducks, and unidentified species of small fishwere observed.

Central Valley watershed [Killam and Johnson (2013)]*:*

- Killam and Johnson (2013) reported that they estimated the Chinook salmon populations to beas follows:
  Video / DIDSON Stations at instream weirs:
  - Clear Creek (operated from August 15-December 15, 2012): 8,857 fall-run Chinooksalmon with 90% confidence limits of 7,438 and 11,570.
  - Battle Creek (dates operated were not described): 116,847 fall-run Chinook salmon with90% confidence limits of 108,848 and 125,907.
  - Cow Creek (operated from September 15-November 20, 2012): 1,488 fall-run Chinooksalmon with 90% confidence limits of 1,195 and 1,818.
  - Cottonwood Creek (operated from September 15-November 29, 2012): 2,556 fall-runChinook salmon with 90% confidence limits of 2,333 and 2,812.

  Video / DIDSON Stations at a fish ladder plus counts at Ward Dam:
  - Mill Creek (Video operated February 20 –July 02, 2012 and DIDSON operated from March 28-June 03, 2012): 768 spring-run Chinook salmon with 90% confidence limits of720 and 814.
- Killam and Johnson (2013) reported that there was "little difficulty" in identifying large adult salmon. However, reviewers of the footage were often unable to identify smaller fish (within therange of 45 to 60 cm TL). Errors generated by misidentification were minimized by primarily counting fish with the video camera and using DIDSON during conditions of low visibility (e.g.high turbidity).
- Difficulty in distinguishing the following species from DIDSON footage was reported: small Chinook salmon, steelhead, Sacramento pikeminnow (Ptychocheilus grandis), hardhead (Mylopharodon conocephalus), Sacramento sucker, beaver (*Catostomus occidentalis*), and riverotter (*Lutra canadensis*).

B. ROVING STATIONS

Lower Feather River [Seesholtz and Manuel (2013)]*:*

- Seesholtz and Manuel (2013) reported that they observed 137 adult green sturgeon in the lower Feather River between April 11, 2011 and September 08, 2014, and estimated the population to be within the range of 21-28. Although most sturgeon were observed at the Thermalito Afterbay Outlet pool, they were documented to be present in both the low flow and high flow channels from the Bear River confluence (River Mile 13) upstream to Fish Barrier Dam (River Mile 67).
- Seesholtz and Manuel (2013) reported that the DIDSON unit was "instrumental to success of the spawning survey for egg mat placement" which allowed the DWR for the first time to document green sturgeon spawning in the lower Feather River.
- Limitations of DIDSON included difficulty in detecting sturgeon in locations with heavy bubble curtain (e.g., Thermalito Afterbay and Sunset Pumps). There were initial issues with connectivity between Trimble GPS and DIDSON but these were overcome when researchers gained more experience and changed the software settings. Additionally, researchers found that the connectivity issues were reduced by powering up the Trimble and the laptop *prior* to powering the DIDSON.

San Joaquin River [Department (unpublished data)]:

- No written operations reports have been received. Department staff are currently using DIDSON to assess salmonid movements around and into fyke nets in fish monitoring stations and to locate sturgeon holding areas. To date, salmonids appear to not be avoiding the fyke nets and no sturgeon holding areas have been located. (Steve Tsao, February 2, 2015).

C. LABORATORY

UC Davis (UC Davis Timothy Mussen, January 27, 2012):

- UC Davis researcher reported that although the DIDSON successfully documented juvenile Chinook salmon in the laboratory flume when there was no current, it became ineffective by the presence of a bubble curtain generated by the current. Researchers returned the DIDSON to the Department as they determined they could not use it for their specific study questions which required current.

DISCUSSION AND SUMMARY

With respect to the Coastal Monitoring Plan, results showed that DIDSON has the potential to meet Department and State needs as a tool for estimating adult salmonid escapement. Although Adams et al. (2011) emphasizes monitoring at fixed stations as key for California's Southern Area monitoring, DIDSON performance demonstrated that they also can play important roles in California's Northern Area in locations where: (1) traps / weirs may be impractical (e.g., where high flow events are common and pose safety or equipment risks); (2) unobtrusive monitoring technique is preferred; (3) the additional count information when paired with other monitoring methods can fill in data gaps (e.g., due to weirs blowing out, migration during nighttime hours and /or high turbidity conditions where video cameras are ineffective); and (4) calibrating spawner to redd ratios for population extrapolation to Regional scales. In California's Southern Area, where hydrology is flashy and salmonid populations are relatively small with patchy distributions, DIDSON performance demonstrated that they can function effectively as fixed stations. The main challenges in the streams monitored in the Southern Area included both security issues as well as the risk of the DIDSON locations' being de-watered, potentially damaging the equipment and requiring field staff to remain on site during the entire deployment. Another major challenge is when passage is impaired due to low flow conditions and milling rates are increased producing noise in escapement estimates.

As expected, species identification was a greater challenge in the Northern Area due to the presence of multiple salmonid species, but researchers adapted by employing supplemental monitoring techniques, knowledge of the stream and time of year, as well as morphological characteristics, behavior, and swimming patterns to differentiate species.

To potentially improve species identification, the Department recently purchased five adaptive resolution imaging sonar (ARIS) units, the latest technology for sonar imaging by Sound Metrics, Inc. The Department will be assessing improvements in image quality using this equipment this monitoring season (2014/2015). We intend to continue monitoring as we did with the DIDSON, including pairing ARIS recording with video cameras, weir counts, seining, and hook and line sampling. In addition, we plan to pair DIDSON and ARIS video together to determine differences in image quality. In the meantime, Sound Metrics, Inc., states that it is actively working on developing algorithms based on tail beat and swimming pattern for improved species identification capability. The Department is also interested in exploring use of other remote-sensing methodologies including manned and unmanned ("drone") aircraft to count salmonids and to assess habitat. Idaho Power Company's Environmental Department reported that, in pairing with the University of Alaska at Fairbanks researchers, they had success using Aeryon Scout with a Photo3STM high resolution camera to count redds allowing estimation of salmon escapement in the Snake River. Idaho Power Company also reported benefits of remote sensing in terms of safety in comparison to conducting surveys in helicopters or by foot in narrow canyons, remote locations, and during high flow conditions.

Other states of the Pacific Northwest are finding similar successes and challenges in using DIDSON for fisheries assessments. Similar to studies in California, researchers in the Pacific Northwest report using methods in addition to DIDSON to identify and apportion salmonid species, including use of optical cameras, gill nets, fish wheels, traps, hook and line sampling, etc. (Maxwell and Gove 2004, Kucera 2009, Carroll and McIntosh 2011, Saviour 2013). Fleischman and Burwen (2003) reported that they were able to use size frequency distribution generated from echo-length measurements to differentiate between Chinook and Sockeye salmon on the Kenai River, Alaska. Also, on the Kenia River, Mueller et al. (2010) reported a correlation between tail-beat frequency and species (Chinook and sockeye salmon) independent of size. These researchers concluded there to be potential in using tail-beat patterns for species identification as well for bioenergetics studies. Burwen et. al. (2010) and Mueller et. al (2010) speculated that in addition to frequency, tail beat amplitude may also be a parameter important in specifies identification, either by itself or in combination with total length measurements. Burwen et al. (2010) reported relatively accurate, precise measurement, and no range-dependency using a long range DIDSON fitted with an ultra-high resolution lens of tethered Chinook and sockeye salmon on the Kenai River up to at least 21m, potentially up to 30m.

Future research topics the Department plans to address using DIDSON / ARIS technology include the following: improving species identification techniques; determining minimum sample size and rate of video for review; estimating smolt production; data analysis, including fish counting techniques; and data storage and security issues. Additionally, the Department sees a high potential to use this technology to passively monitor salmonids in order to gain a better understanding of their behavior, habitat, and channel usage patterns, all of which can be challenging to do with existing methodologies. Research by DIDSON of movement has the potential to help elucidate environmental factors that influence milling behavior, habitat use, migration, avoidance, migration delays at barriers or obstructions (e.g., traps, diversions, bridges, lighted , riverside structures), as well as inter- and intra- specific interactions. We believe that this kind of information gained could potentially provide valuable information to help address the design of restoration activities to maximize the response of the effective population size. By increasing our understanding of movement and channel usage patterns, the effectiveness of monitoring techniques and selection of methodology employed could be improved (e.g., to improve trap design to reduce avoidance, to improve efficiency of trawling and seining techniques, etc.).

Next Steps:

The Department is working to develop a DIDSON salmonid monitoring deployment protocol (Appendix A), including examples of mounting and stream placement. The Department is also developing a data analysis, storage, and maintenance protocol to assist researchers in the future. Within the next few years, the Department recommends that DIDSON and ARIS research focus on development of a Quality Assurance and Quality Control protocol those cross-compares reviewers to produce more accurate escapement and length estimates. Operational reports are expected by Fisheries Branch from field staff after completion of the monitoring season (Appendix B). These reports will be compiled regularly into state-wide documents to report the latest biological and operational research using DIDSON and ARIS. To improve implementation of CMP, we recommend that workshops be held on a regular basis to update, train, and review existing protocols.

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APPENDIX A

CALIFORNIA DEPARTMENT OF FISH AND WILDLIFE'S COASTAL MONITORING PLAN: DUAL-FREQUENCY IDENTIFICATION SONAR (DIDSON) DEPLOYMENT AND DATA PROTOCOLS

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  d. Data acquisition and analyses
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IV. Review of where we are now and current status
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APPENDIX B

SUMMARY OF DUAL FREQUENCY IDENTIFICATION SONAR OPERATIONS

Suggested Annual Report Outline
DATE
Authors

ABSTRACT

INTRODUCTION

Background and History

Site Description

Why selected

Characteristics that make it appropriate for DIDSON deployment What's in this report? And why?

Who should read this report?

METHODS AND MATERIALS

Installation and/or re-installation of dual frequency identification sonar
Required and/or modification of equipment for dual frequency identification sonar operation
Field Site:

- DIDSON and/or ARIS, cable and associated electronics
- Number of laptop (tough book or other weather proof laptop) with a minimum processor speed of 2GHz, 1GB RAM
- Number and size of external hard drives
- Type of power supply with backup
- Supplemental Equipment used (e.g., Sand bags, fish screens, silt shield
- Miscellaneous hardware (cables, locks, etc.)
- Security Measures

Laboratory:

- Number of computers with large monitors (32"LG 32LK450 LCD TV monitors)
- Number of vehicles (part-time)
- Number of Fisheries Technicians for length of field season
- Secure office space

Software Operations

Issues, problems, procedures, etc.

Modifications and/or corrective actions

Imaging

Positioning, focus, background effects, etc.

RESULTS

Biological (escapement numbers)

Operational results (e.g., what worked / didn't work) Data recording (quality, missing, etc.)

Data Storage (QA/AC, memory, transfer, etc.)

Data Analyses (statistical approach, statistical analysis, etc.) Efforts to date that address biological questions

DISCUSSION AND SUMMARY

Effectiveness and efficiency

Data Management and Analysis Issues Sonar Comparisons (e.g., DIDSON to ARIS)

Next steps in this effort

Questions being answered

Future questions that needs to be addressed using this technology Lessons learned

How sonar camera efforts in California compare to those elsewhere

ACKNOWLEDGEMENTS REFERENCES APPENDICES

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Data Summaries

Data Analyses Methods Summaries (equations, etc.) Photos