NOAA Technical Memorandum NMFS

APRIL 2010

OPERATION OF DUAL-FREQUENCY IDENTIFICATION SONAR (DIDSON) TO MONITOR ADULT STEELHEAD *(Oncorhynchus mykiss)* IN THE CENTRAL CALIFORNIA COAST

Kerrie Pipal
Mark Jessop
Galen Holt
Peter Adams

NOAA-TM-NMFS-SWFSC-454

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Southwest Fisheries Science Center

The National Oceanic and Atmospheric Administration (NOAA), organized in 1970, has evolved into an agency that establishes national policies and manages and conserves our oceanic, coastal, and atmospheric resources. An organizational element within NOAA, the Office of Fisheries is responsible for fisheries policy and the direction of the National Marine Fisheries Service (NMFS).

In addition to its formal publications, the NMFS uses the NOAA Technical Memorandum series to issue informal scientific and technical publications when complete formal review and editorial processing are not appropriate or feasible. Documents within this series, however, reflect sound professional work and maybe referenced in the formal scientific and technical literature.

NOAA Technical Memorandum NMFS

APRIL 2010

OPERATION OF DUAL-FREQUENCY IDENTIFICATION SONAR (DIDSON) TO MONITOR ADULT STEELHEAD *(Oncorhynchus mykiss)* IN THE CENTRAL CALIFORNIA COAST

Kerrie Pipal, Mark Jessop,
Galen Holt, Peter Adams

Southwest Fisheries Science Center
Fisheries Ecology Division
110 Shaffer Road
Santa Cruz, California, USA 95060

NOAA-TM-NMFS-SWFSC-454

U.S. DEPARTMENT OF COMMERCE
Gary F. Locke, Secretary
National Oceanic and Atmospheric Administration
Jane Lubchenco, Undersecretary for Oceans and Atmosphere
National Marine Fisheries Service
Eric C. Schwaab, Assistant Administrator for Fisheries

Contents

Page

List of Tables iv

List of Figures v

Summary 1

1 Introduction 2

1.1 Background 2

1.2 Dual-frequency identification sonar (DIDSON) 4

2 Equipment and logistical considerations 7

2.1 Recommended components 7

2.1.1 DIDSON unit and mount 7

2.1.2 Pan and tilt rotator 11

2.1.3 Controller computer 12

2.1.4 On-site data storage 12

2.1.5 Power supply 13

2.2 Costs 14

2.3 Site selection 15

2.3.1 Habitat type 16

2.3.2 Channel profile 16

2.3.3 Accessibility 18

2.4 Security 19

2.5 Staffing requirements 20

3 Study sites 21

3.1 San Lorenzo River 21

3.2 Big Creek 24

3.3 Scott Creek 26

4 Methods 28

4.1 DIDSON Deployment 29

4.2 Data recording 31

4.3 Data processing 32

4.4 Data analysis 34

4.4.1 Species and life-history form identification ... 34
4.4.2 Best guess approach ... 36
4.4.3 Decision Support Tool ... 37
5 Results ... 47
6 Discussion ... 47
6.1 Limitations ... 48
6.2 Specific implementation recommendations ... 51
6.3 Additional applications ... 51
6.4 Conclusions ... 53
Acknowledgements ... 54
References ... 55
Appendix A ... I

`List of Tables

UUTable 1. Power specifications for required components. 14

Table 2. Costs associated with starting a DIDSON monitoring project 15

Table 3. Point value system for the Decision Support Tool (DST) 39

List of Figures

Figure 1. Map and watershed diagrams showing DIDSON study locations in central California in 2006 (San Lorenzo River, Santa Cruz County), 2007 (Big Creek, Monterey County) and 2008-2010 (Scott Creek, Santa Cruz County) 5

Figure 2. Tripod-style DIDSON mount showing adjustable 'arm,' sled-like 'feet' and sturdy base 9

Figure 3. DIDSON mount components 10

Figure 4. Pan and tilt rotator and aluminum housing around the DIDSON 11

Figure 5. Weatherproof storage box for electronic components 13

Figure 6. Diagram illustrating DIDSON lens orientation and aiming, as related to object ensonification on a river bottom 18

Figure 7. Diagram illustrating a side view of the DIDSON deployment at the San Lorenzo River 23

Figure 8. DIDSON study site on the San Lorenzo River (Santa Cruz County, CA). 24

Figure 9. DIDSON study site on Big Creek (Monterey County, CA). 26

Figure 10. DIDSON study site on Scott Creek (Santa Cruz County, CA)................. 28

Figure 11. DIDSON hoist system supported by cabling across the stream at the Big Creek (Monterey County, CA) site... 31

Figure 12. Example plot used in the Decision Support Tool to identify the time of year (*t*) when daily net count peaks and begins to decline. 39

Figure 13. DIDSON Decision Support Tool (DST) framework. 44

Summary

Monitoring trends in abundance of Endangered Species Act (ESA) listed adult steelhead (*Oncorhynchus mykiss*) is essential to assessing their viability. However, in central and southern California (the southern extent of their range), monitoring is difficult due to the low abundance and patchy distribution of adults. The only successful method has been counting stations at barriers (e.g., dams, weirs, etc.) that involve a certain amount of ESA "take" in handling listed fish. As a new alternative that avoids "take," we have successfully used dual-frequency identification sonar (DIDSON) for monitoring adult steelhead abundance (Pipal et al. In press). The operational aspects of using DIDSON to monitor small fish populations in a more urbanized setting are different than for its more common use to enumerate large runs of salmon in more remote regions. We have deployed DIDSON in three different locations in central California to monitor steelhead and have gained significant insight into the necessary operational considerations. These are described here in detail and include the following:

- site selection
- DIDSON unit configuration
- deployment and system security
- data management (recording, processing and storage)
- species identification
- and data analyses, which include a Decision Support Tool used to standardize fish counts.

We also identify areas needing further research, particularly species identification, and offer suggestions for possible solutions.

1 Introduction

1.1 Background

Monitoring adult steelhead abundance is critical to effectively managing California's steelhead populations, of which all but those in the Klamath Mountains Province are listed as threatened or endangered under the federal Endangered Species Act (ESA).[1] Obtaining escapement estimates is essential for assessing current population status and trends and the effectiveness of recovery efforts and for the eventual evaluation of population delisting under the ESA. However, in many central and southern California streams and rivers where naturally-occurring populations of steelhead exist, little or no adult steelhead data are available. This is due to a variety of reasons, but in general is because no feasible method has existed to enable accurate adult steelhead counts. The unique physical properties (e.g., hydrology, geology, and turbidity levels) of streams and rivers in this region, combined with steelhead life history attributes, make it more difficult to enumerate steelhead population size than in more northern regions. Turbid and flashy stream conditions typical during winter spawning periods combined with the rare and widely-spaced nature of steelhead in these regions make it difficult to obtain population estimates. Counting is made even more challenging in systems with presumed low fish abundance, as relatively few fish are present and/or migrating during the spawning season, making it difficult to determine when they are in the system. As a consequence, current methods used in other areas either are not effective in these southern systems or have greater concerns if they require handling or might alter

---

[1] Three Distinct Population Segments (DPSs) for steelhead exist along the central and southern California coast, including the Central California Coast, South Central California Coast, and Southern California DPSs. These extend from the Russian River in Mendocino and Sonoma counties to the United States-

behavior in these smaller populations. For example, redd count survey methods for steelhead have recently been used in Northern California (Gallagher and Gallagher 2005) in conjunction with redd surveys for salmon. However, this method is not likely to be effective in southern California streams since small populations often migrate upstream during high flow events when high turbidity obscures redd visibility and creates difficulty in determining the location of spawning grounds to conduct surveys. A weir or other fish trap (associated with a fish ladder or dam structure) can be used to enumerate upstream-migrating steelhead. However, these methods require handling of fish, increasing the chance for mortality and requiring ESA permitting. Weirs are also either subject to over-topping or need to be removed during high flow events, which is when steelhead are most active in their upstream migration. Weirs and other trapping structures also present passage barriers which may deter some fish from traveling farther upstream instead of being trapped and/or counted.

Therefore, new methods are needed to meet monitoring needs in central and southern California that are effective under the unique conditions in the region and are sensitive to the more imperiled status of steelhead in the area. In this report, we describe one potential method that meets these criteria, DIDSON. The purpose of this document is to discuss operational considerations; we evaluate performance and results in another paper (Pipal et al. In Press) and plan on a future manuscript detailing results from a 3-year comparison study between DIDSON and a counting weir on Scott Creek (Santa Cruz County) upon completion of the final year of data collection (2010).

Mexico border. The Central California Coast and South Central California Coast DPSs are listed as threatened and the Southern California DPS is listed as endangered.

1.2 Dual-frequency identification sonar (DIDSON)

For this study, we used dual-frequency identification sonar (DIDSON) to monitor adult steelhead in central and southern California streams and rivers where abundance is low and environmental conditions can be highly variable. To date, the use of DIDSON to count salmonids has only been applied in high-abundance, high-flow settings. As part of investigating the use of DIDSON to count low abundance salmonids, we gained a great deal of experience implementing the device in conditions with lower fish numbers and flashier flows than previous studies. Since 2006, we have deployed a DIDSON in three different systems on California's central coast: the San Lorenzo River (2006) and Scott Creek (2008-2010) in Santa Cruz County and Big Creek (2007) in Monterey County (Fig. 1). This document describes the approaches used for operating DIDSON in these different circumstances and presents a Decision Support Tool for the analysis of acquired data.

The standard version DIDSON uses high (1.8 MHz) or low (1.1 MHz) frequency sound waves to produce high resolution underwater images. Its high frequency sound waves, acoustic lens configuration, and high resolution transducer array make this type of sonar unique. The high frequency beam configuration consists of 96 beams, each beam spanning 0.3 degrees in the horizontal plane and 12 degrees in elevation, yielding a 28.8-degree horizontal span. The low frequency beam consists of 48 0.6- to 12-degree beams. Maximum range for the high frequency setting is 12 m, while the low frequency range is 40 m, although resolution is much lower with the low frequency setting. Developed by the University of Washington's Applied Physics Laboratory (Belcher et al. 2001; Belcher

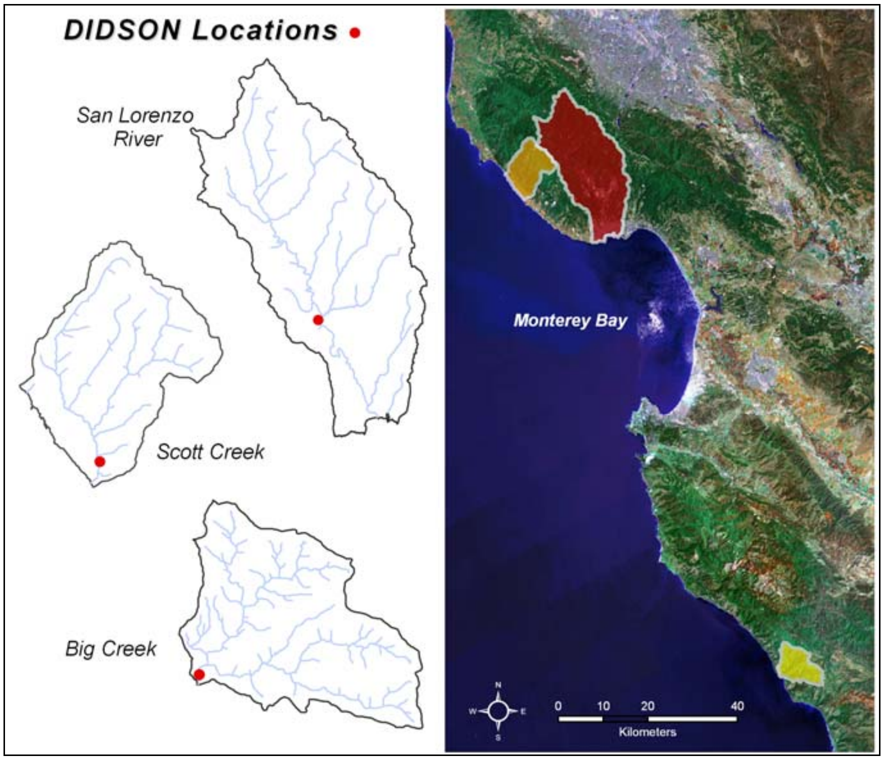


Figure 1. Map and watershed diagrams showing DIDSON study locations in central California in 2006 (San Lorenzo River, Santa Cruz County), 2007 (Big Creek, Monterey County) and 2008-2010 (Scott Creek, Santa Cruz County). Red dots in the watershed diagrams indicate specific DIDSON locations.

et al. 2002), this technology was originally designed for use by the United States Navy to aid in underwater mine identification and diver detection. Its application is widening to use in fisheries biology to estimate adult salmon escapement (Maxwell and Gove 2004; Galbreath and Barber 2005; Kucera and Faurot 2005; Cronkite et al. 2006; Holmes et al. 2006; Kucera and Faurot 2006), monitor fish behavior near passage barriers (Moursund et al. 2003; Weiland and Carlson 2003; Baumgartner et al. 2006), enumerate salmon redds (Tiffan et al. 2004), and observe fish behavior near baited fishing gears in the marine environment (Rose et al. 2005). While this technology does not allow for determination of fish sex or age, it does provide information on fish size and relative shape. Insight into natural fish behavior during spawning migration can also be achieved (Tiffan and Rondorf 2005).

DIDSON appears to be superior to other types of sonar (e.g., single-, dual- and split-beam) that have traditionally been used to estimate salmon escapement in river systems with high abundance and higher flow such as those in Alaska and British Columbia (Maxwell 2007). DIDSON was evaluated by the Alaska Department of Fish and Game (ADFG) for monitoring salmon run size on various rivers, including the Copper, Kenai, and Wood Rivers (Maxwell and Gove 2004). Comparisons were made between the DIDSON and two different sonar systems (single- and split-beam) along with other counting methods, including tower and underwater video counts. In these applications, the DIDSON was used as a side-looking sonar from a fixed location near the streambank. Results showed significant improvement with use of the DIDSON over the other sonar systems. DIDSON was easier to aim and required less experience to operate than single- and split-beam sonar. The wide viewing angle of the DIDSON and the ability to 'push' or 'bury' the large vertical beam into the substrate was a significant improvement over the other sonar types and proved especially important for monitoring bank-oriented salmonids. DIDSON offered improved image resolution, providing clearer fish images and enabling determination of directionality of fish passage. Analyzing data using the DIDSON software was also an improvement from analysis of more traditional sonar data. This software featured options such as background subtraction and fish detection algorithms, which remove the static bottom image and flag frames suspected to contain fish for easier detection during the reviewing process.

2 Equipment and logistical considerations

Operating DIDSON for the purpose of enumerating adult salmonids from a fixed location within a river system requires careful deliberation when contemplating necessary resources required for achieving study goals. Successful performance includes selecting relevant equipment needed for effective operation and choosing a study site that maximizes DIDSON operational efficiency and meets project objectives. Factors such as power supply, overall feasibility of project costs, habitat type, channel profile, accessibility, site security, and staffing requirements should also be included in the decision-making process when considering a study location.

2.1 Recommended components

The basic equipment required for successful operation of the DIDSON for monitoring adult escapement is a DIDSON unit, sonar mount, pan and tilt rotator, laptop computer, data storage device, associated cables, and a weather-proof storage box.

2.1.1 DIDSON unit and mount

We purchased the standard DIDSON (DIDSON-S) model (created by Sound Metrics, Corp. www.soundmetrics.com and sold/distributed by Ocean Marine Industries[2,3]), which can image out to 35 m at the low frequency setting. Sound Metrics also offers a long range unit, but it has lower resolution. Each unit comes with a lens assembly, software, sonar cable, video and Ethernet cables, a topside box and a 24-V power supply. Our unit included a 100 ft. sonar cable, although longer cables were available but

---

[2] Ocean Marine Industries, Inc. 2810 Hudson Str., Chesapeake, VA (www.oceanmarineinc.com)

required slightly different set-up procedures. We designed a tripod-style mount (Fig. 2), modeled after various mount types created by ADFG (examples originally provided by D. Burwen, ADFG). Our mount featured sled-like 'feet' that enabled the entire unit to be dragged over the bottom substrate as flows and water levels fluctuated. The mount ‘arm’ could be moved up or down to adjust the unit to varying depths. The heavy (over 50 lb) circular base (Fig. 3-A, B) provided stability during high flow events, anchoring the entire unit to the streambed. The mount could also be secured to the substrate by pounding rebar stakes through a hole in each foot (Fig. 3-C). Each foot had a loop welded to its top edge which was used to run a security cable through each part of the mount. An aluminum housing (Fig. 4) was fitted around the DIDSON unit to protect it from large debris traveling downstream during high flow events. Detailed computer-aided design (CAD) mount drawings showing dimensions and materials used for this project are available from the author upon request.

---

[3] References to specific brand names or products does not constitute endorsement by NOAA or the Department of Commerce (DOC).

Figure 2. Tripod-style DIDSON mount showing adjustable ‘arm,’ sled-like ‘feet’ and sturdy base. This design was modeled after a mount used by the Alaska Department of Fish and Game.

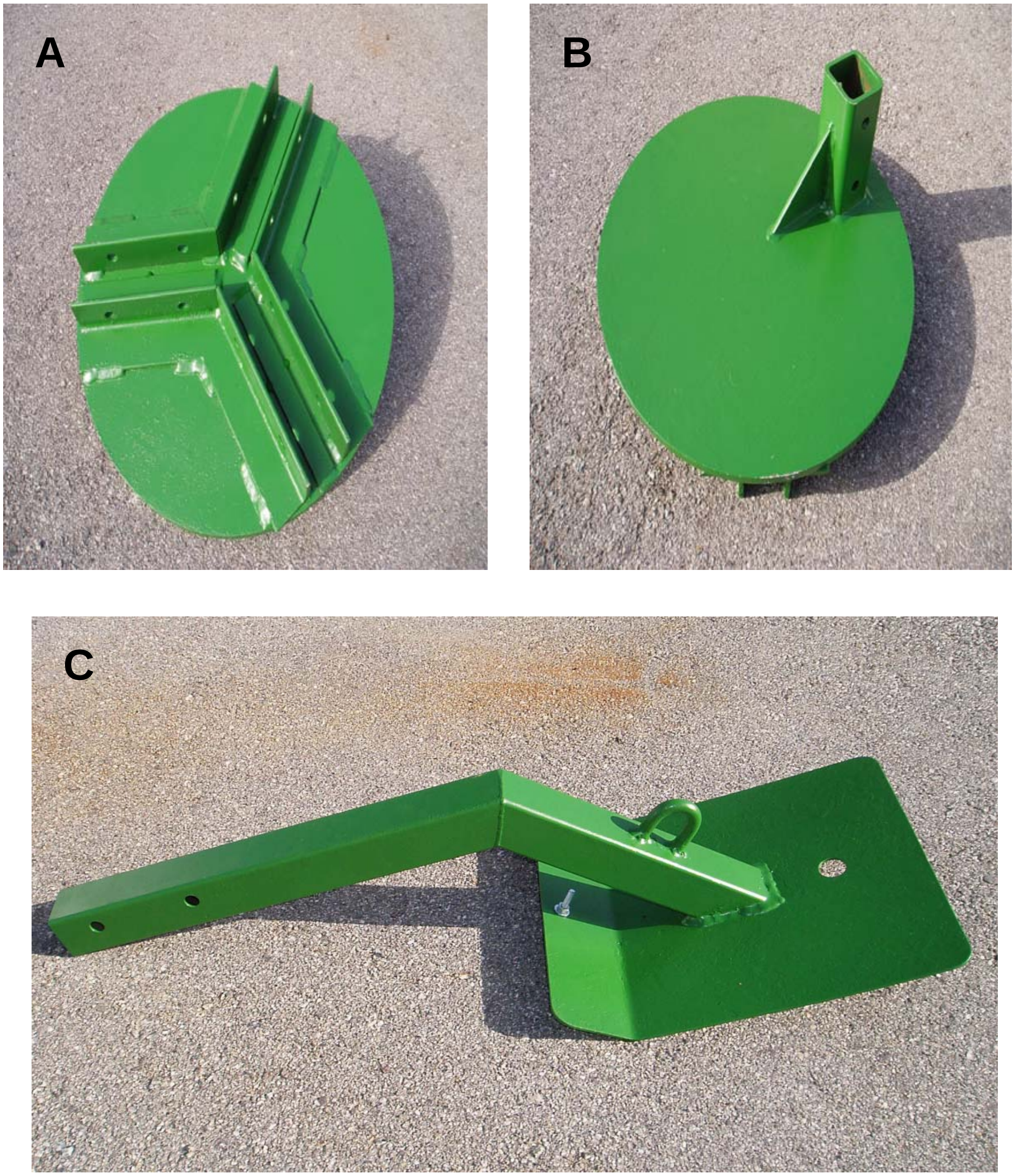


Figure 3. DIDSON mount components. A: Underside of base with support structures for tripod-style extensions. B: Top-side of base with insert sleeve for sonar support post. C: Mount foot showing anchor hole and loop for security cable attachment.

2.1.2 Pan and tilt rotator

We utilized a dual axis, heavy-duty pan and tilt rotator (Fig. 4) to enable DIDSON re-positioning and aiming, providing 40 N-m (30 lb-ft) of output torque on each axis (model PT-25-FB from Remote Ocean Systems, www.rosys.com)[4] . The rotator was operated remotely using specialized communication software (RS-485 communication protocol) on the controller computer. This feature alleviated the need for study personnel to enter the water to adjust sonar angle.

Figure 4. Pan and tilt rotator and aluminum housing around the DIDSON. The aluminum housing was designed to protect the DIDSON from debris floating downstream during high flow events. The dual axis pan and tilt rotator enabled remote sonar positioning.

2.1.3 Controller computer

We used a Panasonic Toughbook 29 (Fig. 5) as an interface for the DIDSON software, pan and tilt rotator operations, and external hard drive functions. This laptop featured durable qualities which made it appropriate for outdoor applications.

2.1.4 On-site data storage

Recording DIDSON images generates large data files, approximately 1 gigabyte (GB) of data per hour of recording. To handle the large number of files generated during our studies, we recorded data on-site using a 300 GB external hard drive which was exchanged weekly. External hard drives with greater storage capacity are now available and if used could decrease the frequency of site visits if project staff were confident in the reliability of their unit's operation over longer periods unchecked. Internet access to the DIDSON imaging and operations is possible, although we have not attempted this. This would enable the user to remotely check on system status (e.g., system error messages, image quality, DIDSON positioning, power supply, etc.), alerting project staff of a potential operational problem requiring immediate attention.

Electronic components were stored on-site in a weatherproof, metal box (Fig. 5) with a single hole drilled in the back to accommodate the DIDSON and pan and tilt rotator cables and a power cord. The box featured heavy gauge steel construction and a recessed deadbolt-style locking mechanism. The handles were also recessed, which allowed for a security cable to run through one or both handles and around a tree or other support.

---

[4] References to specific brand names or products does not constitute endorsement by NOAA or the Department of Commerce (DOC).

Figure 5. Weatherproof storage box for electronic components (i.e., laptop, external hard drive, back-up battery system, and DIDSON topside box). Box dimensions measured 56 cm high (closed position) x 48 cm wide x 91 cm long; 0.20 m^3 storage capacity; weight 44 kg.

2.1.5 Power supply

We used 110-V, AC power at all field sites, since operating all components for this application continuously for a 4-5 month period required a steady and reliable power supply. We considered other power supply options (e.g., solar, deep cycle marine batteries, generators, wind/hydro power) besides AC, 110-V power, but these alone or in varying combinations could not meet the power requirements for our equipment (Table 1) within the constraints of our project (i.e., cost, size, or required maintenance). (Note: In other remote applications of DIDSON such as those in Alaska and British Columbia, alternate sources of power were used.) All of the installations at our sites required extending power lines from existing power sources to the DIDSON site.

Table 1. Power specifications for required components. Values were obtained with all components operating while measuring power usage with a Watt-meter.

Device	AC/DC	Volts	Amps	Watts	Hrs/day	Watt-Hrs/day	Amp-Hr/day
DIDSON	DC	24	1.3	30	24	720	30
Rotator	DC	24	0.4	10	0.1	1	0
Laptop	AC	12	3.3	40	24	960	80
Ext. hard drive	AC	12	0.8	10	24	240	20
Totals			5.8	90		1921	130

We encountered several power outages during the study period at Big Creek. Although the outages were brief, they caused the DIDSON to lose its connection with the topside box, and the laptop batteries eventually failed as well. To alleviate system downtime, we installed a back-up battery source, which was triggered in the event of a power outage and kept the DIDSON and laptop running, at least temporarily (10-20 minutes). This mainly kept the unit in operation during brief power fluctuations but not for any periods of sustained power loss.

2.2 Costs

Current costs for starting a DIDSON monitoring program are provided in Table 2. These costs are approximate and are based on 2006 costs incurred during our initial project start-up. Once initial equipment is purchased, the main costs would be data storage upgrades and personnel salaries. Otherwise, ongoing maintenance costs are minimal.

Table 2. Costs associated with starting a DIDSON monitoring project. Prices are approximate and are based on 2006 costs incurred during our initial project start-up.

Item	Cost per unit ($)
DIDSON sonar unit, including cables	75,000
Mount	3,800
Pan and tilt rotator	13,000
Laptop computer	3,500
External data storage (on-site)	400
External data storage (storage/archival)	2,500
Power installation [a]	5,000
On-site storage box	500
Misc. hardware (bolts, cables, locks, etc.)	200
Fencing materials	100
Total	104,000

[a] Power installation included all equipment and labor (licensed electrician paid at prevailing wage rates). Cost for this feature could vary drastically based on installment complexity and local rates.

2.3 Site selection

Selecting an optimal site is critical to collecting informative and useful DIDSON data that satisfy study goals. We considered the following factors when determining where to operate the DIDSON at each study site: habitat features (e.g., habitat type, channel profile, and substrate), distance from the ocean, power availability, system security, and accessibility. To count migrating salmonids in a riverine environment to determine escapement using DIDSON, it is best to select a site that is relatively close to the ocean and downstream from any tributaries where spawning occurs to monitor the entire population.

2.3.1 Habitat type

The type of habitat selected in which to deploy the DIDSON is extremely important and affects the ability of the DIDSON to detect migrating fish. A run or glide where flow is laminar and the substrate is either mud, sand, gravel, or small cobble is the most suitable habitat type in which to use DIDSON. These substrate types alleviate the chance that a fish could hide behind a larger rock and be missed by the sonar. Pools should be avoided, as they are conducive to milling behavior that complicates counting the total number of fish migrating past the site. Excessive turbulence (e.g., riffle-type habitat) or bubble curtains should also be avoided, as entrained bubbles can affect image clarity. Boulders or other obstacles present within the ensonification zone (i.e., portion of the stream channel ensonified by the DIDSON beams), create 'acoustic shadows' where fish may pass undetected. Such objects should be moved out of the viewing range of the sonar or, if not possible, another site should be selected. The unit should be placed in a location where fish are actively migrating past the study site. Selecting a site where the user is familiar with flow events and how these events affect water depth and velocity at the site is helpful. Historical flow data as they relate to stream depth at the study site are also useful, if available.

2.3.2 Channel profile

The channel profile should be analyzed before sonar deployment to maximize beamspread coverage. At each of our sites, we used reflections from the river bottom (as appeared on the DIDSON imaging software) and target detection to determine if a site was suitable for deployment. A cross-section of the channel should be completely ensonified to ensure maximum fish detection.

In addition to selecting a site with a suitable channel profile, careful aiming of the transducer is required to ensure the proper beam coverage of the channel. Correct orientation means the beams hit the river bottom at a shallow angle and fill the display screen on the controller computer, ensonifying the target (i.e., fish) of interest (Fig. 5-C). If the sonar angle is too steep (Fig. 5-A), the ensonification zone may be limited to only a small portion of the channel, whereas if it is angled too high it may lose its ability to detect fish migrating close to the stream bottom (Fig. 5-B). If the channel profile forces the beam to be either too steep or too shallow, another site should be selected.

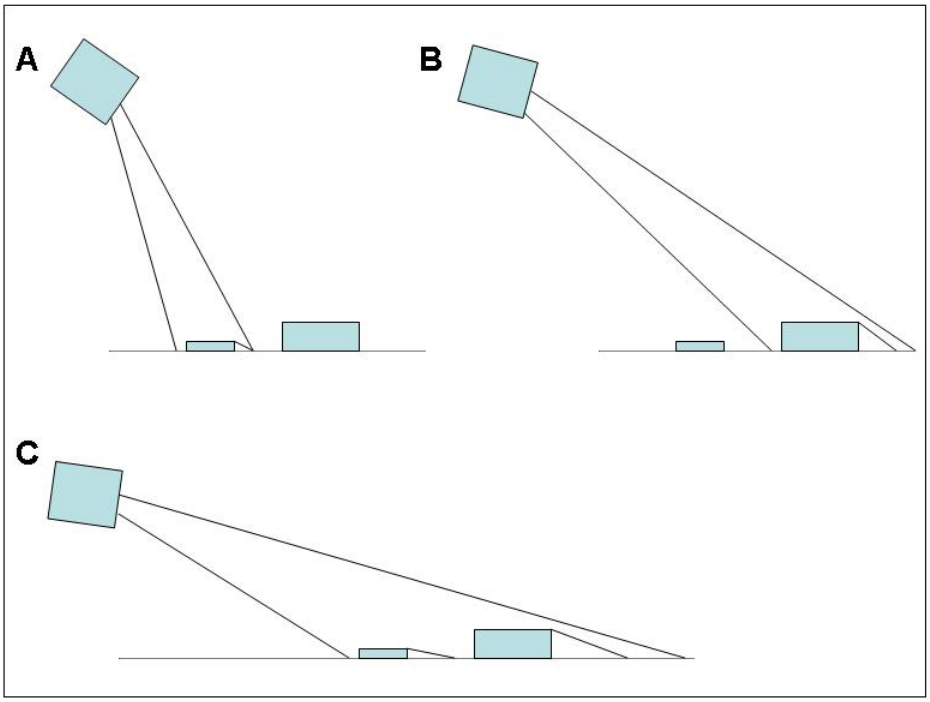


Figure 6. Diagram illustrating DIDSON lens orientation and aiming, as related to object ensonification on a river bottom. All diagrams are side views. A: Sonar angle is too steep and only captures the object closest to the sonar. B: Sonar held too high and only captures a single object farther out from the sonar. C: Correct sonar orientation striking the river bottom at a shallow angle and ensonifying both objects.

2.3.3 Accessibility

It is important that the DIDSON site be close enough to the staffing location to enable frequent site visits if needed. Being able to respond to rapidly changing flow conditions (i.e., moving the sonar up or down the streambank or completely removing the unit if flooding is imminent and potential loss of equipment is expected) is essential to ensuring proper channel coverage and equipment safety as water levels fluctuate. During rain events, we were sometimes on-site on a daily basis to re-aim or re-position the camera, as needed. Our sites were within a two hour drive from our laboratory.

The availability of AC power was also an important factor in our site selection process. Although we did have some instances of power outages during storm events, in general AC power provided the most stable and maintenance-free power supply to the DIDSON equipment. Other power sources (e.g., batteries, generators, etc.) may require more frequent site visits to maintain consistent power supply, which should be considered when selecting a site, especially if it is at a greater distance from the workplace.

2.4 Security

System security was also an important factor during the site selection process due to the high cost of the study equipment. In general, many potential locations for using DIDSON units for this application would be in heavily populated areas of central and southern California. Security will be a major consideration for any of these future applications and should be carefully considered. Equipment theft and/or vandalism would lead to project downtime and substantial costs. To enhance equipment security at our study sites, we extended cables through all components and pad-locked ends to nearby trees or other permanent structures. We also used security fasteners whenever possible on several components. For future study sites with long-term monitoring goals, a more permanent structure should be constructed to ensure equipment safety. Even with these measures, however, the system is vulnerable to vandalism, especially the relatively exposed power cord and the cables associated with the DIDSON and the pan and tilt rotator.

Security concerns varied among our study sites. Our initial trial on the San Lorenzo River was located within a California State Park, where public access was unrestricted. Due to security concerns, this site was staffed on a 24-hour per day basis. This proved to be a costly practice and was one reason why our trial at this location was limited in duration. Our site on Big Creek was located on a private natural reserve with a locked access gate. It was also located near the reserve manager's residence, making this site generally more secure. At Scott Creek, the DIDSON was located on private property owned by Swanton Pacific Ranch (California Polytechnic State University, San Luis Obispo), however some degree of public access was allowed, primarily during the fishing season.

2.5 Staffing requirements

Staffing requirements vary according to study phase, study site distance from staff base, and changing flow resulting from storms. Deployment and take-down events generally require 2-3 people to assist with transporting equipment to the study site, equipment set-up/take-down, and target detection. Once the unit is deployed and operating, 1-2 people should be available to visit the site as often as every day to monitor sonar location within the stream channel, maintain a proper image as flows increase or decrease, clear debris from deflection fencing, move fencing as required by high flow events, and exchange external hard drives. The closer the study site is to the staff base, the easier it is to monitor the sonar's status. During periods of higher flow, it is important to have at least two study personnel on-call that can respond to the site in case equipment removal is needed (e.g., flooding is predicted and equipment loss is possible). However, if flows are stable and all other aspects (e.g., power, security, sonar position) remain constant, checking on the unit can occur as infrequently as once per week to exchange hard drives, which can be accomplished by one person.

3 Study sites

The original goal of our study was to operate the DIDSON for three years at a location where an alternate method of obtaining counts (e.g., from a fish trap or weir) was available for comparison. Over a two-year period from 2006-2007, we used DIDSON at two sites, the San Lorenzo River and Big Creek. However, for different reasons (which we found out as the study progressed at each location) these sites did not fully meet our expectations. Security concerns at the San Lorenzo and excessive fish milling at Big Creek were our main issues at these sites. We started using DIDSON at Scott Creek in 2008 and have subsequently used this location in 2009 and 2010 with successful results.

3.1 San Lorenzo River

The 2006 DIDSON site was located on the San Lorenzo River (Santa Cruz County, California) near the town of Felton and within the Henry Cowell Redwoods State Park boundaries. The San Lorenzo River watershed drains 360-km^2, with its headwaters originating in the Santa Cruz Mountains and its endpoint the Pacific Ocean within the Monterey Bay. The study site was approximately 12 km upstream from the river mouth and 185 m downstream from the Felton Diversion Dam and associated fish trap. The inflatable dam was constructed by the Santa Cruz City Water Department in 1976 and is used to augment local water supplies in dry years. The fish trap is operated by volunteers, in cooperation with the Monterey Bay Salmon and Trout Project and the California Department of Fish and Game. This DIDSON site was selected based on its proximity to the fish trap and our ability to compare counts between the two methods.

The DIDSON was deployed on the San Lorenzo River from March 14-17 and 21-24, 2006 for a total of 141 hours. The channel was 20 m wide with a depth ranging from about 0.5 m at the south bank (DIDSON side) of the channel to 1.5 m at the opposite side (Figs. 7, 8). DIDSON placement from the opposite bridge support varied from a distance of 15-18 m depending on river height. Flows during the study period were moderate, averaging 616 cfs with a range from 426 to 1120 cfs (values obtained from USGS gaging station No. 11160500 “San Lorenzo River at Big Trees, CA”). This first effort at DIDSON deployment for this application was successful in fish counting operations (See Pipal et al. In press) but was ultimately unsuitable for long-term deployment due to security concerns. Other locations in the San Lorenzo River such as those on private or state-owned property that may have had fewer security concerns were not investigated for our project; however, it is likely that another site would be suitable. We wanted to be close enough to the fish trap at the Felton Diversion Dam for comparison purposes and therefore did not consider alternate locations.

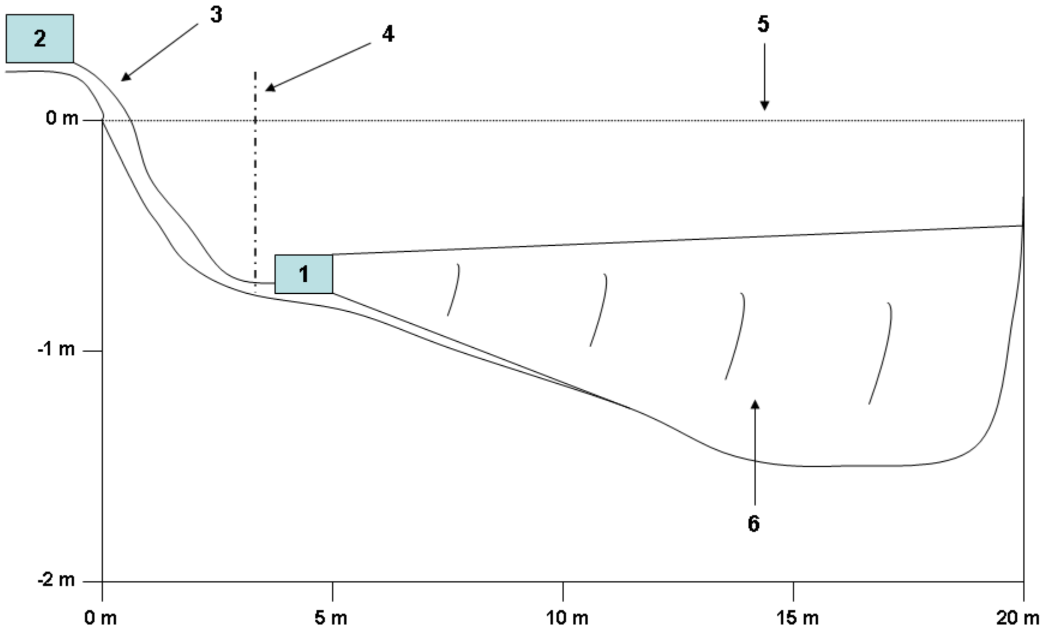


Figure 7. Diagram illustrating a side view of the DIDSON deployment at the San Lorenzo River. Numbers refer to the following: 1) DIDSON unit with pan and tilt rotator mechanism, 2) controller computer and external hard drives housed in a weatherproof storage box, 3) cables connecting DIDSON to controller unit, 4) fencing material, 5) water level, and 6) volume of water ensonified by DIDSON beam. Note that the vertical and horizontal scales differ.

Figure 8. DIDSON study site on the San Lorenzo River (Santa Cruz County, CA). Note: this photograph was taken before deflector fencing was installed downstream of the sonar unit.

3.2 Big Creek

After the San Lorenzo River deployment revealed security as a major issue, we moved the study during the 2007 steelhead run season to Big Creek (Monterey County, California) where higher security in the Landels-Hill Big Creek Reserve managed by the University of California at Santa Cruz allowed us to operate the DIDSON for the whole season. Big Creek is a small coastal drainage (58-km^2) that supports anadromous and resident *O. mykiss* populations and is one of many small streams draining the Santa Lucia Mountains along the Big Sur coastline. Big Creek empties directly into the Pacific Ocean with no estuary or lagoon at the mouth. Access to anadromous fish is possible year-round but can sometimes be dependent on tidal fluctuations or the size and magnitude of waves breaking at the beach. The DIDSON site was located 300 m upstream from the ocean and was downstream from any tributaries. Extensive *O. mykiss* population dynamics studies started in 2004 were concurrently underway by associate NMFS researchers. These studies included biannual mark and recapture surveys and PIT tagging of juvenile steelhead, which allowed insight into resident trout maximum size and population estimates. Both were useful in determining minimum anadromous *O. mykiss* size and a general comparison between derived mark-recapture-based population estimates for juveniles/residents and the suspected number of returning adult steelhead contributing to the population. However, no alternate method of enumerating adult steelhead escapement was available at this study location.

At the Big Creek site, the DIDSON was deployed on the south bank from January 3 – May 8, 2007, yielding approximately 2636 hours of footage. Stream width was 10 m with a maximum depth of 2.5 m near the opposite bank (Fig. 9). No stream gage was present on this system during the study period, so flow data were not available. Overall, the deployment effort at Big Creek was unsuccessful at achieving study goals of estimating steelhead escapement due to excessive milling at this location, which led to unreliable fish counts. However, we did attempt to estimate escapement based on our review of the data collected (see Section 5). We investigated other locations in the lower watershed (from the creek mouth to approximately 600 m upstream) and did not find an ideal location in which to use DIDSON for this application.

Figure 9. DIDSON study site on Big Creek (Monterey County, CA).

3.3 Scott Creek

We continued our studies during the 2008 and 2009 steelhead spawning seasons in Scott Creek (Santa Cruz County, California), where due to the habitat we expected milling would be less of a problem than it had been at Big Creek, and where steelhead were being counted at a weir to provide a comparison. Scott Creek drains directly into the Pacific Ocean and is located about 22 km north of the city of Santa Cruz. The Scott Creek watershed is a small, coastal drainage with an area of about 70-km^2. Scott Creek maintains anadromous runs of *O. mykiss* as well as coho salmon (*O. kisutch*), although coho runs have been severely depressed in recent years. Anadromous fish access to the creek during the spawning season was subject to the natural opening and closing of an estuary depending on breaching of the sandbar at its mouth with the ocean by rainfall and tides. The estuary could open and close throughout the spawning season (December through April), but generally stayed open for longer periods once significant storm events raised and sustained creek levels. A floating resistance panel weir is operated during the spawning season approximately 1 km upstream from the ocean on Scott Creek. The DIDSON was located 180 m upstream from the weir, allowing for comparison between weir and DIDSON-derived counts.

At the Scott Creek location (Fig. 10), stream width and depth varied depending on flow and creek levels. Flows were generally low throughout most of the study period due to unusually dry winters. Stream widths varied from 7 to 15 m and depths averaged approximately 0.3 to 1.5 m. In 2008, DIDSON was deployed on Scott Creek from January 15 through April 30. Due to late rains in 2009 and the resulting delayed creek mouth opening, we did not deploy the DIDSON until February 9; image recording continued through March 24. Image recording for the 2010 season started on January 17 and was continuing during the finalization of this manuscript. DIDSON deployment at Scott Creek has been successful and a separate manuscript is in preparation on those results.

Figure 10. DIDSON study site on Scott Creek (Santa Cruz County, CA) with fencing installed just downstream of the unit to prevent fish passage behind the sonar unit.

4 Methods

After selecting an appropriate DIDSON site and obtaining the recommended components, the unit should be deployed and data recording should begin in advance of the first steelhead migrating into the system, if possible. Additional components such as deflector fencing and a unit hoist system may also be installed. These enhancements may be site-specific and could also include increased security measures. On a weekly basis (depending on the size of the external hard drives), data should be transferred from on-site external hard drives to more permanent (and larger) drives at the workplace for processing and analysis.

4.1 DIDSON Deployment

Study site characteristics were carefully considered before each DIDSON deployment and included examination of habitat type, substrate characteristics, power supply availability, security, and distance from the ocean as previously mentioned. Selecting an ideal site affects image quality, operational efficiency, data integrity, and overall safety of the equipment and study personnel. Before a DIDSON site is selected for a long-term monitoring station, it is recommended that all factors be carefully considered to ensure overall project success.

To further enhance the performance and security of DIDSON at each of our study sites, we included several additional components during the deployment phase. Deflector fencing was installed at each site and adjusted as flows varied throughout the study period. The fencing prevented upstream-migrating fish from swimming behind the DIDSON unit (i.e., would not be included in the escapement estimate). Fencing materials included T-posts (6-8 ft) and orange plastic fencing similar to that used in road construction projects. The fencing was effective at low to moderate flows. However, it proved not to be resilient during higher flow events. The orange plastic fencing was also more susceptible to clogging with leaves and other debris and was more difficult to clear of accumulated debris. Later in our studies, we determined 5 cm ‘chicken wire’ fencing and T-posts to be the most effective and sturdiest of materials that were easily adjusted (i.e., fencing panels could be added or removed) as flows fluctuated. More advanced and complicated designs of fences and weir-type deflectors are available and in use on larger systems (Enzenhofer et al. 1998; Holmes et al. 2006).

A crank-pulley hoist system was also used at the Big Creek (Fig. 11) and Scott Creek study sites to enable a quick response to rapid changes in stream flow. The DIDSON-side bank at Big Creek was steep and bordered by redwood trees, making it impossible to move the DIDSON unit up/down the bank as flows fluctuated. Also, it would have been nearly impossible to remove the DIDSON unit for equipment safety during an extremely high flow event. Therefore, the hoist system (cables, pulleys, and a boat-trailer style crank) was developed to enable quick removal of the unit from the water column until potentially-damaging high flows subsided. When the system was enacted, the DIDSON unit could be completely removed from the creek by suspending the entire mount and unit in the air.

Figure 11. DIDSON hoist system supported by cabling across the stream at the Big Creek (Monterey County, CA) site.

4.2 Data recording

Since our goal was to enumerate all steelhead passing our study site, the DIDSON was configured to record images for 24 hours per day for each day during the study period. It was necessary to record the entire steelhead run since numbers were so low and we were interested in an estimate of total escapement. For other studies where target population sizes were much larger and sub-sampling was acceptable (e.g., salmon escapement in large Alaskan River systems), the DIDSON was configured to record for a set number of minutes per hour (Maxwell and Gove 2004). Detailed DIDSON recording options and other functions can be found in Sound Metrics (2009).

DIDSON generates images stored as .ddf files, which is a format specific to the DIDSON software. Data files were recorded on-site continuously in 20-minute increments, which were saved to a 300-GB external hard drive. Saving files in 20-minute increments made for easier transfer and manipulation of files (since they were smaller). Also, if a file ever became corrupted either during recording or processing, much fewer data were lost when recording in smaller increments of time. All images were recorded using the high-frequency mode (1.8 MHz) at 6-8 frames per second. Depending on flow conditions and DIDSON positioning, window length was set to either 5 or 10 m and window start length ranged between 0.42 to 3.0 m. Occasional data recording interruptions were due to power outages, software glitches, brief periods of switching data storage devices, and several errors with recording operations during initial deployment (San Lorenzo River only). External hard drives were swapped on a weekly basis and returned to the laboratory for processing and data archival. Working copies of data files were stored at the laboratory using multiple 1 Terabyte (TB) external hard drives. Copies of all files were made for archival purposes and transferred to off-site storage tapes.

4.3 Data processing

Individual files were processed for analysis using the Convolved Samples over Threshold

(CSOT) program included with the DIDSON software (all versions).[5] This program uses an algorithm to select frames where movement is detected utilizing user-selected parameters of sample size (pixel cluster) and threshold (in decibels). The CSOT program shortens large data files to those frames where movement is detected based on the user-selected parameter input. In general, processing raw data using the CSOT program can result in significant file size reduction, thus saving hours of reviewer time. The magnitude of file size reduction is dependent on the number and frequency of fish passing the site.

CSOT settings can have a significant impact on the final fish counts, therefore testing is required to determine which settings are appropriate for any particular study location. CSOT output can be adjusted for sensitivity based on image quality, turbidity, and flow rates. For example, in periods of high flow after a rain event, turbidity levels increase while the resultant image quality decreases. By decreasing the sensitivity of the CSOT program, the resulting CSOT file will contain more frames for review (See Appendix A). This increases the reviewer's chance of detecting a fish which may not yield as strong an acoustic return as when turbidity levels are lower.

After running the CSOT program over raw data files (See Appendix A), the files were batch-processed together by each 24-hour period (0000 to 2359 hours). Each daily CSOT file was reviewed manually by a single reviewer. Background subtraction was used during file review to remove any static objects from the image, thus making moving fish

---

[5] Sound Metrics, Inc. regularly updates the DIDSON software and posts new versions on their website as they become available. The newest available software version was always used when processing our data.

targets appear more readily.

4.4 Data analysis

Analyzing DIDSON data for estimating steelhead escapement is complicated by species and life-history identification and fish behavior. Identification to species using DIDSON is based on major differences in fish size, body shape, or timing of when a particular species may or may not be present in the system (migratory species only). Determining life-history for steelhead would primarily be based on size and relies on some knowledge of fish in the system to determine minimum size to be included in counts. Fish behavior such as milling or kelt migration can also impact analysis, as there is no way to identify individual fish passing in front of the sonar to know if it is a ‘new’ fish or one previously encountered. We suggest ways to account for these issues in this section.

4.4.1 Species and life-history form identification

Differentiating between species or life-history forms (resident versus anadromous *O. mykiss*) which are similar in body morphology is difficult using DIDSON because fish are not herded into a narrow opening as with video counts, and therefore the image is not as precise. However, characteristics other than body shape such as size, timing, or spatial clues can be used. Given our study locations and focus on steelhead, large (40-80 cm) adult salmonids returning from the ocean, identification was relatively easy and involved discriminating adult steelhead from (1) suckers, (2), coho salmon, and (3) resident trout. Sacramento suckers (*Catostomus occidentalis*) occur in the San Lorenzo River system and can reach 50 cm total length (TL). This could have caused potential size overlap with steelhead in this system. However, we were able to differentiate between suckers and steelhead passing in front of the DIDSON by using swimming behavior. Steelhead tended to move upstream without changing direction or slowing their swimming speed. Suckers tended to linger in the ensonification zone for several minutes at a time, often traveling from the far to near bank instead of swimming directly upstream. Suckers also tended to circle the substrate or small cobble in the ensonification zone, apparently exhibiting feeding behavior. No other species should have been present in the system during the study period that could have been confused with adult steelhead based on size.

Different species of salmonids can be particularly difficult to separate by body shape. Steelhead and coho salmon (*O. kisutch*) are the most difficult due to similar size and run timings that overlap. At our study sites, steelhead was the only salmonid at the San Lorenzo River and Big Creek sites, and coho occurred only rarely at Scott Creek and were not an issue during our study. During the 2007-08 steelhead run season, coho salmon returns were severely depressed, with only 9 fish returning, 7 of which were collected at the weir (downstream of the DIDSON site) and taken directly to a nearby hatchery, thus not passing the upstream DIDSON location for enumeration. The other two coho were encountered at the weir as spawned-out carcasses and had presumably passed the DIDSON site either before it was in operation or during a period of high flow when the weir was non-operational; this is a small number compared with the approximately 150 steelhead counted during the study period.

Size is also important when considering species identification. The San Lorenzo River analysis included fish greater than 40 cm TL which was determined by examining data from the Felton Diversion Dam fish trap for minimum steelhead size passed upstream at the dam. For Big Creek, we used a minimum size of 40 cm TL, which was based on the maximum size (30 cm TL) of the largest juvenile/resident *O. mykiss* captured during electrofishing surveys from 2005-2008. Based on comparative weir data, we utilized 40 cm TL as the minimum size to be considered a steelhead at Scott Creek. One potential difficulty when working in a new system would be the selection of the minimum-sized fish to be included in the upstream count (resident vs. anadromous) in drainages where this information would not be known previously based on other surveys (e.g., weirs, mark-recapture surveys, etc.).

4.4.2 "Best guess" approach

A count of salmonids in large river systems such as those in Alaska and British Columbia where population sizes are large is generally represented as a total count, considered the escapement estimate. Precision is important but not as critical as with smaller, depressed populations such as those of steelhead in central and southern California where the number of adults returning to a river system can be fewer than 20 individuals. In these situations, it is important for counts to be as accurate as possible. In contrast to these large river systems, monitoring escapement of low-abundance steelhead populations from DIDSON counts required new approaches to account for iteroparity and milling, which we developed in an evolutionary manner. Our first attempt at analyzing data files involved recording relevant information about each fish passage (upstream or downstream), including date/time of passage, fish size, direction of passage, distance from the sonar unit, and any notable comments unique to each passage event or ‘observation.’ From these data, the experienced reviewer would determine how to classify each observation: 1) include in the net upstream count, 2) include in the net downstream count to be subtracted from the escapement estimate, or 3) not include in any net count as fish was previously observed milling at this location. This method involved using a ‘best guess’ approach based on the reviewer’s experience and taking into account other factors such as fish size, direction of passage, the amount of time that passed between observations, and whether a fish was paired with another fish.

4.4.3 Decision Support Tool

During processing of the San Lorenzo River and Big Creek data using the ‘best guess’ approach, it became clear that steelhead movement was more complicated than typically assumed (i.e., swimming directly upstream until reaching their desired spawning grounds and then either dying after spawning or heading straight downstream and returning to the ocean as a kelt) and that a high degree of milling sometimes occurred. The exact reasons for milling are unknown but could be the result of waiting for a potential mate to enter the system, searching for suitable spawning habitat, awaiting stream conditions that would make movement between habitat units possible, resting before traveling further upstream, etc.

We therefore realized that we needed to standardize our decision process about determination of each observed fish as being the ‘same’ or ‘different’ as the previously observed fish to account for milling behavior. We also wanted to develop a method that was less subjective to reviewer's opinion as with the 'best guess' method. We developed a Decision Support Tool (DST) for making quantifiable, standardized decisions about downstream migrants and potentially differentiating between milling fish and downstream-migrating kelts. Differentiating between fish that were milling and kelts migrating downstream was important when estimating steelhead escapement. Net movement could be used to assess milling fish, but kelts migrating downstream should not be subtracted from the escapement estimate.

The DST was based on the following criteria which were used to evaluate the likelihood of two or more independent observations being the same fish: 1) fish size, 2) time between observations, 3) pairing, and 4) distinctive swimming characteristics. Point values were applied to each observation for each of the criteria (Table 3) and then summed for a total point value for each observation. Depending on the point total for each observation, a fish was either considered the same as the previous observation (≥ 5 points) or different (≤ 4 points). This helped to identify fish that were milling versus those that were possible kelts. Once all fish were assessed using the DST, daily net counts were then recorded and plotted versus time (Fig. 12). The plot was used to identify the time of year (*t*) when the daily net count peaks and begins to decline (i.e., more kelts were migrating downstream than new fish were heading upstream). At this point, any fish migrating downstream that was not assigned a "milling" status by the DST would be considered a kelt and not subtracted from the total net count.

Table 3. Point value system for the Decision Support Tool (DST) used during DIDSON data analysis on the San Lorenzo River. Observations receiving greater than or equal to 5 total points were classified as being the same fish previously observed (milling), while those observations receiving less than or equal to 4 points were classified as a different fish than previously observed.

Parameter	Category	Assigned point value
Fish Size	≤ 2 cm difference	4
	≤ 5 cm difference	3
	≤ 7 cm difference	1
Time between observations	< 5 min	3
	< 30 min	2
	< 60 min	1
Distinctive swimming pattern	Present	1
	Absent	0
Pairing	Paired going up/downstream	3
	Not paired	0

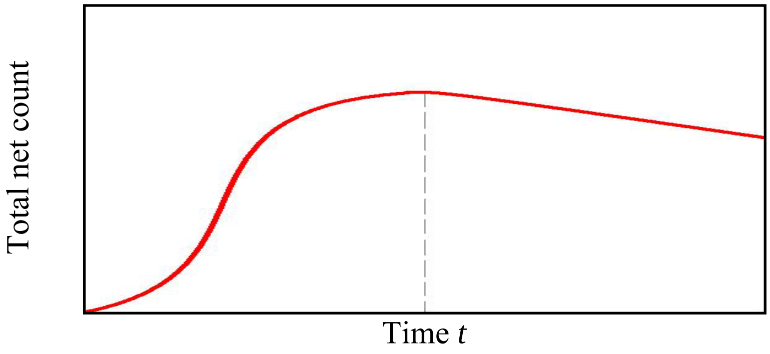


Figure 12. Example plot used in the Decision Support Tool to identify the time of year (*t*) when daily net count peaks and begins to decline.

Development of the DST arose due to the difficulties surrounding the interpretation of in-river adult steelhead behavior using DIDSON. The inability to differentiate between individual fish using DIDSON meant the reviewer needed to use a 'best guess' approach, leaving the review subject to 'expert' opinion instead of a more objective methodology. Creating and implementing the DST was an attempt to eliminate or decrease the effects of a subjective review by devising a more transparent and unbiased analysis tool. The four variables selected (fish size, time between observations, fish pairing, and distinctive swimming pattern, all coupled with direction of travel) were factors that could be measured using the image properties and software functions available. Fish size, time between observations and fish pairing were selected as the primary factors and assigned the largest possible point values (1 to 4, 1 to 3, and 0 or 3, respectively), as these variables were easily interpreted during review with a low degree of subjectivity. The overall point system and thresholds within each of the four criteria were developed based on trial-and-error using known counts as a control.

In our studies, we found sizing fish using the DIDSON measuring tool provided with the DIDSON software to be sufficiently inaccurate that we needed to classify fish measurements according to size bins for the DST. With respect to the accuracy of using the DIDSON software to measure fish size, Burwen et al. (2007) concluded that DIDSON measurements for free-swimming fish were not subject to substantial bias and that reasonably accurate measurements could be taken when using the high frequency setting and measuring fish at close range from the sonar. We generally found this statement to be true, except we did find that DIDSON measurements tended to be slightly inaccurate based on limited experiments we implemented using either a target fish or a free-swimming fish of known size released in front of the sonar. We also used the DIDSON box-measuring technique as opposed to the manual line-drawing technique used in Burwen et al. (2007), as the line-drawing technique had an even greater bias associated with it based on our trials. For these reasons, we decided to use three size bins (0 - 2, 2.1 - 5, and 5.1 – 7 cm) when making fish size comparisons in the DST. If the size difference was greater than 7 cm after averaging three total length measurements, the following migrant would automatically be called a different fish and thus would be considered a new observation.

The rationale behind the parameter 'time between observations' was primarily based on study observations from Big Creek and the difficulties we encountered trying to interpret milling fish behavior. The greatest challenge in interpreting and incorporating milling fish into the analysis occurs when fish are entering and exiting the ensonification zone (Note: only when the origin of Fish 2 is the same as the destination of Fish 1), and there is no way to know if they are the same fish, especially if there are several fish present over a period of hours or days and they are of similar size. Determining a cut-off time to make the distinction between multiple fish passages over a short period of time was necessary to try to differentiate between milling fish versus fish heading up or downstream (i.e., non-milling fish). Our selection of 1 hour as the maximum 'time between observations' to be included in the DST was based on trial and error using data from Big Creek and Scott Creek and our knowledge of steelhead behavior. During review of the Big Creek data, the primary reviewer initially chose 5 hours as the cut-off to make the decision if a fish was the same as previously observed or not. However, this drastically decreased the number of fish observations considered to be "new" when it was clear that new fish were entering the system. A second reviewer chose 1 hour as the cut-off when making the determination if the observation was a new fish or a different fish. This yielded a more realistic number of observations. Also, with the given structure of the DST, 'time between observations' was just one of four main factors used when making comparisons between multiple fish observations, so it was not too heavily weighted or emphasized over any other parameter which could have been considered less arbitrary.

The DST process starts with review of a CSOT file to record each fish observation, followed by assignment of defined DST values into a spreadsheet (Appendix A). Each time a fish was observed passing upstream or downstream, the following data were recorded: date, time fish first appeared, total fish length (repeated to yield three measurements, each taken using a different frame if available), distance from the sonar, time when fish swims off-screen, frame quality, direction of passage, and a unique fish number (Fig. 13). Three different measuring tools are available for use on the DIDSON software: 1) a box can be drawn around the object of interest (total length is measured as the diagonal), 2) a line can be manually drawn using the mouse along the entire object's length, or 3) a series of dots can be made by clicking along the length of the object; the dots are then connected for a total length measurement. As previously stated, we found the box technique to be the most accurate when applied to several 'test' fish of known sizes. The box method was also the most repeatable and consistent measurement, especially when using more than one reviewer. The measurement was started by left-clicking the mouse at the head of the fish then dragging the mouse over the fish to the tail to define the measurement area. Measurements in meters of object width, height, and diagonal values were returned with each box drawn. The diagonal measurement is the one used for obtaining Total Length.

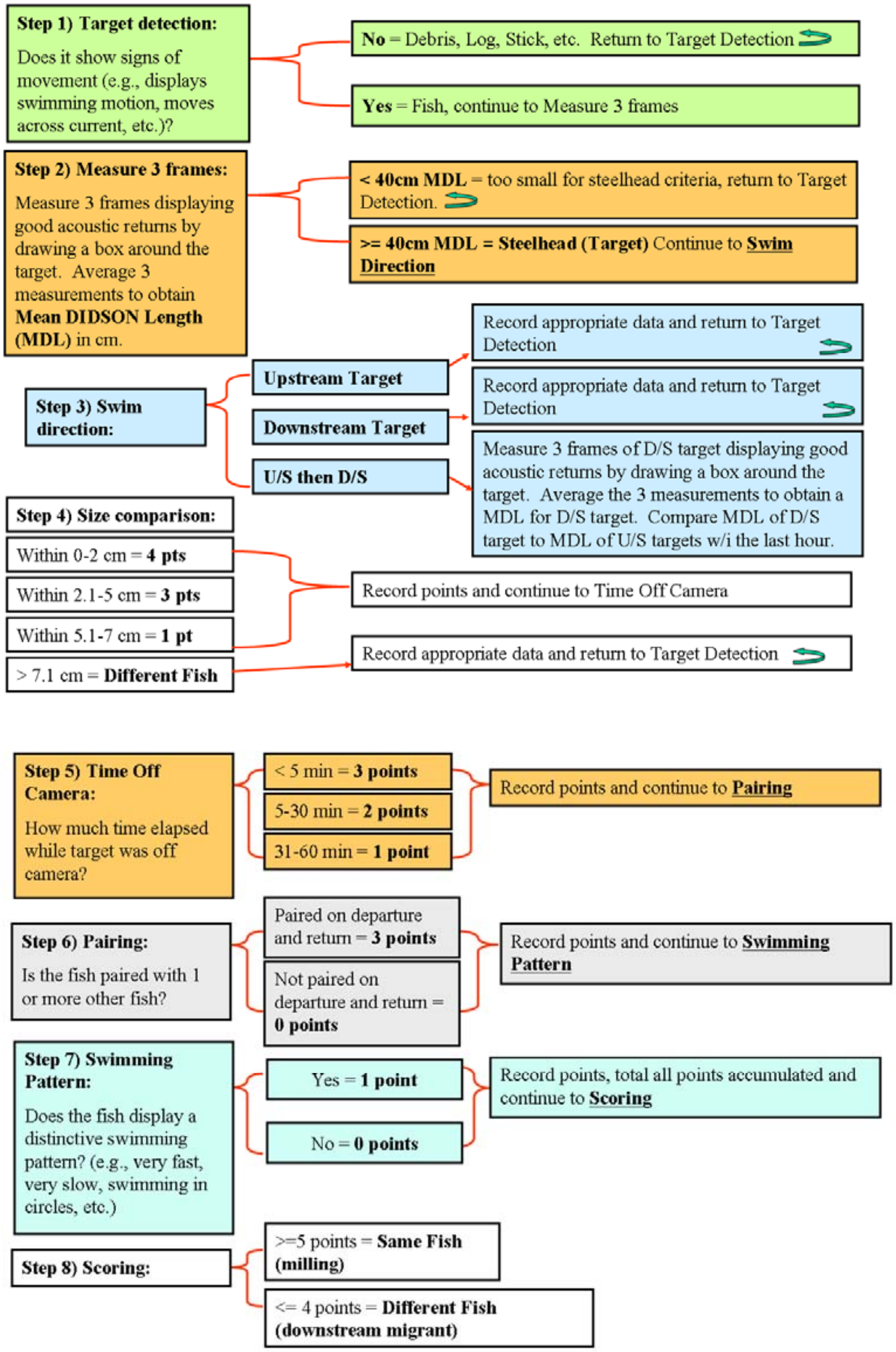


Figure 13. DIDSON Decision Support Tool (DST) framework.

Frame selection was important when selecting still images in which to measure fish targets. We avoided frames where fish appeared to have significant flare or ‘noise’ associated with the image. We also avoided measuring fish at the screen margins, as these tended to have more flare and were overly-elongated at the edges of the screen, making the targets appear larger. If possible, we utilized frames where the fish was at a slight angle to the sonar, as these fish tended to have less flare than those which were perpendicular to the sonar. The average of three measurements (each taken using a different frame) was used to estimate TL for each fish. (See Appendix A for example images.)

With regard to the paired fish rating, if two fish were present on the screen in the same frame, they were considered paired. However, they did not necessarily receive points for being paired. To assign the three points for being paired, a pair must have traveled downstream paired and returned paired to the screen (or vice-versa) and have been of similar size. If a pair of fish traveled downstream and two individual (i.e., unpaired) fish returned upstream, no points were awarded. If a large fish and a smaller fish were paired going downstream and two large fish returned paired swimming upstream, no points were awarded.

Determining if a fish exhibits a distinctive swimming pattern can be difficult and does maintain some degree of reviewer subjectivity in the DST. Examples of distinctive swimming pattern include: very fast or very slow swimming speed, holding in the same location for a period of time, swimming in circles, exhibiting chase behavior, etc. To award a point for this behavior, the distinctive swimming characteristic must be present on the initial and following migrant. This parameter was only used sparingly during analysis.

Once an observation was recorded, additional CSOT footage was played until the next fish target was detected. In order to compare the initial (prior) observation to the following observation, two conditions needed to be met: 1) the time elapsed between observations had to be less than one hour, and 2) the origin of the following observation had to be the same as the destination of the initial fish. For example, if the initial fish traveled from upstream to downstream and the following fish traveled from downstream to upstream, this would be appropriate for making a comparison as long as the first condition was met. If either of the above criteria was not met, the reviewer entered the following observation as a new entry, which would be considered a new or ‘different’ fish from the prior observation. However, if both criteria were met, a comparison would be made between the pair of observations to determine if they were the same or different fish. After all values were entered, spreadsheet formulas (based on the values presented in Table 3) were used to determine the results of the comparison (i.e., same or different fish). Daily net upstream movement counts were tallied and adjusted for kelt migration to provide a final escapement estimate.

5 Results

Both the 'best guess' method and the DST were applied to the San Lorenzo River dataset, resulting in a net upstream fish count of 41 (Pipal et al. In press) versus 48, respectively. The results from the DST review were able to more closely reflect those of the fish trap (46), however both numbers were generally close to the fish trap count.

The DST was not used to re-process the Big Creek dataset due to excessive milling issues there. This is not to imply that the DST would not work in instances where milling is occurring to a large degree, but we chose not to reanalyze the data using the DST due to time constraints. Including all instances of milling, there were 990 fish observations (i.e., each time a fish passed in front of the sonar) over a 4-month period at Big Creek, however this only resulted in a final, 'best guess' escapement estimate of 22-33 steelhead. Excessive milling at this site made data analysis exceptionally time-consuming and nearly infeasible. Selecting a more appropriate habitat type (i.e., run or glide) would have avoided this problem.

The Scott Creek DIDSON data will be processed exclusively using the DST. Results from this analysis will be available in a future manuscript.

6 Discussion

DIDSON can be used as a viable method for monitoring adult steelhead in central and southern California where population abundance is low, distribution can be patchy, and stream conditions are flashy and turbid during migration. Site selection is a key factor in determining a successful DIDSON deployment for this application. Choosing a site with a laminar flow, a gently sloping channel profile free from obstacles, and one that is accessible to study personnel are all important features. Availability of AC power was important for our study, but other types of power sources are used in more remote regions and could be feasible for different studies depending on project location and budget. Although data analysis is straightforward and should be a basic assessment of upstream versus downstream net movement, it is complicated by instream fish behavior such as milling and kelt migration. We incorporated these issues into our Decision Support Tool which yielded results that were similar to other methods (e.g., fish trap data). Use of DIDSON for this application does have limitations however, including species identification and application of the Decision Support Tool to datasets where significant milling is occurring.

6.1 Limitations

One of the main aspects of DIDSON technology needing improvement is the ability to differentiate between species, especially those similar in size and morphology, and this limitation will affect the regions in central and southern California where it can be used. For regions south of Santa Cruz County, species identification should be less of an issue as most systems should not have other species present during steelhead migration periods (January through March) that could be confused with adult steelhead based on size. In the systems in which we used DIDSON, the only species present that would have been difficult to distinguish from steelhead were coho salmon (*O. kisutch*), and possibly Sacramento suckers (*Catostomus occidentalis*). In the San Lorenzo River, suckers and steelhead were differentiated by size and swimming behavior past the DIDSON site. With Scott Creek coho, adult abundance estimates were so low that we assumed all fish greater than 40 cm TL to be steelhead. Coho in Scott Creek also typically enter the system in December (depending on flow), and we never deployed the DIDSON until January or later. However, for DIDSON use in coastal California systems north of Scott Creek, abundance for both species would generally be higher in most systems, thus increasing the chance for an overlap in timing and complicating species identification. Research into improving species identification is underway using the software program "Echoview" (http://www.echoview.com/) to analyze tail-beat frequency of salmon in an attempt to differentiate between salmonid species (Mueller 2008), and automated software programs that attempt to use fish size, shape, and behavioral information are also being developed to distinguish between sockeye and chinook salmon[6], but additional work is required before these techniques can be applied. Where multiple species of salmonids overlap temporally, ancillary data from gill netting or seining have been used in conjunction with DIDSON counts to discriminate between species (Melegari and Osbourne 2008). However, such practices cannot be used when dealing with an ESA-listed species or run. DIDSON could be used in conjunction with a video weir (e.g., Mill Creek in northern California, 2008[7]) to aid in species identification, but this would require good water clarity and restricting fish passage through a narrower opening to obtain comparative video images.

Another potential limitation of this study would be the application of the DST to a dataset

---

[6] John Holmes (holmesj@pac.dfo-mpo.gc.ca), Fisheries and Oceans Canada, Nanaimo, British Columbia, Canada.

where milling was occurring to a high degree. The DST can be used in cases of milling fish to varying degrees. If milling is deemed excessive, however, its use may be too tedious, especially when more than one fish is passing in front of the camera for hours or days. In these instances (as with our Big Creek data), it may be preferable to use the 'best guess' method as to how many fish are present and what the net upstream migration could would be over these periods. Most importantly, however, it is best to select a site where this is least likely to occur. We are assuming that milling is related to habitat and is not more or less likely to occur in different watersheds, however it may also be related to watershed size. It is conceivable to think that smaller watersheds will have fewer fish which may be entering the system individually at different times. As they wait for potential mates to arrive, milling may increase and occur to a higher degree in these smaller watersheds with fewer fish. In these cases, it may be best to have the DIDSON sited as low as possible in the system and to use the 'best guess' method for analysis if milling is occurring to a high degree and use of the DST is not feasible.

Determining the peak of the run date may be easier in some systems (i.e., peak will be sharp and well defined) than others where the peak may be multi-modal or not well-defined at all. It is best to review the entire dataset before determining the peak by applying the daily net count versus time criteria. Selecting the peak date can affect the final count, but it depends on how many fish (i.e., kelts) migrate downstream after that date and what fraction of the total count those fish represent.

---

[7] Doug Killam (dkillam@dfg.ca.gov), California Department of Fish and Game, Red Bluff, California

6.2 Specific implementation recommendations

Before starting a long-term monitoring program using DIDSON for this application, it is recommended that a shorter-term trial be implemented one year in advance of starting the actual monitoring project. This will yield important insight into any site deficiencies, possible equipment needs beyond the scope of this paper, and flows that may be detrimental to effective operation. If this is not feasible, it is recommended that significant time be spent in advance of deployment locating the best possible site, considering habitat type, substrate, availability of power, and security options as primary concerns.

Also, there are two different DIDSON versions (standard and long-range) available and different additional components (e.g., concentrator lens, silt exclusion enclosure, lens spreader, etc.) that should be considered on a site-by-site basis.[8] Each deployment may require different strategies for overall equipment set-up (e.g., mount design, DIDSON type, cable length, etc.) based on channel width, substrate type, riparian features, power accessibility, etc. This document serves as a general guide for most deployments, but there are situations where different set-up and operational procedures will be necessary.

6.3 Additional applications

DIDSON images revealed that fish passage past any point has a great deal of unique fish behavior associated with it. Understanding this behavior can lead to better recovery actions and in particular, improved monitoring. Movement is the most obvious area of fish behavior that could be potentially investigated using DIDSON and could include timing and seasonality of fish movement, fish milling, and intraspecific interactions. Another area of fish behavior that could be investigated using the DIDSON is environmental or habitat cues that cause movement, attraction, or avoidance. Knowledge of these behaviors may be very useful in planning or monitoring habitat restoration actions. There may also be behaviors related to interspecific interactions, of which predation is the most common which could be detected using DIDSON technology. Some of these areas of fish behavior investigation could come from standard monitoring efforts, while others would require focused installation of the DIDSON equipment.

DIDSON data can be used to assess many aspects of movement, including diel patterns, whether fish pass individually or in association with other fishes, and whether there is any discernable pattern to an association. DIDSON monitoring can also provide clues to movements that are associated with flow or other environmental events. Finally, DIDSON monitoring can give some insight into interspecific interactions. The most likely instance of this would be observations of predation or predator avoidance. Observations of this type are likely to be opportunistic, but can provide useful information about contacts with other species that affect upstream steelhead migration.

Another area of fish behavior that could be investigated using the DIDSON is monitoring for environmental or habitat prompts that might cause attraction or avoidance. This would be very useful for investigating habitat restoration activities. The DIDSON could be used to monitor an area before and after habitat restoration is implemented. There should be a control DIDSON monitoring site at another location which was not part of

---

[8] More information is available on the Sound Metrics website (www.soundmetrics.com).

the habitat restoration action. The ability to passively monitor an area without harassing fish with sampling efforts makes this monitoring design a much more powerful indicator of habitat restoration effectiveness. In addition, DIDSON would be useful in determining if interspecific interactions such as predation were more or less likely in different habitats. It is unlikely that any such habitat restoration effectiveness monitoring could be done in conjunction with abundance monitoring and would require separate deployments.

6.4 Conclusion

DIDSON serves as a passive monitoring tool which does not deter fish passage or alter instream behavior. It is effective in turbid streams and low-light conditions, which is essential to detecting steelhead during their spawning migration. Monitoring sites should be carefully selected, considering factors such as habitat type, available power supply, potential security issues, other species present, and distance from staff location. The Decision Support Tool assists in reviewing and analyzing adult steelhead abundance data collected using DIDSON. It serves as an objective tool when differentiating between milling fish and downstream migrating kelts while providing a final escapement estimate. Use of DIDSON in central and southern California systems can provide important adult steelhead abundance information which will aid in developing better recovery actions.

Acknowledgements

We would like to thank Debbie Burwen (Alaska Department of Fish and Game) for providing mount designs and Dale Chastagner (National Marine Fisheries Service, Santa Cruz, CA) for assistance with mount design and fabrication consultation. Henry Cowell Redwoods State Park granted access to the San Lorenzo River study site. The City of Santa Cruz Water Department provided electricity for the operation of all sampling equipment. U. S. Geological Survey allowed access into their gaging station, enabling control over the power supply. Kurt Merg and Feynner Arias provided power, project assistance and equipment monitoring at the Big Creek location. We are grateful to Lewis Barnett, Heidi Fish, Ethan Mora, Jeremy Notch, Brian Spence, and Thomas Williams for their help during field trials. Project funding was provided by the National Oceanic and Atmospheric Administration, National Marine Fisheries Service and the University of California, Santa Cruz. DIDSON is manufactured by Sound Metrics, Inc. in Lake Forest Park, WA (www.soundmetrics.com).

References

Baumgartner, L. J., N. Reynoldson, L. Cameron, and J. Stanger. 2006. Assessment of a dual-frequency identification sonar (DIDSON) for application in fish migration studies. NSW Department of Primary Industries, Fisheries Final Report Series No. 84. Narrandera, New South Wales.

Belcher, E. O., B. Matsuyama, and G. M. Trimble. 2001. Object identification with acoustic lenses. Pages 6-11 *in* Conference proceedings MTS/IEEE Oceans, volume 1, session 1. Honolulu, Hawaii, November 5-8.

Belcher, E. O., W. Hanot, and J. Burch. 2002. Dual-frequency identification sonar. Pages 187-192 *in* Proceedings of the 2002 International Symposium on underwater technology. Tokyo, Japan, April 16-19.

Burwen, D. L., S. J. Fleischman, and J. D. Miller. 2007. Evaluation of a dual-frequency imaging sonar for estimating fish size in the Kenai River. Alaska Department of Fish and Game, Fishery Data Series No. 07-44. Anchorage, Alaska.

Cronkite, G. M. W., H. J. Enzenhofer, T. Ridley, J. Holmes, J. Lilja, and K. Benner. 2006. Use of high-frequency imaging sonar to estimate adult sockeye salmon escapement in the Horsefly River, British Columbia. Can. Tech. Rep. Fish. Aquat. Sci. 2647.

Enzenhofer, H. J., N. Olsen, and T. J. Mulligan. 1998. Fixed-location riverine hydroacoustics as a method of enumerating migrating adult Pacific salmon: comparison of split-beam acoustics vs. visual counting. Aquatic Living Resources 11(2):61-74.

Galbreath, P. F. and P. E. Barber. 2005. Validation of a long-range dual frequency identification sonar (DIDSON_LR) for fish passage enumeration in the Methow River. Columbia River Inter-Tribal Fish Commission Technical Report 05-4. Portland, Oregon.

Gallagher, S. P. and C. M. Gallagher. 2005. Discrimination of chinook salmon, coho salmon, and steelhead redds and evaluation of the use of redd data for estimating escapement in several unregulated streams in northern California. North American Journal of Fisheries Management 25:284-300.

Holmes, J. A., G. M. W. Cronkite, H. J. Enzenhofer, and T. J. Mulligan. 2006. Accuracy and precision of fish-count data from a “dual-frequency identification sonar” (DIDSON) imaging system. ICES Journal of Marine Science 63:543-555.

Kucera, P. A. and D. Faurot. 2005. Chinook salmon *(Oncorhynchus tshawytscha)* adult abundance monitoring in Lake Creek and Secesh River, Idaho 2004. Annual report to the Bonneville Power Administration. Nez Perce Tribe, Department of Fisheries Resources Management, Lapwai, Idaho.

Kucera, P. A. and D. Faurot. 2006. Chinook salmon *(Oncorhynchus tshawytscha)* adult abundance monitoring in Lake Creek and Secesh River, Idaho 2005. Annual report to the Bonneville Power Administration. Nez Perce Tribe, Department of Fisheries Resources Management, Lapwai, Idaho.

Maxwell, S. L. 2007. Hydroacoustics: rivers. Pages 133-152 in D. H. Johnson, B. M. Shrier, J. S. O'Neal, J. A. Knutzen, X. Augerot, T. A. O'Neil, and T. N. Pearsons. Salmonid field protocols handbook: techniques for assessing status and trends in salmon and trout populations. American Fisheries Society, Bethesda, Maryland.

Maxwell, S. L. and Gove, N. E. 2004. The feasibility of estimating migrating salmon passage rates in turbid rivers using a dual frequency identification sonar (DIDSON), 2002. Alaska Department of Fish and Game, Regional Information Report No. 2A04-05. Anchorage, Alaska.

Melegari, J. L. and B. M. Osborne. 2008. Evaluation of sonar for enumeration of chinook salmon in the Chandalar River, Yukon Flats National Wildlife Refuge, Alaska, 2004-2006. U.S. Fish and Wildlife Service, Fairbanks Fish and Wildlife Field Office, Alaska Fisheries Data Series, Number 2008-1, Fairbanks, Alaska.

Moursund, R. A., T. J. Carlson, and R. D. Peters. 2003. A fisheries application of a dual-frequency identification sonar acoustic camera. ICES Journal of Marine Science 60:678-683.

Mueller, A. 2008. Echograms that bring out patterns related to tail-beat. Paper presented at the *Alternate Strategies in fish counting from DIDSON data* session, workshop on DIDSON-based fish assessment: techniques for monitoring migratory fish in rivers. Anchorage, Alaska; 27-28 October 2008.

Pipal, K. A., M. A. Jessop, D. A. Boughton, and P. B. Adams. In press. Using dual-frequency identification sonar to estimate adult steelhead escapement in the San Lorenzo River, California. California Fish and Game.

Rose, C. S., A. W. Stoner, and K. Matteson. 2005. Use of high-frequency imaging sonar to observe fish behaviour near baited fishing gears. Fisheries Research 76:291-304.

Sound Metrics. 2009. Dual-frequency identification sonar (DIDSON), operation manual V5.23. 18 July 2009. Lake Forest Park, Washington.

Tiffan, K. F., D. W. Rondorf, and J. J. Skalicky. 2004. Imaging fall chinook salmon redds in the Columbia River with a dual-frequency identification sonar. North American Journal of Fisheries Management 24:1421-1426.

Tiffan, K. F. and D. W. Rondorf. 2005. Measuring nighttime spawning behavior of chum salmon using a dual-frequency identification sonar (DIDSON). Paper presented at *Measuring Behavior 2005,* 5th International Conference on Methods and Techniques in Behavioral Research. Wageningen, The Netherlands; August 30 – September 2, 2005.

Weiland, M. A. and T. J. Carlson. 2003. Technologies for evaluating fish passage through turbines. PNNL-14437, Pacific Northwest National Laboratory, Richland, Washington.

Appendix A

Dual-frequency identification sonar (DIDSON) - Decision Support Tool User Guide for Steelhead Escapement Data

The purpose of this document is to provide guidance to users processing DIDSON data using the Convolved Samples Over Threshold (CSOT) program (Sound Metrics) and the Decision Support Tool (DST) we developed to analyze steelhead escapement data collected using DIDSON. The intended use is for low abundance populations where milling and kelt migration are present and can impact results.

What is the Problem?

Steelhead are iteroparous and can return to freshwater multiple times to spawn. After spawning, the surviving fish (referred to as "kelts") can migrate back downstream to the ocean. Steelhead also exhibit milling behavior in these small systems, traveling upstream and downstream presumably in search of mates or quality spawning habitat. These factors affect how individual fish passage at the DIDSON site is handled during analysis, as fish moving downstream present these questions:

1) Is this a kelt heading downstream to the ocean?

OR

2) Is this fish milling?

If simple net movement past the camera were used to determine escapement, the final count would be too low (i.e., Escapement estimate – number of kelts).

The Decision Support Tool

Differentiating between fish that are milling and kelts that are migrating downstream is critical in estimating an accurate escapement. Net movement can be used to assess milling fish, but kelts migrating downstream should not be subtracted from the escapement data. We developed a Decision Support Tool (DST) for making quantifiable, standardized decisions about downstream migrants and potentially differentiating between milling fish and downstream-migrating kelts. The DST addresses the following questions:

- Is the downstream migrant the same as a recent upstream migrant? (milling)
- Is the downstream migrant different than any recent upstream migrant? (possible kelt)

How does the DST Work?

The DST uses the following four criteria to evaluate the likelihood of two or more independent observations being the same fish: 1) size, 2) time between observations, 3) pairing, and 4) distinctive swimming characteristics. Point values are applied to each observation for each of the four criteria. Depending on the point total for each observation, a fish is either considered the *same* as the previous observation or *different*. This helps to identify fish that are milling. Once all fish have been assessed using the DST, daily net counts of fish moving upstream are then recorded and plotted verses time. The plot is used to identify the time of year (*t*) when the daily net count peaks and begins to decline (i.e., more kelts are traveling downstream than new fish are heading upstream). At this point, any fish migrating downstream that is not assigned a "milling" status by the DST would be considered a kelt and not subtracted from the total net count.

DST Point values and final scoring

<u>Size</u>
<= 3cm difference = 4 points
<=5cm difference = 3 points
<=7cm difference = 1 point

<u>Time Off Camera</u>
<5 min = 3 points
<30min = 2 points
<60 min = 1 point

<u>Distinctive swimming patterns</u>
Yes = 1 point
No = 0 points

<u>Pairing</u>
Paired going both directions = 3 points
Not paired = 0 points

<u>Scoring</u>
>=5 points – same fish (milling)
<=4 points – different fish (possible kelt)

Data Processing

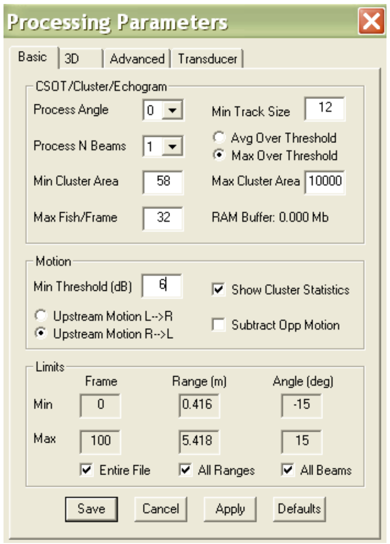
Raw files to CSOT

1. Begin by running the CSOT processing parameters on the raw files. We used different CSOT parameter combinations depending on flow conditions (high/low). Each monitoring site will require testing of CSOT parameters to ensure migrating fish are being captured for each unique situation (study site, flow conditions, etc.). Choose a set of parameters appropriate for flow conditions and DIDSON viewing window length.

   Examples:

Low water setting	High water setting
Window length = 5m	Window length = 10m
Factor A = 0.97	Factor A = 0.97
Min cluster area (cm^2) = 58	Min cluster area (cm^2) = 40
Min threshold (db) = 6	Min threshold (db) = 5
Persistence (frames) = 0	Persistence (frames) = 0

   There is some trial and error involved with this. If your resulting CSOT file has many fish blinking in and out, lower the threshold and decrease the sample size.
2. Select raw files from one week (or other time increment) of recording and move them into a temporary folder. (Note: Working with small batches of data enables the user to re-run the CSOT program faster in case parameter changes are required. This is also helpful when window length is changing frequently (e.g., changes in flow or camera positioning) which often result in a change to the CSOT parameters.)
3. Open the first file in the temporary folder using the DIDSON software.
4. Set CSOT parameters (last icon on right of the DIDSON 'Image Processing' toolbar) using the 'Basic' and 'Advanced' tabs.



CSOT/Cluster/Echogram
Process Angle 0
Min Track Size 12
Process N Beams 1
○ Avg Over Threshold
● Max Over Threshold
Min Cluster Area 58
Max Cluster Area 10000
Max Fish/Frame 32
RAM Buffer: 0.000 Mb

Motion
Min Threshold (dB) 6
☑ Show Cluster Statistics
○ Upstream Motion L-->R
● Upstream Motion R-->L
☐ Subtract Opp Motion

Limits

	Frame	Range (m)	Angle (deg)
Min	0	0.416	-15
Max	100	5.418	15
	☑ Entire File	☑ All Ranges	☑ All Beams

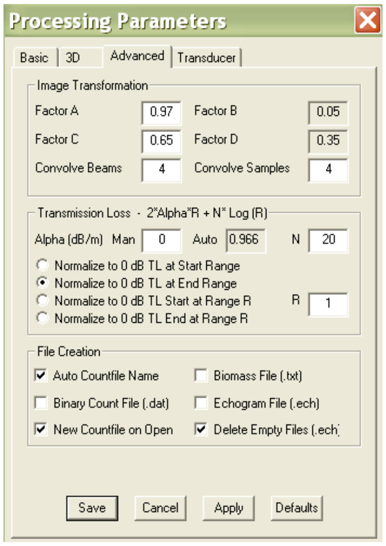
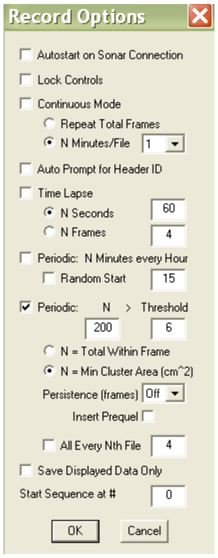


Image Transformation
Factor A 0.97
Factor B 0.05
Factor C 0.65
Factor D 0.35
Convolve Beams 4
Convolve Samples 4

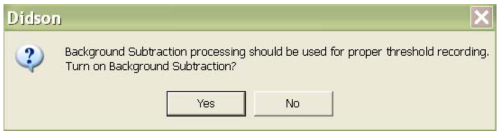
Transmission Loss - 2*Alpha*R + N* Log (R)
Alpha (dB/m) Man 0 Auto 0.966 N 20
○ Normalize to 0 dB TL at Start Range
● Normalize to 0 dB TL at End Range
○ Normalize to 0 dB TL Start at Range R
○ Normalize to 0 dB TL End at Range R
R 1

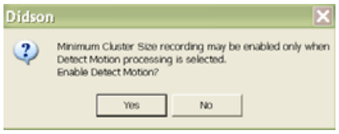
File Creation
☑ Auto Countfile Name
☐ Biomass File (.txt)
☐ Binary Count File (.dat)
☐ Echogram File (.ech)
☑ New Countfile on Open
☑ Delete Empty Files (.ech

5. From the File menu, choose Set Save Dir/Name and save to a new file created for CSOT originals. Make sure the destination folder (save dir) has enough space to accommodate the new files. You will be prompted about file naming; select NO for ‘Replace HHMMSS with #NNN in filenames?’ and YES for ‘Append frequency designation (_LF, _HF) to filenames?’
6. From the File menu, go to Set Aux File Dir and make sure Image Save Dir is checked.
7. Check CSOT settings (Image/Capture/Record Options, check Periodic N > threshold where N=Sample size or cluster in cm² and Threshold = brightness in db. Check N = Min cluster Area (cm²)).


Record Options
☐ Autostart on Sonar Connection
☐ Lock Controls
☐ Continuous Mode
  ○ Repeat Total Frames
  ● N Minutes/File 1
☐ Auto Prompt for Header ID
☐ Time Lapse
  ● N Seconds 60
  ○ N Frames 4
☐ Periodic: N Minutes every Hour
  ☐ Random Start 15
☑ Periodic: N > Threshold
  200 6
  ○ N = Total Within Frame
  ● N = Min Cluster Area (cm^2)
  Persistence (frames) Off
  Insert Prequel ☐
  ☐ All Every Nth File 4
☐ Save Displayed Data Only
Start Sequence at # 0

You will be prompted to turn on background subtraction and motion detection. Click Yes for both.


Didson
Background Subtraction processing should be used for proper threshold recording. Turn on Background Subtraction?


Didson
Minimum Cluster Size recording may be enabled only when Detect Motion processing is selected.
Enable Detect Motion?

8. Set Processing parameters (Processing/CSOT – check Batch mode and Export CSOT frames).
9. Processing will begin. Red clusters will appear on the screen. These are the clusters that meet your criteria set in the CSOT parameters. It is helpful to watch the actual processing initially and note the statistics displayed in the lower right portion of the DIDSON screen. Area = the cluster size of the currently displayed cluster. Pk = the peak cluster size for the file being processed. By watching the processing, you can get a good idea of how cluster size relates to the actual acoustic returns.

See the DIDSON Operation Manual for more details on CSOT processing.

CSOT to Appended CSOT

1. Once you have processed the raw files, you will be left with a corresponding set of CSOT files. For viewing, it is very efficient to consolidate these 20min files into a single file for each day.
2. Open the folder in CSOTS_Originals with the new files just created. Move all CSOT files for each day into a new folder and label the folder with the corresponding date.
3. Open the first file in the new dated folder using the DIDSON software.
4. Set the save directory to CSOTS_Appended (File/Set save dir/name). You will be prompted about file naming; select NO, then YES.
5. Merge files (File/Merge/All files to new file).
6. The output SOT file will be dated with the current date, not the date of the files. You will need to manually rename the SOT file with the appropriate date. We also added a 3-digit code to the end of the file name that corresponded to the CSOT processing parameters used on that file (e.g., "HW5" for High Water setting #5 or "LW2" for Low Water setting #2).
7. Only merge one day's worth of files at a time. This way, if you find you have to adjust your CSOT parameters, you don't have to repeat this process. Merging one day's worth of files can take between 2-20min, depending on the CSOT parameters used.

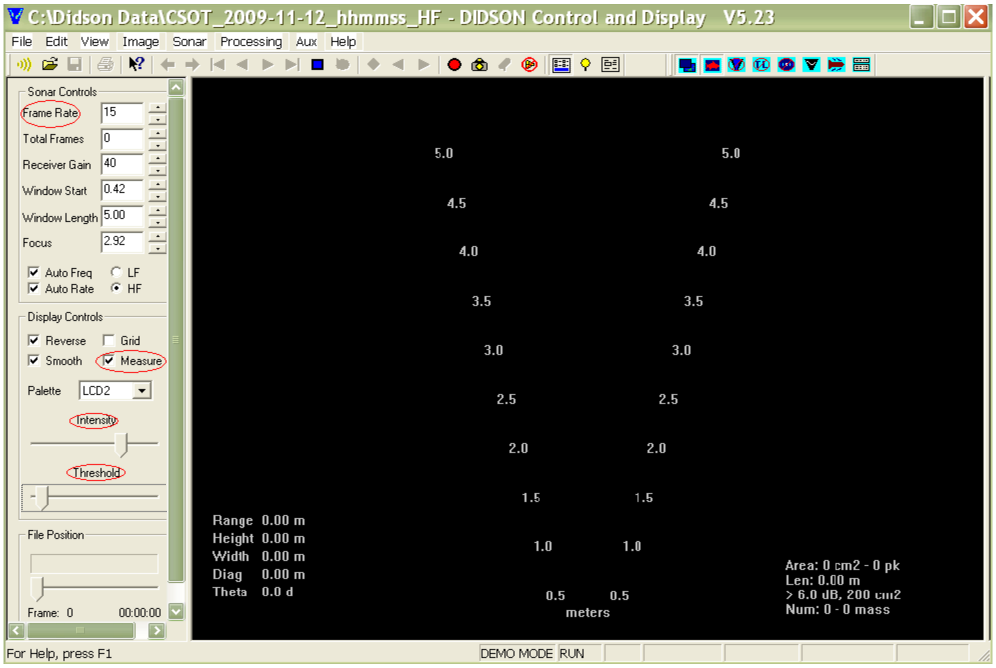
See DIDSON Operation Manual for more details on merging files.

File Review Using DST

Getting Started

1. Open SOT file from CSOTS_Appended folder.
2. Turn on background subtraction (Processing/Background/Background Subtraction).
3. Click on the yellow magnifying glass on the tool bar.
4. Check ‘Measure’ on the Display Controls pane.

5. Set frame rate on the sonar controls pane to desired rate (15-17 is a good start).
6. Set intensity slider in sonar controls pane to 65-70.
7. Set threshold slider in sonar controls pane to 4.



C:\Didson Data\CSOT_2009-11-12_hhmmss_HF - DIDSON Control and Display V5.23

Frame Rate 15
Total Frames 0
Receiver Gain 40
Window Start 0.42
Window Length 5.00
Focus 2.92

☑ Auto Freq ○ LF
☑ Auto Rate ● HF

☑ Reverse ☐ Grid
☑ Smooth ☑ Measure

Palette LCD2

Frame: 0 00:00:00

Range 0.00 m
Height 0.00 m
Width 0.00 m
Diag 0.00 m
Theta 0.0 d

Area: 0 cm2 - 0 pk
Len: 0.00 m
> 6.0 dB, 200 cm2
Num: 0 - 0 mass

8. Play file using blue arrow or keyboard controls.

Identifying and Processing Your First Fish using the DST*

*We used Microsoft Excel to set-up/run our Decision Support Tool. A copy of the DST spreadsheet is available from the author upon request.

1. Pause file when a fish appears. Fish must show signs of movement (e.g., moves across current, moves faster than current, moves upstream, displays a rhythmic undulation, etc.) Debris floating downstream can sometimes look like a fish. Play the footage forward and backward to get a good look at your target. If you are still unsure, you can look at the acoustic shadow created by the target. Items floating on the surface will not cast a shadow. To look at a shadow, adjust the threshold slider to 0 and then play the footage forward and backward. Shadows from steelhead should be obvious (Example 4). Sticks will have very thin shadows or none at all. You can also look at the raw footage or turn off the background subtraction to get a different view. You can also use the Transmission Loss button on the fish toolbar to reduce the amount of noise and "Flare" in the image. In rare instances, it may not be possible to positively determine if the target you are viewing is a fish or not; in these cases, use all the tools available in the DIDSON software to aid in target review to make the best decision possible.
2. Rewind footage to the first frame in which the fish appeared.
3. Record the Date in the DST. (Note: This is the date of the file, not the review date).
4. Copy and paste the PC Clock time from the Identification window on the DIDSON screen to the Time INI arrive column on the DST.
5. Play the footage forward until the fish is *fully* in the field of view.
6. Take measurements of three frames showing good acoustic returns. Note the diagonal measurements and range in the "L" and "R" columns of the DST. (For more on measuring, see 'Measuring Fish' and 'Choosing Frames to Measure' sections of this document).
7. Advance the footage until the fish disappears from view, then rewind back to the last frame in which the fish is present. Copy and paste the PC Clock time into the Time INI Leave column of the DST.
8. Note the quality of frames (see 'Choosing Frames to Measure' section).
9. Direction is a two-digit code consisting of an origin (first letter) and a final destination (second letter). U = upstream and D = downstream. For example, DU = a fish that originated downstream of the camera and disappeared upstream of the camera. UD = a fish that originated upstream of the camera and disappeared downstream of the camera.
10. If the CSOT footage is inconclusive, it may help to look at the raw footage. This is most easily done by opening a second DIDSON pane. Note the PC Clock time and open the corresponding raw file. Use the file position slider to advance to the time of interest. Play the footage. If you use the raw footage for any reason, make sure to note it in the comments field.

11. If you are still undecided about the directional fate of your fish, add a "?" to the two digit code. Warning – by doing so, the fish will not be tallied in the net count.
12. Your first fish will get a Fish ID of 1. (See 'Making Comparisons' for more on FISH ID.)

Measuring Fish

1. To measure fish, use the rectangle/box technique.
2. To use the box measuring technique, first make sure that the measure box in the Display Controls pane is checked. Make sure that the yellow magnifying glass on the tool bar is also checked.
3. Zoom in on your target by right-clicking on the target.
4. Start at the head of the fish and right-click (holding down button); then drag a box around the target to the tail. The measurement will be displayed in the lower left portion of the DIDSON screen. The diagonal ("Diag") is the value that should be used for the length measurement. The range from the camera is also displayed here. Range is measured from the camera to the bottom line of your box.
5. If you make a mistake, simply re-draw a new box and new measurements will appear.
6. Once you have completed the first measurement, you can zoom out (by right-clicking) and advance the footage to the next frame you want to measure. (See 'Choosing Frames to Measure' section.)
7. Repeat process until you have recorded three length measurements and three ranges for each fish observed.

Choosing Frames to Measure

1. Always look for frames with quality acoustic returns, where the true length of the fish is displayed. This is not always the brightest return.
2. Look for frames away from the margins (Example 1). Fish tend to have more flare and tend to be elongated at the edges of the screen. It is also possible that a portion of the fish is off the screen, resulting in a poor measurement.
3. Look for frames where the fish is at a slight angle to the camera. Fish that are perpendicular often have heavy flare (Example 2).
4. Look for "Gap Fish" frames where the head and tail are lit up but the body is not. Gap Fish tend to be very accurate frames to measure (Example 3).
5. Look for frames without a lot of flare or noise. Flare can easily make a fish look much larger than it really is (Example 6). Fish that are perpendicular to the camera often have a lot of flare (Example 5). Small fish will often display a lot of flare, making them appear as if they are large enough to include in the DST (depending on study-specific size criteria). Play the footage forward and

6. Avoid frames where fish are overlapping (Example 7).
7. Look for frames with defined start and end points (Example 8).
8. If two or more fish are on the screen at once, make sure that they are not masking each other by watching the footage forward and backward (Examples 7 and 8).
9. Even if the return is faint (Example 9), it can still yield a good measurement if the head and tail are displayed.
10. There is a rating scale for the quality of frames used for each fish.

    3 = 3 good frames
    2 = 1-2 good frames
    1 = 1 good frame or less (or shadow only)

    If you encounter a fish where there are fewer than 3 frames total, you can repeat the measurement from the best frame you have. Be sure to highlight repeated measurements in light green.
11. If a fish is never present in any frames, but clearly a fish-shaped shadow passes the camera, you can estimate the length of the fish, based loosely on the size of the shadow. Be sure to highlight these measurements in pink.
12. Beware of floating objects (e.g., logs, sticks, debris) that may appear to be a fish and other aquatic animals such as ducks, mergansers (Example 10), otters, beavers, etc. These are usually easy to decipher that they are non-fish, but can take some experience to determine initially.

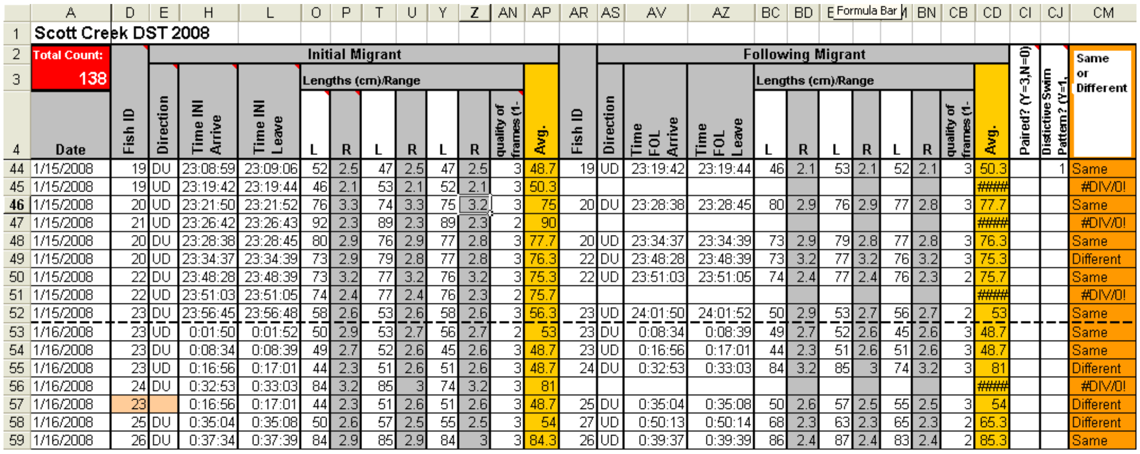
Not enough good frames to measure

1. Fish may swim past the DIDSON viewing area very quickly or at a steep angle to the camera, resulting in only one or two good frames in which to measure.
2. You can repeat a measurement from a frame you have already measured. To do this, simply copy and paste the measurement from the previous frame. Be sure to highlight these repeated measurements in light green. These measurements may not be included in the final analysis.
3. A fish may swim directly in front of the camera, casting only a shadow. Although the fish is not present, the shadow can still tell you the direction of travel. Play the footage forward and backward to determine the direction. Estimate the length for fish only displaying a shadow. Flag any cell with an estimated measurement in pink. These measurements may not be included in the final analysis. Try not to make DST comparisons with fish only appearing as shadows, as their length measurements are only ‘best-guess’ estimates. Assign a new Fish ID and continue with the next fish.

Making comparisons using the DST

1. Play the footage until you find the next fish and pause.

2. **To compare two observations of fish, the following criteria must be met:**
    - **The time elapsed between observations must be less than 1 hour.**
    - **The origin of the following fish must be the same as the destination of the original fish. (Example: you can compare a UD fish to a DU fish. You cannot compare a DU fish to another DU fish.)**
3. If either of the above criteria is not met, you will enter the fish as Fish ID 2 on the line directly below the first fish you entered in the Initial Migrant column. This fish will not be compared to the first fish.



	A	D	E	H	L	O	P	T	U	Y	Z	AN	AP	AR	AS	AV	AZ	BC	BD	E	Formula Bar	M	BN	CB	CD	CI	CJ	CM
1	Scott Creek DST 2008																											
2	Total Count:	Fish ID	Initial Migrant											Fish ID	Following Migrant											Paired? (Y=3,N=0)	Distictive Swim Pattern? (Y=1,	Same or Different
3	138		Direction	Time INI Arrive	Time INI Leave	Lengths (cm)/Range							Avg.		Direction	Time FOL Arrive	Time FOL Leave	Lengths (cm)/Range							Avg.			
4	Date					L	R	L	R	L	R	quality of frames (1-						L	R	L	R	L	R	quality of frames (1-				
44	1/15/2008	19	DU	23:08:59	23:09:06	52	2.5	47	2.5	47	2.5	3	48.7	19	UD	23:19:42	23:19:44	46	2.1	53	2.1	52	2.1	3	50.3		1	Same
45	1/15/2008	19	UD	23:19:42	23:19:44	46	2.1	53	2.1	52	2.1	3	50.3												#####			#DIV/0!
46	1/15/2008	20	UD	23:21:50	23:21:52	76	3.3	74	3.3	75	3.2	3	75	20	DU	23:28:38	23:28:45	80	2.9	76	2.9	77	2.8	3	77.7			Same
47	1/15/2008	21	UD	23:26:42	23:26:43	92	2.3	89	2.3	89	2.3	2	90												#####			#DIV/0!
48	1/15/2008	20	DU	23:28:38	23:28:45	80	2.9	76	2.9	77	2.8	3	77.7	20	UD	23:34:37	23:34:39	73	2.9	79	2.8	77	2.8	3	76.3			Same
49	1/15/2008	20	UD	23:34:37	23:34:39	73	2.9	79	2.8	77	2.8	3	76.3	22	DU	23:48:28	23:48:39	73	3.2	77	3.2	76	3.2	3	75.3			Different
50	1/15/2008	22	DU	23:48:28	23:48:39	73	3.2	77	3.2	76	3.2	3	75.3	22	UD	23:51:03	23:51:05	74	2.4	77	2.4	76	2.3	2	75.7			Same
51	1/15/2008	22	UD	23:51:03	23:51:05	74	2.4	77	2.4	76	2.3	2	75.7												#####			#DIV/0!
52	1/15/2008	23	DU	23:56:45	23:56:48	58	2.6	53	2.6	58	2.6	3	56.3	23	UD	24:01:50	24:01:52	50	2.9	53	2.7	56	2.7	2	53			Same
53	1/16/2008	23	UD	0:01:50	0:01:52	50	2.9	53	2.7	56	2.7	2	53	23	DU	0:08:34	0:08:39	49	2.7	52	2.6	45	2.6	3	48.7			Same
54	1/16/2008	23	DU	0:08:34	0:08:39	49	2.7	52	2.6	45	2.6	3	48.7	23	UD	0:16:56	0:17:01	44	2.3	51	2.6	51	2.6	3	48.7			Same
55	1/16/2008	23	UD	0:16:56	0:17:01	44	2.3	51	2.6	51	2.6	3	48.7	24	DU	0:32:53	0:33:03	84	3.2	85	3	74	3.2	3	81			Different
56	1/16/2008	24	DU	0:32:53	0:33:03	84	3.2	85	3	74	3.2	3	81												#####			#DIV/0!
57	1/16/2008	23		0:16:56	0:17:01	44	2.3	51	2.6	51	2.6	3	48.7	25	DU	0:35:04	0:35:08	50	2.6	57	2.5	55	2.5	3	54			Different
58	1/16/2008	25	DU	0:35:04	0:35:08	50	2.6	57	2.5	55	2.5	3	54	27	UD	0:50:13	0:50:14	68	2.3	63	2.3	65	2.3	2	65.3			Different
59	1/16/2008	26	DU	0:37:34	0:37:39	84	2.9	85	2.9	84	3	3	84.3	26	UD	0:39:37	0:39:39	86	2.4	87	2.4	83	2.4	2	85.3			Same

4. *If **both** of the above criteria are met*, you will enter the fish in the Following Migrant column of the DST, in the same row as the fish you are using for the comparison. Leave the Fish ID blank until the comparison has been made. Once all the information on the Following Migrant has been entered, the spreadsheet (orange column to far right) will tell you if the fish are the same or different, based on the point values described earlier.
5. If the Initial and Following Migrants are determined to be the *Same*, the Following Migrant Fish ID will be the same as the Initial Migrant Fish ID. For example, in the screen shot above on line 44, the Initial and Following Migrants were determined to be the same, so the Fish ID (19) numbers are the same for each.
6. If the Initial and Following Migrants are determined to be *Different*, the Following Migrant will get the next sequential Fish ID. For Example, on line 49 above the Initial and Following Migrants were determined to be different. The Initial Migrant's Fish ID was 20. The Following Migrant was assigned a Fish ID of 22, since Fish ID 21 was already used on line 47.
7. Regardless if the fish are determined to be the same or different, you will copy all of the information from the Following Migrant section (everything between the gold 'Avg.' columns) and paste it on the next available Initial Migrant row. This should be done for every fish that is entered in the Following Migrant section. The reason is that the Following Migrant section is used solely for making comparisons. The Initial Migrant section is essentially a list of ALL fish that

Making Multiple Comparisons

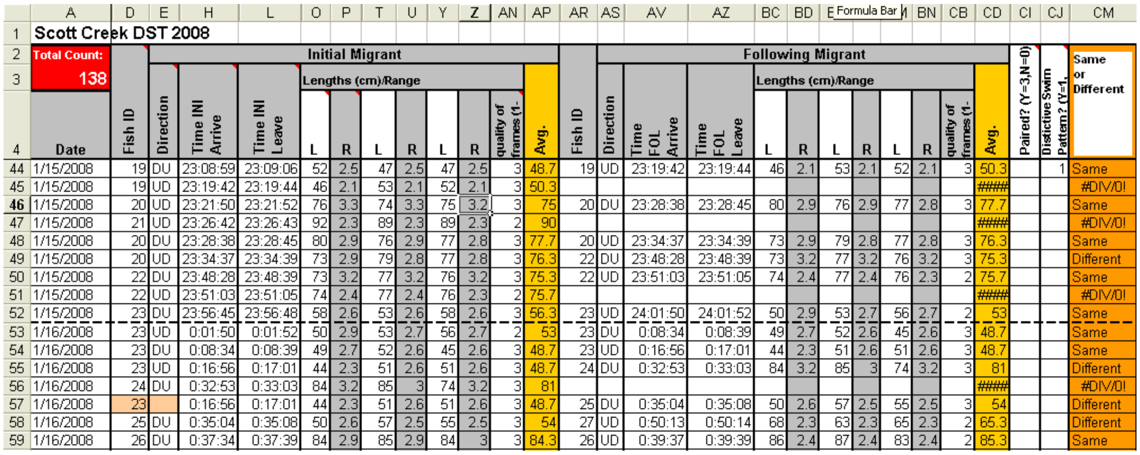
1. Often, the comparisons you make will result in fish being different. But what if you wanted to compare this fish to a second or third fish? For example, four consecutive fish go downstream, and then one comes back up. Which fish will you compare it to?
2. In order to make multiple comparisons, you will have to duplicate the data.
3. First, copy the fish you wish to compare again into the INI section on the next available row.
4. Highlight the Fish ID and Direction cells light tan (See line 57 in previous example). This flags the data as duplicate so it is not later counted as a new fish.
5. Erase the directional cell. This is to avoid recounting the duplicate data in the automatic net count (See line 57 in previous example). Notice the INI Fish ID 23 was also used on line 55.
6. You can then make a second comparison with this fish by entering a fish in the adjacent Following Migrant section. WARNING: By doing this, your Fish ID numbers will be non-sequential. This is OK, but take caution to make sure you are not inadvertently re-using Fish ID numbers.
7. You can repeat this process as many times as you like, but it is not recommended to make more than three comparisons.
8. When a fish has multiple opportunities to be compared, enter the data on a blank line of the spreadsheet to get the average length, and then make the comparison to the fish of most similar size.

Pairing and Distinctive Swimming Patterns

1. There are two columns to the right of the Following Migrant section, 'Pairing' and 'Distinctive Swimming Pattern.'
2. If two fish are present on screen, in the same frame, they are considered paired. This does not mean, however, that they receive pairing points.
3. To get the three points for being paired, a pair must go downstream paired AND come back upstream paired (or vice versa) AND be of similar size. If a pair of fish goes downstream, and two individual fish come back upstream, no points are awarded. If a large fish and a small fish are paired going downstream and two large fish return paired going upstream, no points are awarded.
4. Distinctive swimming pattern can be subjective depending on the reviewer. Some examples of distinctive swimming patterns include: swimming VERY fast, swimming VERY slow, holding in the exact same spot for periods of time, swimming in circles, etc. To qualify for a point, the behavior must be present on

Comparisons Across Different Days

1. Occasionally you will have a fish milling at the end of a day's file and the fish reappears early in the next day's file.



	A	D	E	H	L	O	P	T	U	Y	Z	AN	AP	AR	AS	AV	AZ	BC	BD	E	Formula Bar	M	BN	CB	CD	CI	CJ	CM
1	Scott Creek DST 2008																											
2	Total Count:	Fish ID	Initial Migrant											Fish ID	Following Migrant											Paired? (Y=3,N=0)	Distictive Swim Pattern? (Y=1,	Same or Different
3	138		Direction	Time INI Arrive	Time INI Leave	Lengths (cm)/Range							Avg.		Direction	Time FOL Arrive	Time FOL Leave	Lengths (cm)/Range							Avg.			
4	Date					L	R	L	R	L	R	quality of frames (1-						L	R	L	R	L	R	quality of frames (1-				
44	1/15/2008	19	DU	23:08:59	23:09:06	52	2.5	47	2.5	47	2.5	3	48.7	19	UD	23:19:42	23:19:44	46	2.1	53	2.1	52	2.1	3	50.3		1	Same
45	1/15/2008	19	UD	23:19:42	23:19:44	46	2.1	53	2.1	52	2.1	3	50.3												#####			#DIV/0!
46	1/15/2008	20	UD	23:21:50	23:21:52	76	3.3	74	3.3	75	3.2	3	75	20	DU	23:28:38	23:28:45	80	2.9	76	2.9	77	2.8	3	77.7			Same
47	1/15/2008	21	UD	23:26:42	23:26:43	92	2.3	89	2.3	89	2.3	2	90												#####			#DIV/0!
48	1/15/2008	20	DU	23:28:38	23:28:45	80	2.9	76	2.9	77	2.8	3	77.7	20	UD	23:34:37	23:34:39	73	2.9	79	2.8	77	2.8	3	76.3			Same
49	1/15/2008	20	UD	23:34:37	23:34:39	73	2.9	79	2.8	77	2.8	3	76.3	22	DU	23:48:28	23:48:39	73	3.2	77	3.2	76	3.2	3	75.3			Different
50	1/15/2008	22	DU	23:48:28	23:48:39	73	3.2	77	3.2	76	3.2	3	75.3	22	UD	23:51:03	23:51:05	74	2.4	77	2.4	76	2.3	2	75.7			Same
51	1/15/2008	22	UD	23:51:03	23:51:05	74	2.4	77	2.4	76	2.3	2	75.7												#####			#DIV/0!
52	1/15/2008	23	DU	23:56:45	23:56:48	58	2.6	53	2.6	58	2.6	3	56.3	23	UD	24:01:50	24:01:52	50	2.9	53	2.7	56	2.7	2	53			Same
53	1/16/2008	23	UD	0:01:50	0:01:52	50	2.9	53	2.7	56	2.7	2	53	23	DU	0:08:34	0:08:39	49	2.7	52	2.6	45	2.6	3	48.7			Same
54	1/16/2008	23	DU	0:08:34	0:08:39	49	2.7	52	2.6	45	2.6	3	48.7	23	UD	0:16:56	0:17:01	44	2.3	51	2.6	51	2.6	3	48.7			Same
55	1/16/2008	23	UD	0:16:56	0:17:01	44	2.3	51	2.6	51	2.6	3	48.7	24	DU	0:32:53	0:33:03	84	3.2	85	3	74	3.2	3	81			Different
56	1/16/2008	24	DU	0:32:53	0:33:03	84	3.2	85	3	74	3.2	3	81												#####			#DIV/0!
57	1/16/2008	23		0:16:56	0:17:01	44	2.3	51	2.6	51	2.6	3	48.7	25	DU	0:35:04	0:35:08	50	2.6	57	2.5	55	2.5	3	54			Different
58	1/16/2008	25	DU	0:35:04	0:35:08	50	2.6	57	2.5	55	2.5	3	54	27	UD	0:50:13	0:50:14	68	2.3	63	2.3	65	2.3	2	65.3			Different
59	1/16/2008	26	DU	0:37:34	0:37:39	84	2.9	85	2.9	84	3	3	84.3	26	UD	0:39:37	0:39:39	86	2.4	87	2.4	83	2.4	2	85.3			Same

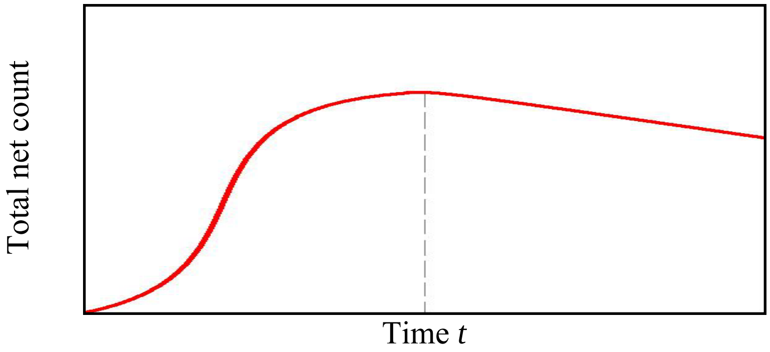
2. An example of this is provided on line 52 above. The last fish on the 15th of January (Fish ID INI-23) disappeared at 23:56:48, and the first fish on the 16th of January (Fish ID FOL-23) appeared at 00:01:50. The time off camera formula would calculate this as a time off camera of ~23 hours. This is inaccurate because the true time off camera is ~5min. To make the comparison between these two fish, you will need to adjust the time on the following migrant to be 24:01:50. The reason for this is that the formula for calculating the time off camera does not incorporate the date. By changing the time on the following migrant from 00:01:50 to 24:01:50, you have essentially put the fish on the same day, while maintaining the correct time stamp. You will see that the comparison was successful (same fish). When copying the following migrant into the initial migrant section, the time stamp is switched back to 00:01:50, to allow for future comparisons for that day's file.

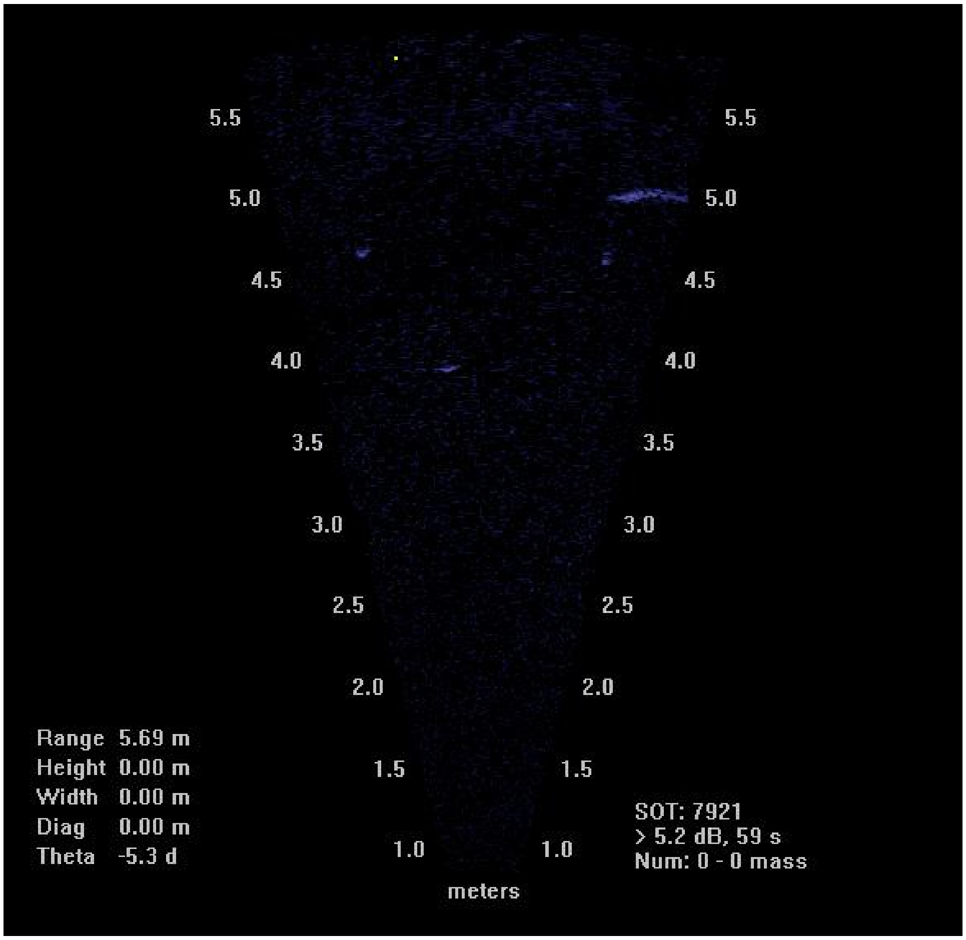
Computing Daily Net Count and Total Escapement

1. To determine the daily total of fish heading upstream, simply count the number of "DU" (downstream to upstream) fish that were different according to the DST and subtract the number of "UD" (upstream to downstream) for each 24-hour period.

2. Determine the peak date when upstream migration begins to decline by plotting total net count versus time (*t*) (see below). After this date, if a migrant is determined by the DST to be different than any recent upstream migrants and originates upstream of the camera and proceeds downstream, then flag as a kelt and do not subtract from the net upstream count.

Kelt Timing: Is date of observation > Time *t* ?

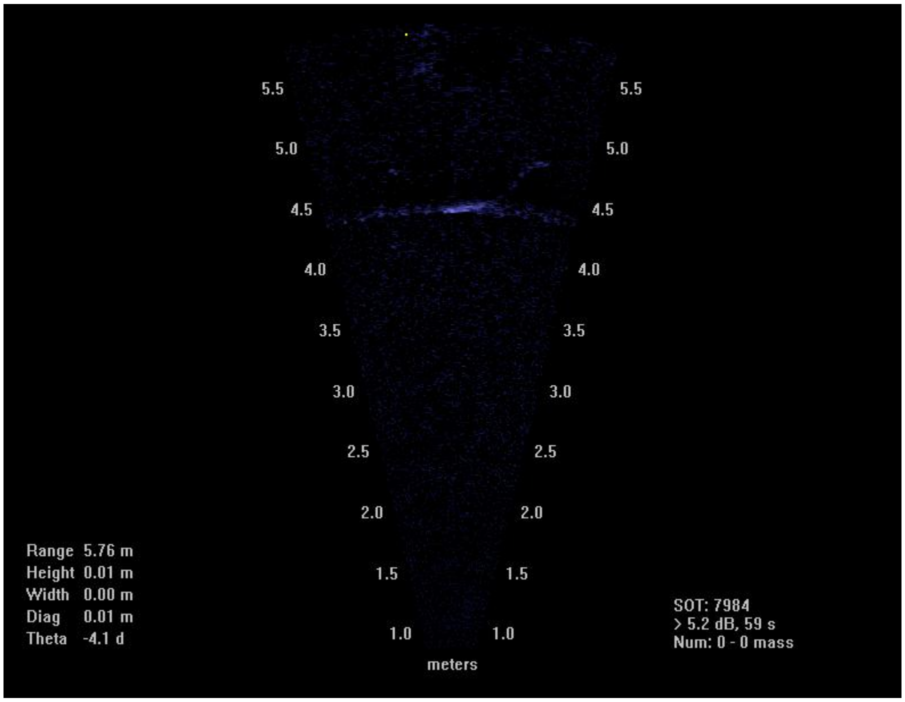




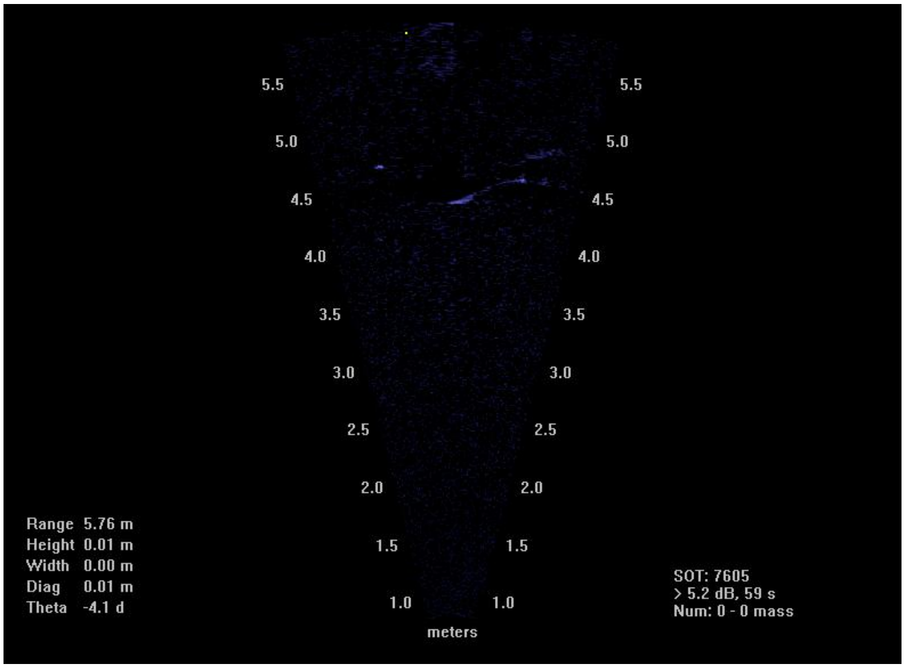
Range 5.69 m
Height 0.00 m
Width 0.00 m
Diag 0.00 m
Theta -5.3 d

SOT: 7921
> 5.2 dB, 59 s
Num: 0 - 0 mass

Example 1. Poor frame to use for measuring. Fish is at margin of frame.



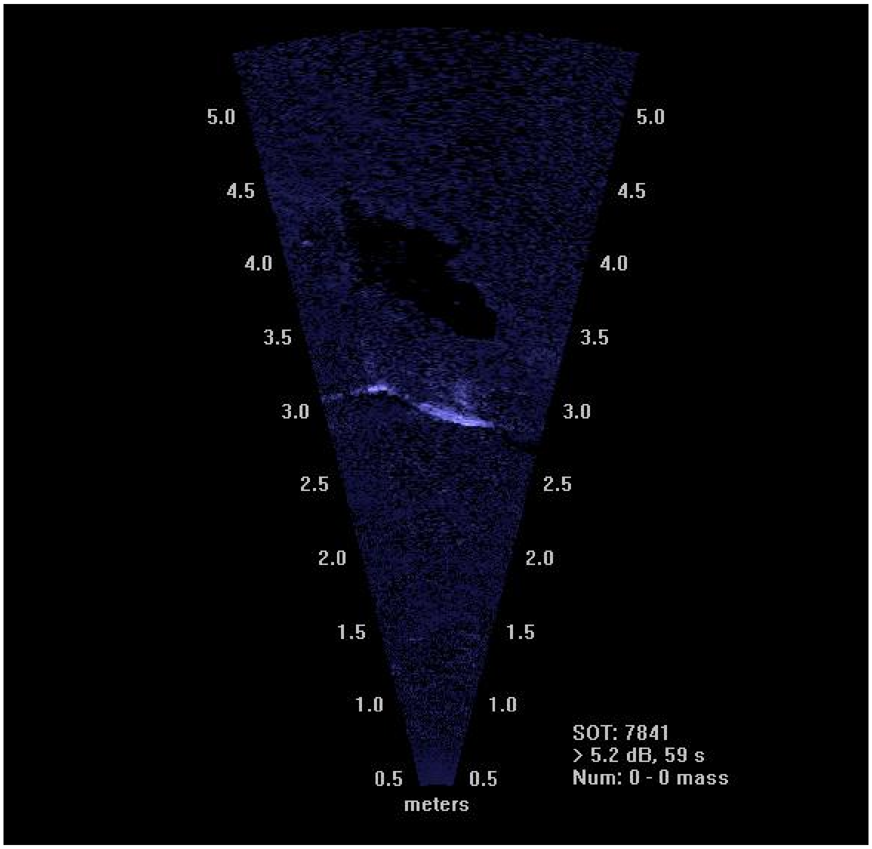
Example 2. Poor frame to use for measuring. Lots of flare and only a portion of the fish are displayed. Example 3 on the next page shows a good frame of this same fish.



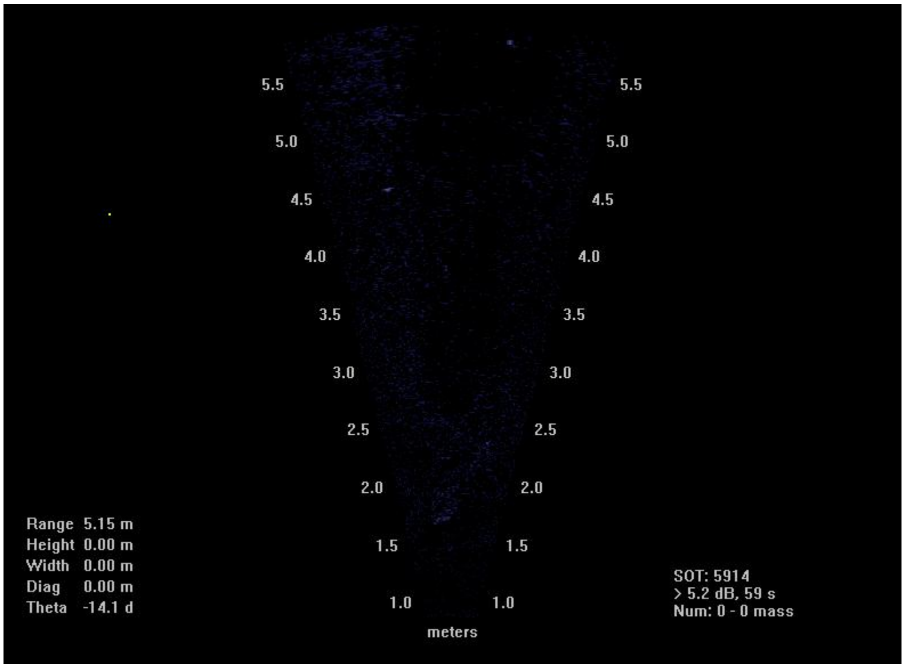
Range 5.76 m
Height 0.01 m
Width 0.00 m
Diag 0.01 m
Theta -4.1 d

SOT: 7605
> 5.2 dB, 59 s
Num: 0 - 0 mass

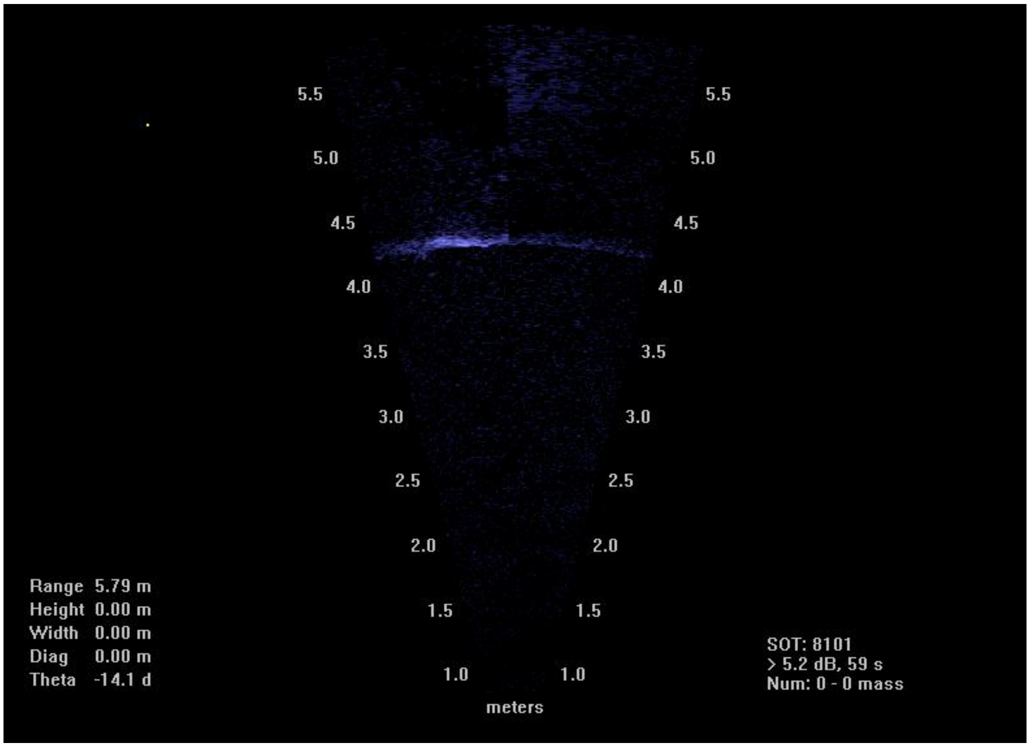
Example 3. This is the same fish as Example 2. This is a good example of a "Gap Fish" which is generally a good frame-type to measure. Both the head and tip of the tail are displayed with little flare. Notice how much shorter the fish appears in Example 2.



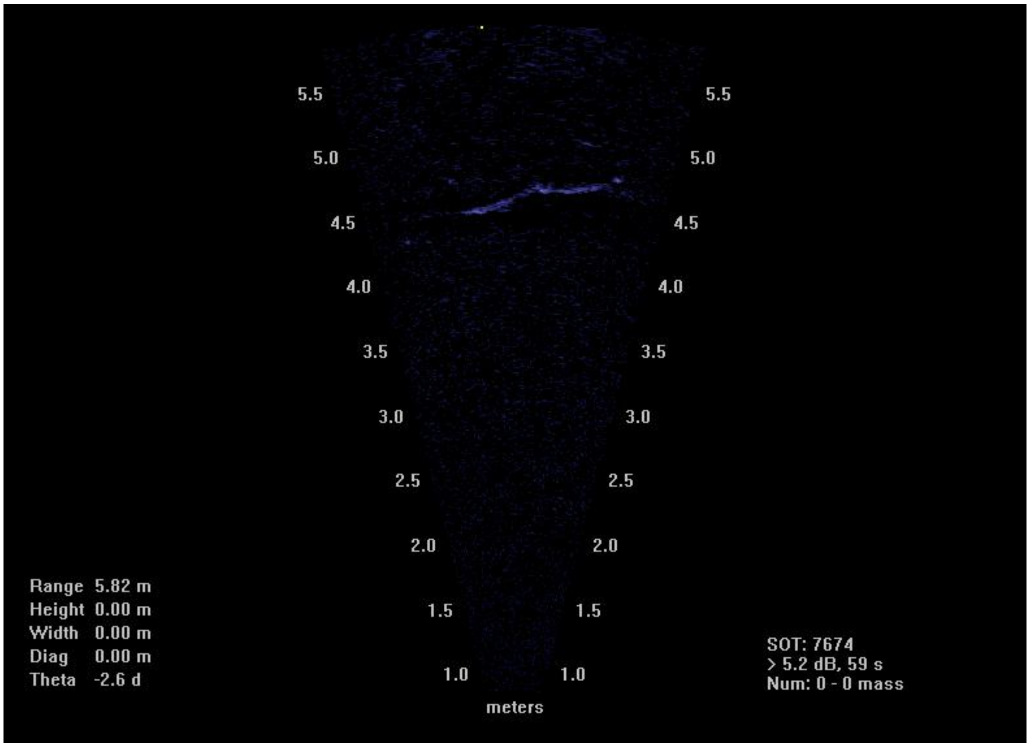
Example 4. Good shadow. Threshold slider was set to 0 to exaggerate the shadow. Use of Transmission Loss here decreases flare and creates a good frame to measure.



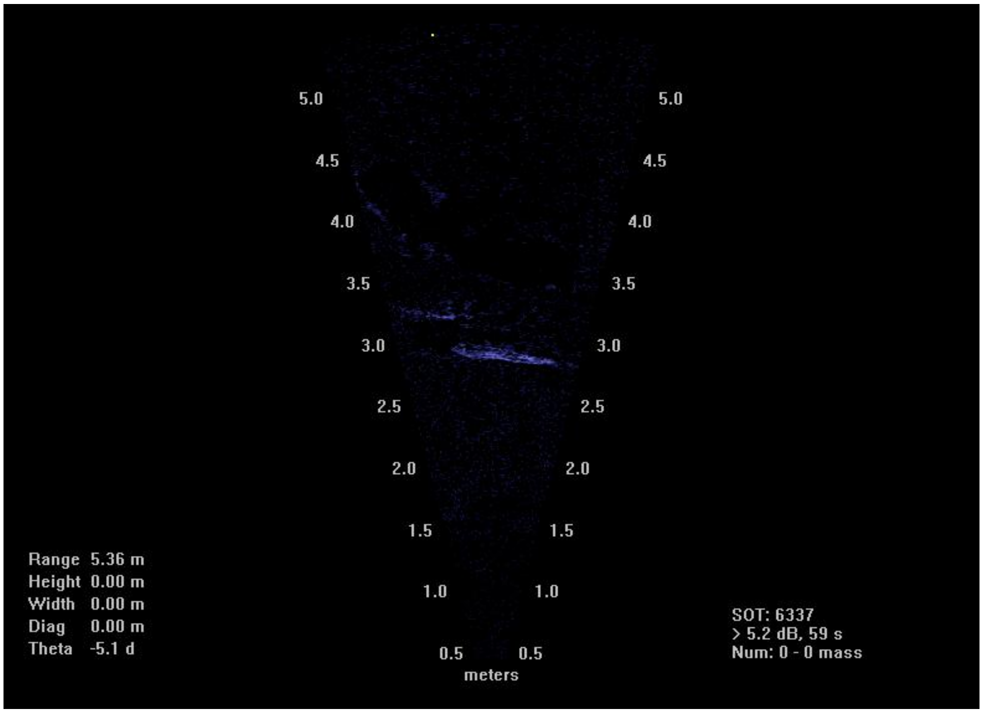
Example 5. Poor frame to use for a measurement. Fish is at a steep angle (~1.75m) with very little acoustic return. Note that the shadow is still apparent, even if the fish is not.



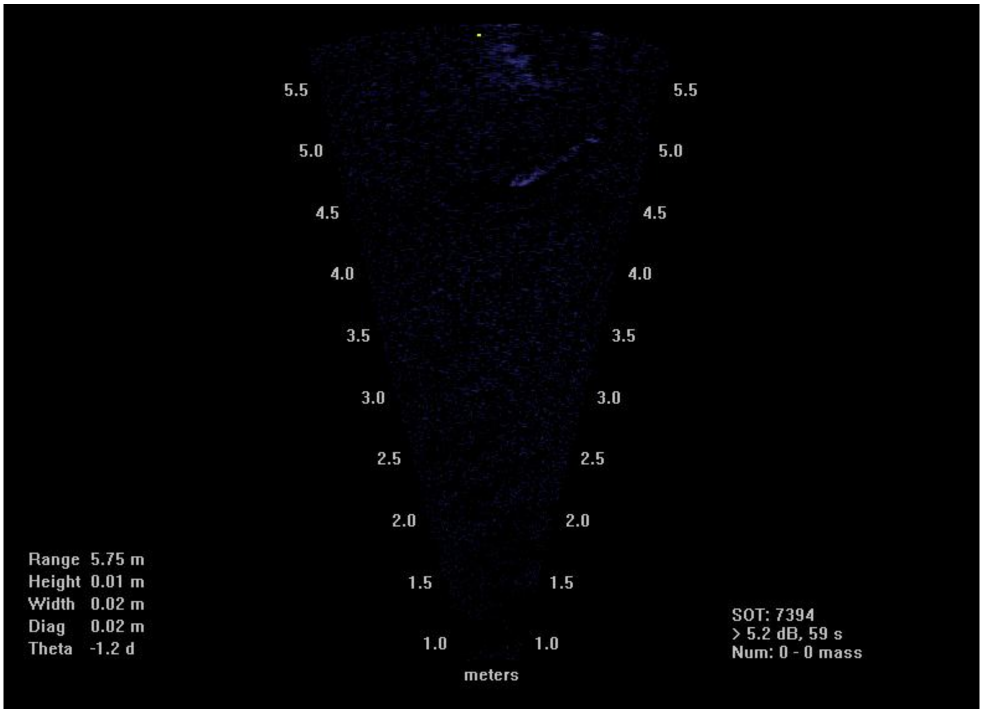
Example 6. Poor frame with excessive flare and no defined head or tail. Note how the shadow shows the true position of the tail.



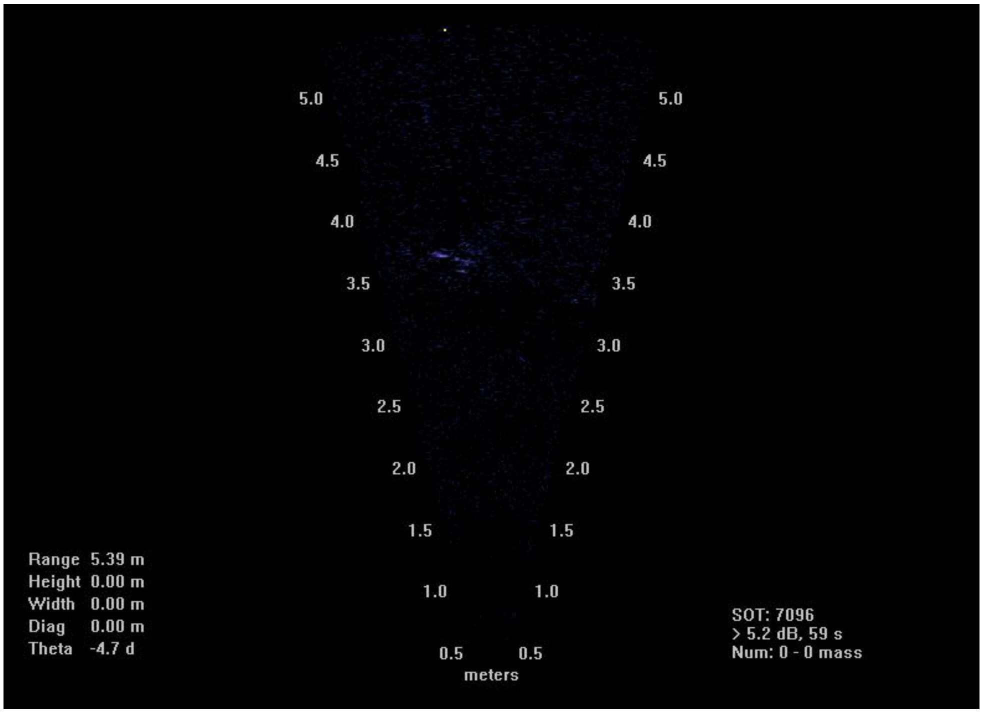
Example 7. Poor frame. Two fish overlapping. Hard to tell where one starts and the other one ends.



Example 8. Great frame for the lower fish. Slight angle to the camera, head and tail displayed with no flare.



Example 9. Good frame. Even though the return is faint, it is still a good return. Head and tail are displayed with no flare.



Range 5.39 m
Height 0.00 m
Width 0.00 m
Diag 0.00 m
Theta -4.7 d

SOT: 7096
> 5.2 dB, 59 s
Num: 0 - 0 mass

Example 10. Merganser. Ducks often show up as a loose collection of moving pixels as seen here at 3.5m.

RECENT TECHNICAL MEMORANDUMS

SWFSC Technical Memorandums are accessible online at the SWFSC web site (http://swfsc.noaa.gov). Copies are also available form the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161 (http://www.ntis.gov). Recent issues of NOAA Technical Memorandums from the NMFS Southwest Fisheries Science Center are listed below:

NOAA-TM-NMFS-SWFSC-444 Predictive modeling of cetacean densities in the eastern Pacific ocean.
J. BARLOW, M.C. FERGUSON, E.A. BECKER, J.V. REDFERN,
K.A. FORNEY, I.L. VILCHIS, P.C. FIEDLER, T. GERRODETTE, and
L.T. BALLANCE
(May 2009)

445 AMLR 2008/09 field season report: Objectives, Accomplishments, and Tentative Conclusions.
A.M. VAN CISE, Editor
(May 2009)

446 Life history aspects of greenspotted rockfish *(Sebastes chlorostictus)* from central California.
D.L. BENET, E.J. DICK, and D.E. PEARSON
(July 2009)

447 What caused the Sacramento River Fall Chinook stock collapse?
S.T. LINDLEY, C.B. GRIMES, M.S. MOHR, W. PETERSON, J. STEIN
J.T. ANDERSON, L.W. BOTSFORD, D.L. BOTTOM, C.A. BUSACK,
T.K. COLLIER, J. FERGUSON, J.C. GARZA, A.M. GROVER, D.G. HANKIN
R.G. KOPE, P.W. LAWSON, A. LOW, R.B. MacFARLANE, K. MOORE,
M. PALMER-ZWAHLEN, F.B. SCHWING, J. SMITH, C. TRACY, R. WEBB,
B.K. WELLS, and T.H. WILLIAMS
(July 2009)

448 Estimation of population size with molecular genetic data.
E.C. ANDERSON and J.C. GARZA
(September 2009)

449 Spawning biomass of Pacific sardine(Sardinops sagax) off California in 2009.
N.C.H. LO, B.J. MACEWICZ, and D.A. GRIFFITH
(October 2009)

450 Review of the evidence used in the description of currently recognized cetacean subspecies.
W.F. PERRIN, J.G. MEAD, and R.L. BROWNELL, JR.
(December 2009)

451 Climate change in California: Implications for the recovery and protection of Pacific salmon and steelhead.
F. SCHWING, S. LINDLEY, E. DANNER, and D. BOUGHTON
(December 2009)

452 Assessment of the Pacific sardine resource in 2009 for U.S. management in 2010.
K.T. HILL, N.C.H. LO, B.J. MACEWICZ, P.R. CRONE and R. FELIX-URAGA
(December 2009)

453 U.S. Pacific marine mammal stock assessments: 2009
J.V. CARRETTA, K.A. FORNEY, M.S. LOWRY, J. BARLOW, J. BAKER,
D. JOHNSTON, B. HANSON, R.L. BROWNELL, JR., J. ROBBINS,
D.K. MATTILA, K. RALLS, M.M. MUTO, D. LYNCH, and L. CARSWELL
(January 2010)