A Decision Matrix for Coho Salmon and Steelhead Life-Cycle Monitoring Stations in California Coastal Streams: Scott Creek Case Study

Submitted To:
Resource Conservation District of Santa Cruz

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INTRODUCTION

Central California Coast (CCC) salmonids have been in decline for many years and only rough estimates of their historical abundances exist, hampering state and federal recovery efforts. The CCC coho salmon (*Oncorhynchus kisutch*) Evolutionarily Significant Unit (ESU) from Punta Gorda in Northern California south to Aptos Creek in Santa Cruz County, is federally listed as endangered (70 FR 37160) due to severe population declines (NMFS 2012). The CCC steelhead (*O. mykiss*) Distinct Population Segment (DPS) from the Russian River to Aptos Creek, is listed as threatened due to declining abundance and productivity (NMFS 2007). However, in developing a Recovery Strategy for California Coho Salmon the California Department of Fish and Wildlife (CDFW; formerly Fish and Game) found that reliable estimates of abundance, population growth rate, population structure, and diversity were not available to assess population viability or to determine viability targets for CCC coho salmon (CDFW 2004). Task *RW-AM-07* of the CDFW Recovery Strategy seeks to address these crucial data gaps by developing and implementing a strategic, long-term population assessment and monitoring program for coho salmon. Likewise, the Federal Recovery Outline for the DPS of CCC Steelhead (NMFS 2007) described information on abundance and productivity trends of naturally spawning CCC steelhead as “extremely limited”, and indicated that improved research and monitoring was a priority task for recovery of the CCC steelhead DPS.

The California Coastal Salmonid Monitoring Plan (CMP) describes the general strategy, design, and methods developed to monitor coastal salmonid populations (Adams et al. 2011). The CMP proposes to use fixed Life-Cycle Monitoring Stations (“Stations”) for collecting long-term, population-level data in a consistent manner to assess progress towards abundance viability goals and the effects of changing freshwater and marine conditions. Stations are a set of monitoring equipment or methods that gather annual census data on adult and juvenile salmonids, and can be an effective and economic tool for collecting standardized long-term data for quantitative evaluation of anadromous fish populations. Stations proposed by the monitoring plan include three components: 1) an adult counting station, 2) spawner surveys upstream from the counting station (i.e., redd surveys to estimate redd-to-adult bias corrections), and 3) outmigrant juvenile trapping. Stations have already been established in several creeks to monitor CCC coho salmon and CCC steelhead (Boydstun and Mcdonald 2005); however, additional Stations are needed “as soon as possible” to extend the geographic coverage (Adams et al. 2011). There are also opportunities to improve the efficiency and effectiveness of adult and juvenile monitoring at existing Stations.

The CMP lays out a strategy for monitoring and describes several sampling techniques that could be used for the adult counting station and juvenile trapping station components (e.g., video systems, weirs, DIDSON), but it does not recommend particular sampling techniques for these Stations, recognizing that the best technique will be site specific. Selecting the appropriate

Station locations and techniques for life-cycle monitoring can be challenging due to the diversity of fluvial environments, range of techniques available, and scope of effort to maintain. Stations can vary widely in initial start-up costs and long-term maintenance expenses. Stations can be logistically complex or relatively simple depending on the monitoring equipment used, and it is important to fully understand the characteristics of the watershed to identify the benefits or drawbacks of potential monitoring techniques.

Often times, resource managers are tasked with developing a sampling plan without much prior experience or knowledge of the sampling techniques that are available and how effective they are under various environmental conditions. Many fish counting methods are implemented as part of long-term monitoring projects, thus peer-reviewed studies describing the methods and operational considerations are uncommon. Duffy (2005) presented to CDFW recommendations on monitoring protocols for detecting responses of salmon and steelhead populations to watershed restoration actions. While this document provides valuable details on the assumptions, limitations and sample designs for each recommended method, it does not provide a tool for determining which monitoring method is ideal for a given set of conditions. Determining the appropriate techniques for a given site requires knowledge of both the monitoring methods and the site itself. The objective of this study was to develop a decision tool to assist resource managers, researchers, and other fisheries professionals in designing a sampling program for CCC coho salmon and steelhead populations to collect reliable data in a cost effective and scientifically sound manner. This tool should give those resource managers a stepping-stone to produce a sampling strategy that will satisfy the CMP objectives. This report will first describe development of the tool and then provide a case study to demonstrate how it can be used to determine the most suitable monitoring techniques.

DEVELOPMENT OF THE LIFE-CYCLE MONITORING STATION DECISION MATRIX

Selecting appropriate techniques for life-cycle monitoring can be somewhat subjective and context dependent. A decision matrix is a useful tool, often used in engineering and business, to provide a quantitative means to objectively compare alternatives. This approach was applied to create a tool that would help determine the most appropriate sampling techniques for Stations in the CCC given site-specific conditions. The lifecycle monitoring station decision matrix ("Decision Matrix") tool allows researchers to systematically identify, analyze, and rank various sampling technique alternatives. A decision matrix is a table in which the various alternatives (i.e., "techniques") are listed in the first column, and the remaining column headers are factors that will affect a user's decision among the these techniques (i.e., "parameters"). This format provides a structure for scoring the alternatives within the body of the Decision Matrix and ranking them by average score. The Decision Matrix is created by using a Parameter Table as a reference guide to manually determine scores for each parameter and every technique, based on site or reach specific information. Thus, the tool relies on input of site-specific information to inform the Decision Matrix (Figure 1). The Decision Matrix tool was created in Microsoft Excel® (Microsoft, Redmond, WA) to make this tool simple to use and accessible to a broad base of users.

Figure 1. The process of using the Parameter Table and site-specific information to create a life-cycle monitoring station Decision Matrix.

Developing the Parameter Table

The main reference for the Decision Matrix tool is the Parameter Table. This table was created to describe the key environmental parameters (e.g., depth, water velocity) that may impact how effective each alternative sampling technique would be for a particular location and target lifestage. The first step in creating the Parameter Table was developing a list of all sampling techniques used in salmonid life-cycle monitoring stations. A literature review was conducted to identify all potential sampling techniques and their related parameters for both adult and juvenile salmonid monitoring. In addition to the literature review, existing Stations on Scott Creek, Pudding Creek, Casper Creek, and the Noyo River were visited, and the biologists running these Stations were consulted, to further inform development of the Parameter Table. These sites were selected based on the wealth of experience researchers had with using a variety of sampling techniques and the diversity of stream conditions. An annotated bibliography of literature used in developing the Parameter Table and brief descriptions of the information from each source is provided in Appendix A.

A total of 12 techniques (Table 1), and 4 key parameters were identified. Some techniques for adult counting stations require supporting techniques such as a weir or other type of support, and these were also included in the Parameter Table. The key environmental parameters were:

1. <u>Channel Depth</u>: the effectiveness of gear can vary with water depth. This parameter was chosen to rank the effectiveness of various strategies based on the minimum and/or maximum depths of the site of interest.
2. <u>Water Velocity</u>: Some strategies may not function at high and/or low water velocities. This parameter was chosen to rank the effectiveness of various strategies based on the minimum and/or maximum velocities at the site of interest.
3. <u>Turbidity/Visibility</u>: Many strategies that rely on visual counts and identification lose functionality under high turbidity (e.g., tower counts, video counts), thus it is useful to

account for site-specific turbidity. This parameter was chosen to rank the effectiveness of various strategies based on the maximum turbidities at the site of interest.

4. Substrate Mobility: Deployment of fixed gear may be limited when substrate is highly mobile. This parameter was chosen to rank the effectiveness of various strategies based on the mobility of the substrate at the site of interest.

Additional logistical factors were identified that were not included in the Matrix for ranking, but are critical to consider for the final decision. Cost, equipment portability, and lead-time can be highly variable and context-dependent; therefore they were not used to rank alternatives. These parameters are considered at a later step in the selection of a preferred alternative:

1. Cost: Costs may include investment in equipment, permits, supplies, and labor. Costs are highly variable by equipment type, design specifications, site location, and sampling frequency and duration.
2. Equipment Portability: In some instances researchers may prefer equipment that can easily be removed and re-installed, or transported to remote areas.
3. Lead Time: Some equipment requires time for design, manufacturing, and/or permitting, which may be an important consideration if sampling must begin by a particular date.

Table 1. Sampling techniques by target lifestage. An asterisk denotes sampling strategies that usually require supporting equipment.

Adult Counting Station	Juvenile Outmigration Traps
Infrared counts (e.g., Riverwatcher)*	Fyke net
Resistivity counts (e.g., Logie)*	Incline plane trap
Hydroacoustic (e.g., DIDSON)	Incline screen trap
Upstream Fyke Trap*	5' Rotary screw trap §
Tower counts	8' Rotary screw trap§
Video Counts (recorded)*	
Visual Counts (in person)	
Supporting Equipment*	
Ladder	
Resistance Weir	
Rigid Weir	

§ Rotary screw traps come standard in two different sizes to match the depth of the river or creek

Once the sampling techniques and parameters were identified, forming the structure of the Parameter Table, scoring criteria were defined for each technique and key environmental parameter, filling in the body of the table. For every technique, criteria were established to score each parameter on a scale from 1 to 5, with the magnitude of the score reflecting the suitability of the technique. Scores were first described qualitatively with "5" given to parameter conditions under which the technique is highly functional and "1" considered not functional (Table 2).

To make the scoring process as objective as possible, quantitative criteria were also defined for three of the four parameters (quantitative criteria were not developed for substrate mobility). Due to the limited availability of peer-reviewed information, criteria were largely based on personal experiences and communications with regional biologists. For example, Volkhardt (2007) stated that rotary screw traps work well at water velocities of 0.8–2 m/s (2.6 - 6.5 fps) in Oregon coastal streams, which supported the need for a “water velocity” parameter in the Parameter Table and provided an indication of an ideal velocity for this technique. However, other quantitative water velocity criteria for rotary screw traps were not found in the peer-reviewed literature. Based on personal experiences of biologists familiar with the technique, it was clear that there was a lower and upper limit to water velocities for a rotary screw trap. Therefore, the peer reviewed information and personal experience information was used in conjunction as the basis to define quantitative criteria (5 = >2-5 fps; 4 = 1.5-2 fps or 5-5.5 fps; 3 = 1-1.5 fps or 5.5-6 fps; 2 = 0.5-1 or 6-6.5 fps; 1 = <0.5 or >6.5 fps), with the assumption that water velocities less than 0.5 fps or greater than 6.5 fps would render rotary screw traps ineffective and unreliable (i.e. “not functional”). This process was done for each technique and parameter to the complete the life-cycle monitoring station Parameter Table (Appendix B).

Table 2. An example of scoring a sampling technique with qualitative criteria.

Score	Channel Depth	Water Velocity	Turbidity/ Visibility	Substrate Mobility
5	Highly Functional	Highly Functional	Highly Visible	Very Low
4	Semi-functional	Semi-functional	Semi-visible	Low
3	Diminished functionality	Diminished functionality	Diminished visibility	Moderate
2	Limited functionality	Limited functionality	Limited visibility	High
1	Not functional	Not functional	No visibility	Very High

Identification of Site Specific Data Needs

Site-specific data to describe conditions at potential Station locations are necessary to use the Parameter Table to score each of the four quantitative parameters. There are many factors to consider when selecting a site, several of which are the parameters identified in the Parameter Table. Additional important considerations not included in the Parameter Table were land access, power supply, substrate types, and habitat types. It is also important to select a location downstream of any salmonid-bearing tributaries and suitable spawning habitat so that fish production of the entire watershed can be estimated. The CMP describes specific criteria for placement of a Station (Adams et al. 2011, pg. 63; Boydstun and McDonald 2005, pg. 24). Once a potential monitoring location(s) is identified within the watershed, data should be collected to describe the following:

- Channel Depth: cross sections may be sampled to describe channel morphology, including gradient, average and maximum depth (feet), and the location of thalweg.
- Water Velocity: velocity (feet per second; fps) can be measured along transects at varying water flows to capture the range of velocity expected at the site.
- Discharge: daily average flow data (cubic feet per second; cfs) may be obtained from the nearest gauge or instantaneous discharge may be calculated from latitudinal depth and velocity transects if representative gauge data are not available.
- Turbidity/Visibility: Turbidity (Nephelometric Turbidity Units; NTUs) should be measured over a range of stream discharges and throughout the monitoring seasons of interest to identify typical and maximum expected turbidity for the site.
- Conductivity: conductivity (µS) should be recorded periodically throughout the monitoring seasons of interest to provide information specifically relevant to resistivity counters.
- Substrate Mobility: Wolman pebble counts may be performed (Wolman 1954) along transects to describe substrate size. The type of sediment should also be determined. Pebble counts alone cannot describe substrate mobility, but can be used in conjunction with other information to infer mobility.

How to use the Life-cycle Monitoring Station Decision Matrix

There are five general steps in applying the Decision Matrix: (1) reducing the Parameter Table, (2) collecting site specific data, (3) populating the Decision Matrix, (4) ranking the alternatives, and 5) identifying a preferred alternative. Each step is described in detail below (Figure 2).

Step 1: Reduce the Parameter Table

Identify the target life stage and use the filter in the life stage column of the Parameter Table to limit alternatives to only those that are applicable; all steps must be followed separately for adult counting stations and juvenile outmigration traps. Next, set the fish-handling filter, if desired, to reflect objectives and potential permitting constraints. For example, if fish handling is not allowed due to permitting constraints the filter may be set to only show alternatives that do not require fish handling. Or, if fish handling is desired for the collection of scales or tissues (i.e., for the genetic diversity component of the CMP) or for application of tags or marks, the filter may be set to techniques that require fish handling. Review the reduced list of techniques and supporting equipment and hide or eliminate any remaining techniques that are clearly not suitable for the site (e.g., fish ladder, if none exists at the site and there is no need to construct one).

Step 2: Collect Site-Specific Data

See earlier discussion regarding *Identification of Key Site Specific Data Needed.*

Step 3: Populate the Decision Matrix

In the first column of the Decision Matrix list each of the remaining sampling techniques from the reduced Parameter Table created in Step 1. As some sampling techniques require supporting equipment, the two in combination will need to be listed as a composite technique. For instance, consider that an infrared scanner is identified as a potential sampling technique, which is an approach that requires the use of supporting equipment. Composite scores for multiple combinations of the scanner with various supporting equipment types, such as a portable resistance board weir, rigid weir, or fish ladder, should be calculated to reflect the use of the combined techniques. Due to these composite techniques, Step 3 may result in many more techniques in the Decision Matrix than remained in the reduced Parameter Table.

Using site-specific data collected in Step 2 and the Parameter Table determine and enter the score of each parameter for each technique in the Decision Matrix. Scoring the parameters is accomplished by selecting the criteria for each parameter that best describes the conditions at the site of interest, then scrolling to the left in that row to find the appropriate score. The Parameter Table is configured with parameter criteria in columns sorted by rows according to the score. To generate the composite score for each equipment combination (i.e., infrared scanner with resistance board weir, rigid weir, or fish ladder) the lowest score for each parameter is used, since it would represent the limiting factor for the composite technique.

Step 4: Rank the Alternatives

Now that the Decision Matrix is populated with scores for each parameter, scores may be averaged to calculate an average score for each sampling technique. To rank the alternatives, the matrix may be sorted (highest to lowest) by the average score (Table 3).

Step 5: Identify Preferred Alternative

Highest ranking alternatives must then be evaluated in the context of factors not reflected in the Decision Matrix to identify the preferred alternative that best meets monitoring objectives, and site conditions, as well as budget, permitting, and timeline constraints. Questions to consider at Step 5, in no particular order include:

- Species: Are there fish species similar in size and shape to the target species? Some techniques such as hydroacoustic systems (e.g., DIDSON) may not be suitable if species identification may be an issue, especially in streams with both coho and steelhead (Adams et al. 2011).

- Abundance: Are the fish species in high abundance? If so, it may not be possible to use some techniques such as fyke traps.
- Cost: Does the project have a specific budget? If so, estimate the expected costs of the highest-ranking alternatives (i.e., investment in equipment, permits, supplies, and labor), and eliminate any alternatives that will not be feasible within the project budget.
- Does the equipment need to be portable? If the user prefers equipment that can easily be removed, transported, and re-installed, then this may influence their selection of preferred alternative.
- How much lead-time is needed before the project is implemented? Time requirements for equipment design, manufacturing, and permitting can vary greatly. If the project is under a tight schedule some high-ranking alternatives, such as constructing a weir or a ladder, may not be feasible.

Table 3. An example of a completed Decision Matrix table ranked by average parameter score. PM = parameter.

Sampling Technique	PM1	PM2	PM3	PM4	Avg.
Alternative 1	4	5	1	3	3.25
Alternative 2	5	4	1	3	3.25
Alternative 3	3	2	5	1	2.75
Alternative 4	3	4	2	1	2.50
Alternative 5	2	2	4	1	2.25
Etc.…					

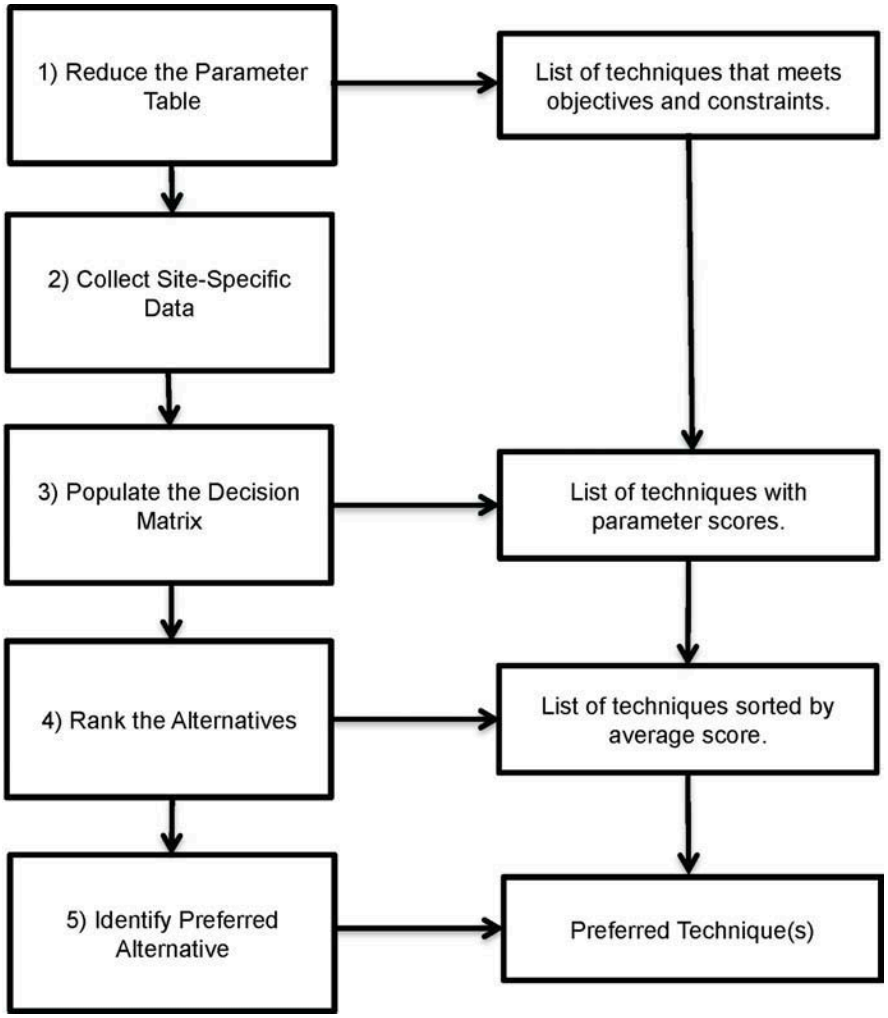


Figure 2. Decision Matrix flow chart indicating the step-by-step process of ranking sampling techniques using site-specific information, and producing recommended monitoring methodology.

CASE STUDY: SCOTT CREEK COHO SALMON AND STEELHEAD LIFE-CYCLE MONITORING

Background

A life-cycle monitoring station was established on Scott Creek in 2003 to estimate coho salmon and steelhead trout migration timing, population size composition, and abundance. The Scott Creek Station, operated by National Oceanic and Atmospheric Administration's Southwest Fisheries Science Center (SWFSC) Fisheries Ecology Division, has continued annual escapement and smolt monitoring data collection, providing the most comprehensive dataset available for one of the few streams with extant populations of both CCC coho salmon and steelhead. Scott Creek is of particular interest to coho salmon recovery because it is considered the southernmost population. In order to enhance recovery efforts, a coho broodstock program was initiated. The importance of the Scott Creek dataset is recognized in the Recovery Plan for Evolutionary Significant Unit of Central California Coast Coho Salmon (Public Draft; March 2010), which includes the following recovery actions:

1) Continue funding NOAA's Scott Creek Lifecycle Monitoring Station – Recovery Action (ScC-A-9.1.2) – funded for the next five years
2) Develop and implement a monitoring project to evaluate the performance of recovery efforts – Recovery Objective (ScC-A-9.1)
3) Monitor population status for Response to Recovery Actions – Recovery Action (ScC-A-9.1.3)

The existing Scott Creek Station consists of a portable resistance board weir with an upstream fyke trap for monitoring adult salmonids, and a makeshift smolt trap (either a paneled fyke trap or inclined plane trap) for juvenile monitoring. Data gathered from the Station is part of a comprehensive monitoring program, complementary to data from redd surveys, PIT tagging studies, water quality monitoring, and analyses of population genetics. The Scott Creek Station data indicate that outmigration of coho and steelhead smolts occurs between January and June, and adult spawner upstream migration occurs between December and May (Hayes et al. 2011). From 2003 to 2010 the annual smolt outmigration abundance estimates ranged between 8 and 3,005 coho, and between 1,370 and 18,850 steelhead. For the same period annual adult escapement estimates of coho salmon ranged between 5 and 329, and for steelhead between 109 and 440.

Although the existing Scott Creek Station has gathered valuable data, the SWFSC is seeking to evaluate alternative, advanced and/or more efficient and effective, monitoring equipment and strategies for the Station. According to Dr. Sean Hayes (Salmon Ocean Ecology Team Leader, NOAA SWFSC), who leads the monitoring efforts at the Scott Creek Station, the current equipment is excessively time-consuming for his staff, and is in need of improvement. For example, Dr. Hayes describes the substrate as highly mobile at moderate flows, hindering the ability of the resistance board weir to float as sediment is deposited on the weir panels. Design changes to the existing weir intended to counteract this issue essentially converted the resistance board weir to a stationary rigid weir, thereby inhibiting the ability of the weir to adjust to varying flow levels. Alternative sampling methods may be more effective at monitoring upstream and downstream migrants, while also reducing the number of fish that are trapped and handled, and the effort it takes to maintain the station. The objective of this case study was to use the life-cycle monitoring station Decision Matrix tool to determine the most appropriate sampling techniques for the Scott Creek Station.

Physical and Biological Characterization of the Scott Creek Watershed

In order to apply the Decision Matrix to a specific watershed, such as Scott Creek, a good understanding of the physical characteristics of the watershed is critical, especially with respect to the key environmental parameters of the Decision Matrix (i.e., channel depth, water velocities, turbidity, and substrate mobility). Information was collected for the Scott Creek watershed during a reconnaissance survey of Scott Creek, a review of pertinent literature, and interviews with experienced researchers to inform the scoring of parameters in the Scott Creek Decision Matrix.

Scott Creek is located approximately 12 miles northwest of the city of Santa Cruz near Davenport (Figure 3). Scott Creek originates in the coastal Santa Cruz Mountains and drains in a southwesterly direction until it meets the Pacific Ocean. The watershed encompasses approximately 30 square miles and has three main tributaries: Little Creek, Big Creek, and Mill Creek. The creek contains approximately 7.5 miles of mainstem anadromous habitat accessible to salmon and steelhead, in addition to limited access to the tributaries (CDFG 2012). An estuarine lagoon forms for part of the year, creating rearing habitat that is physically separated from the Pacific Ocean (Bond 2006). Historically important to juvenile salmonid rearing, the lagoon is described as absent of suitable steelhead rearing habitat for many years over the past two decades due to several factors, including sand-bar dynamics (Sean Hayes pers. comm.). The watershed habitat is comprised of approximately 70% coniferous forest and 30% shrubland, grassland, or riparian hardwood forest. Public access to the stream is very limited, as 95% of the watershed is located on private land, and the remainder is state and military lands. Land uses include forestry, rural residential development, and agriculture. There are 21 barriers to salmon migration, two of which are dams, and the remaining are road crossings, diversion, and natural barriers.

Collecting physical data on the entire watershed would be a considerable task requiring a substantial amount of time and funding; as a consequence, the scope of the characterization was limited to the sites that were conducive to a life-cycle monitoring station ("Survey Reach"; Figure 4). The lower reach of Scott Creek, extending from approximately river mile 0.5 to river mile 1.0 was selected as the Survey Reach based on the monitoring objectives, and due to its location with good land access downstream of mainstem salmonid spawning habitat and major tributaries, but upstream of the estuary. The Survey Reach can generally be classified as an incised channel at low flows to moderate flows (<1,000 cfs) with benched floodplains and a dense riparian canopy. The substrate is dominated by mudstone gravel and cobble, which can be classified as a very mobile material due to its relatively low density.

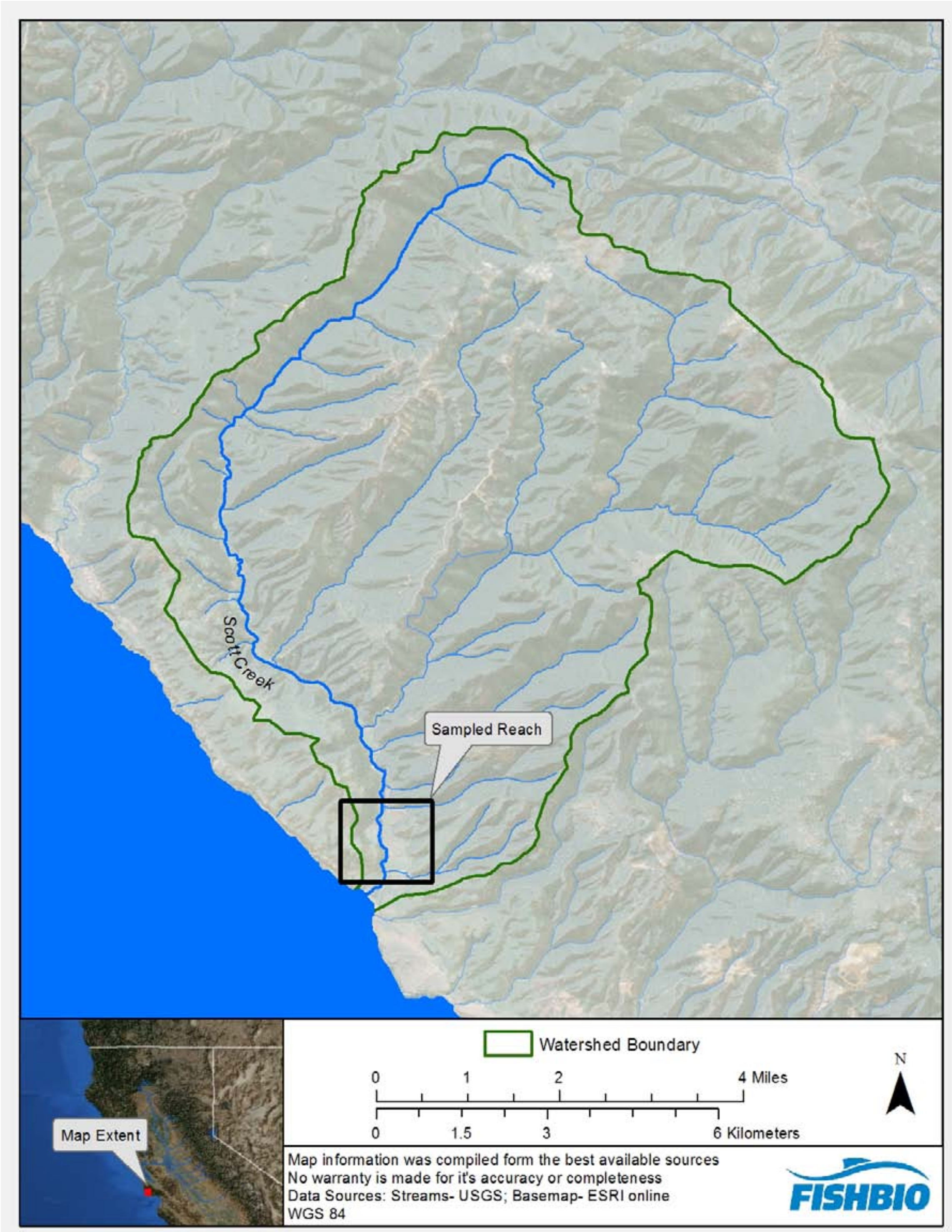


Figure 3. Map of the Scott Creek watershed depicting the sampled reach.

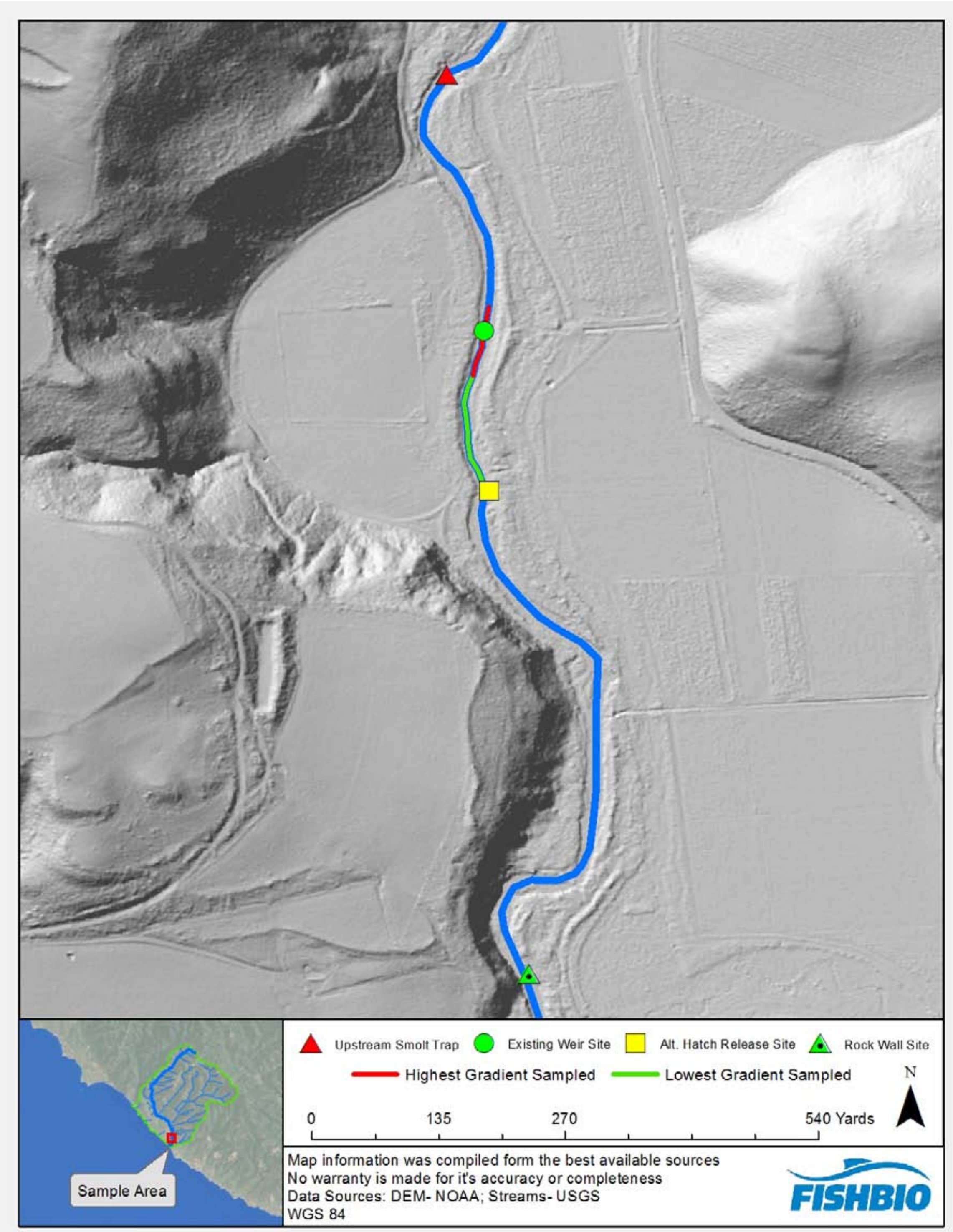


Figure 4. Scott Creek sampling locations for the reconnaissance survey. Note: LIDAR data provided by Noah Finnegan of UC Santa Cruz Department of Earth and Planetary Sciences.

A survey of sites within the Survey Reach of Scott Creek was conducted on April 11, 2013, to collect data on water quality, substrate type, channel morphology, and other habitat characteristics relevant to the Parameter Table. The survey was scheduled to occur during the period of operation of the existing Scott Creek Station (between December and June). Although, environmental data were recorded only as a one-day snapshot, personal communication and supporting literature was relied upon to infer the range of environmental data throughout the defined monitoring period. When a new station is being implemented in a new location, daily average water quality data (e.g., flow, turbidity, depth) should be collected throughout the monitoring period prior to applying the Decision Matrix. However, in scenarios where researchers have already collected several years of life-cycle monitoring data, such as Scott Creek, the Parameter Table information may be inferred from personal communication and existing data. This limited data method has also been effective on past projects, such as the Stanislaus River Adult Counting Station in California's Central Valley (Cuthbert et al. 2010).

During the reconnaissance survey, conductivity (µS) and turbidity (NTU) were collected at the upper and lower boundaries of the Survey Reach. Conductivity was recorded using an ExstikII EC500 portable pH/conductivity meter (Extech Instruments Corporation; Waltham, MA), to provide information relevant to the resistivity counter technique. Turbidity was recorded using an Oakton T100 portable turbidity meter (OAKTON Instruments; Vernon Hills, IL). A snap shot of these two environmental variables at Scott Creek is provided in Table 4.

Table 4. Environmental parameters measured during the survey of lower Scott Creek on April 11, 2013.

	Conductivity (µS)	Turbidity (NTUs)
Upper Boundary of Survey Reach	213	0.55
Lower Boundary of Survey Reach	212	1.38

During the survey, measurements of depth, velocity and pebble counts were taken along three cross sectional transects, perpendicular to the creek; one near the upper survey reach boundary (upstream of existing smolt trap site; UST), one near the existing weir site (EWS), and one near the downstream survey boundary (rock wall site; RWS). A Trimble (GeoXH Explorer 6000 Series, Sunnyvale, CA) was used to record GPS coordinates for cross-section end points, thalweg location, existing Station sampling locations, and Sampling Reach boundaries, and to establish benchmarks for elevation data collection. Channel morphology information (e.g. gradient, average depth, location of thalweg, etc.) was collected along each cross-section. Elevation (ft.) was recorded at 5 ft. intervals between the high water marks on each bank, starting at the south bank using an automatic level with an elevation rod (CST/Berger 26X PAL/SAL N Series, Walnut Ridge, AR). Elevation and gradient profiles were also obtained from LIDAR (provided by SWFSC) and used for comparison to surveyed elevation profiles. The surveyed elevation profiles were plotted from UST and EWS to produce cross-sections for both locations and the LIDAR profiles were used to verify the measurements. This comparison was not made for the RWS cross-section, since the elevation profile generated from LIDAR was unreliable, likely due to the rock wall formation.

Water velocity was recorded at the same 5 ft. intervals between the high water marks on each bank using a portable velocity meter (Hach Company, FH950, Loveland, CO). To describe substrate size, Wolman pebble counts (Wolman 1954) were performed at three randomly selected transects perpendicular to each cross section (Kondolf 1997). At regular intervals along the transect (~ 1ft apart), the observer randomly grabbed bed material and used a gravelometer with predetermined size classes to classify each piece of selected bed material.

Upstream Smolt Trap. Measurements from the UST cross-section revealed a maximum stream depth of 1.6 ft. (average 0.8 ft.; Figure 5) and a maximum water velocity of 0.4 feet per second (fps; average 0.3 fps). The cross-section at this site can be described as a large benched floodplain area on the south bank with an abrupt bank slope that changes in approximately 1 ft. in elevation from the ordinary high water mark to the water surface elevation. The channel appears to be confined to the high water thalweg at low to moderate flows (i.e. < 1,000 cfs), and the north bank has a relatively moderate slope (gradient = 0.7). The substrate at this site consists predominately of small to medium sized mudstone (range: 8-64 mm; Figure 6).

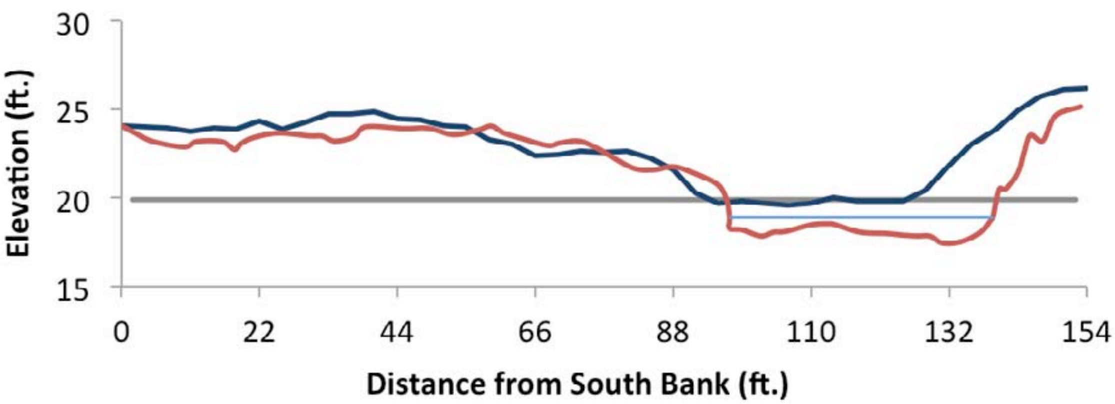


Figure 5. Cross-section profile of the upstream smolt trap site (UST) with elevation profiles from LIDAR (dark blue line) and survey measurements (red line). Gray line indicates the ordinary high water mark and the light blue line indicates the water surface survey measurements.

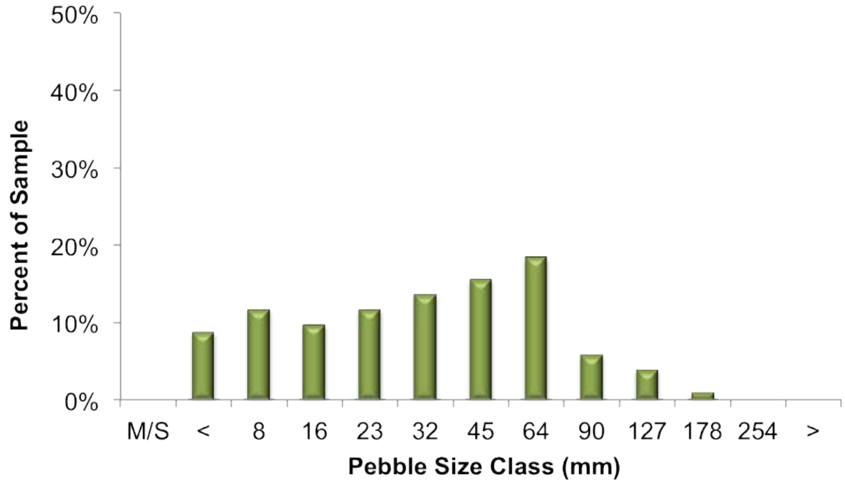


Figure 6. Percent composition of pebble count size classes sampled from the UST transect site.

Existing Weir Site. Measurements from the EWS cross-section yielded a maximum stream depth of 1.1 ft. (average 0.7 ft.) and a maximum water velocity of 1.1 fps (average 0.3 fps; Figure 7). The cross-section at this site can be described as a large benched floodplain area on both the south and north banks with the south bank displaying a more gradual slope (gradient = 0.4) than the north bank (gradient = 0.9). The channel has a very uniform bottom with less than 1 ft. in elevation change across the entire width of the wetted channel and an undefined thalweg at low flows (i.e. < 250 cfs). The predominant size category of mudstone substrate at this site measured less than 8 mm in diameter, and the substrate was interspersed with mud/silt, gravel, and cobble (Figure 8).

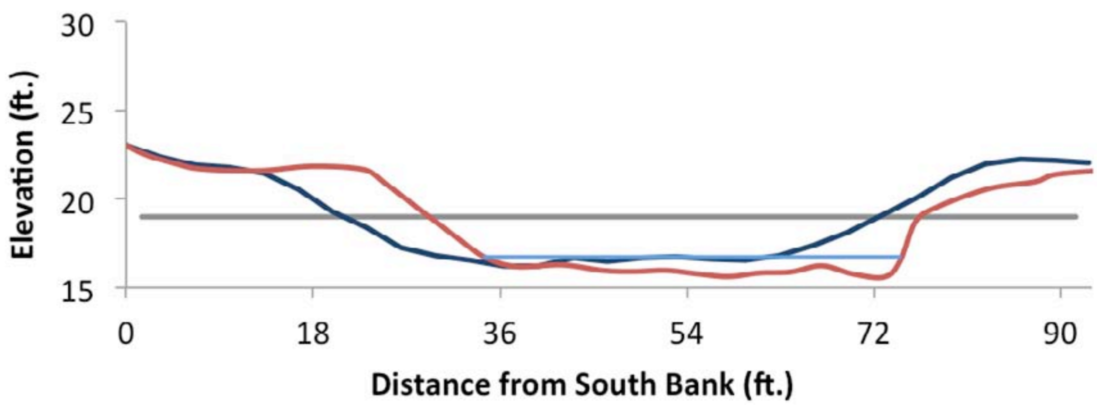


Figure 7. Cross-section profile of the existing weir site (EWS) with elevation profiles from LIDAR (dark blue line) and field measurements (red line). Gray line indicates the ordinary high water mark and the light blue line indicates the water surface survey measurements.

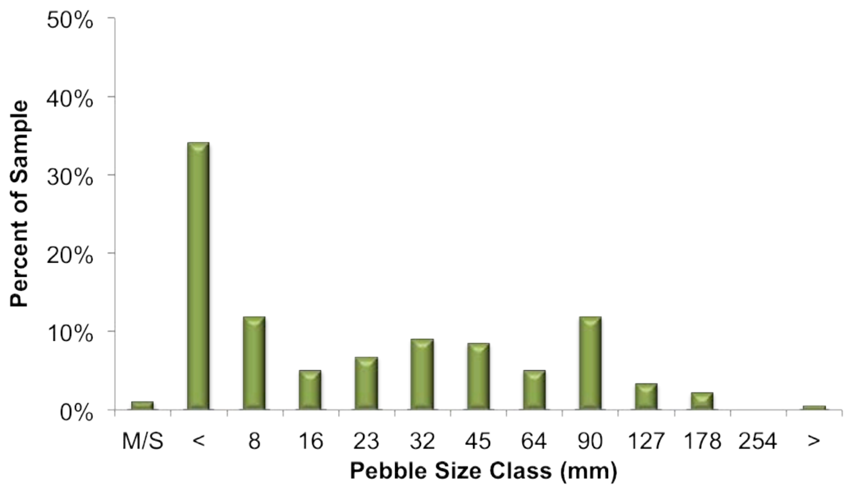


Figure 8. Percent composition of pebble count size classes sampled from the EWS transect site.

Rock Wall Site. Measurements from the RWS cross-section yielded a maximum stream depth of 2.5 ft. (average 1.6 ft.) and a maximum water velocity of 0.4 fps (average 0.2 fps; Figure 9). The cross-section at this site can be described as a gradually sloping floodplain area on the south bank with a very steeply sloped rock-wall (mudstone) for the north bank (gradient = 3.4). The channel has a very uniform bottom that gradually slopes towards the rock-wall at the north bank with a thalweg that is likely more defined at higher flows (i.e. >250 cfs). The predominant substrate size classes at this site measured less than 8mm in diameter (mud/silt and mudstone), and substrate was intermixed with medium to large pieces of mudstone (Figure 10).

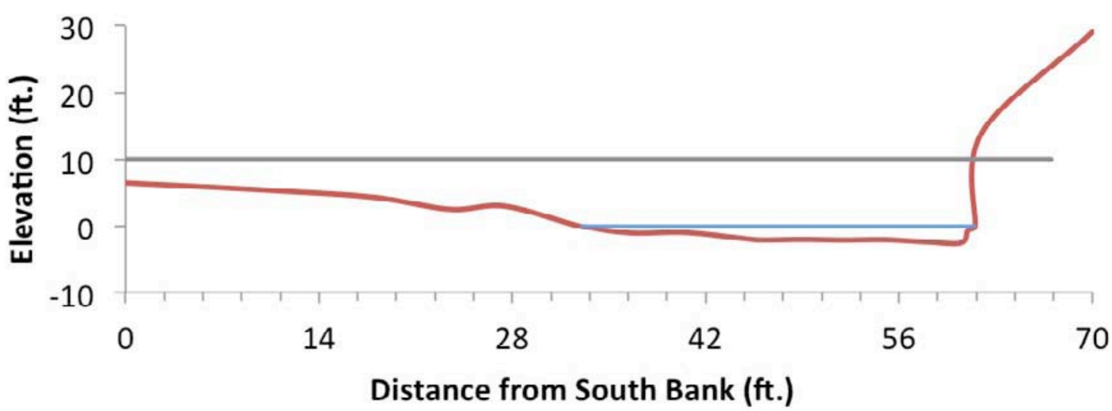


Figure 9. Cross-section profile of the rock wall site (RWS) with an elevation profile from field measurements (red line). Gray line indicates the ordinary high water mark and the light blue line indicates the water surface survey measurements.

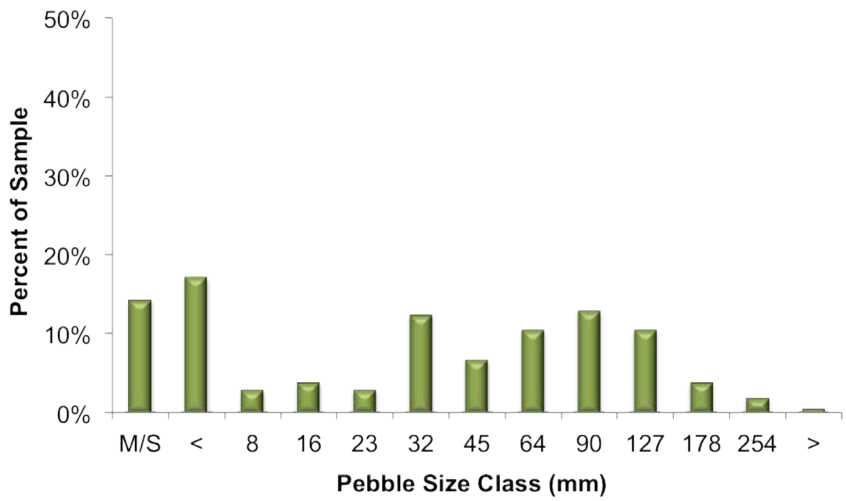


Figure 10. Percent composition of pebble count size classes sampled from the RWS transect site.

Daily average flow data were obtained from California Polytechnic State University (Brian Dietterick, Director of Swanton Pacific Ranch, San Luis Obispo, CA) to provide an indication of the potential range of flow on Scott Creek during the monitoring season. Between 2010 and 2013, daily average flow ranged between 1.6 cfs and 716.7 cfs (average 40.8 cfs; Figure 11). Hourly flow ranged between 1.6 cfs and 1,908.4 cfs (average 38.6 cfs). During this same time period flow only eclipsed 500 cfs during 16 separate events and eclipsed 1,000 cfs during five separate events. Hayes et al. (2008) considered high flow events in Scott Creek to be about 282 cfs. Over the past 3 years during the monitoring period (December to June) the average of the daily average flows ranged from 35 to 95 cfs. The reconnaissance survey was conducted at a flow of 20 cfs (Dietterick, personal communication).

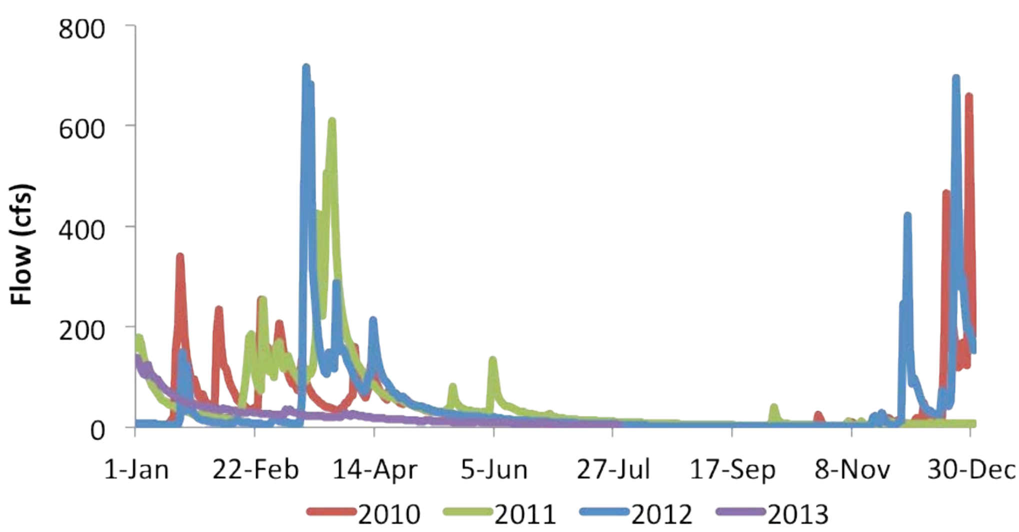


Figure 11. Scott Creek daily average flow at Swanton Ranch; 2010-2013. Data provided by California Polytechnic State University (San Luis Obispo, CA).

Applying the Decision Matrix Tool to Scott Creek

The decision matrix approach requires the life-cycle monitoring 'Parameter Table' and site-specific information to create the actual 'Decision Matrix'. The steps to create a Decision Matrix for Scott Creek as outlined under the section *How to use the Life-cycle Monitoring Station Decision Matrix* above, were as follows:

Step 1: Reduce the Parameter Table. The first step is to identify the objectives and constraints of the monitoring project and the target life stage. After a review of Hayes et al. (2011) and personal communications with Dr. Hayes, we compiled the following objectives of lifecycle monitoring in Scott Creek.

1. Monitor escapement, run timing, survivorship, and age of returning adult coho salmon (*O. kisutch*) and steelhead (*O. mykiss*) in the Scott Creek watershed.
2. Quantify redd deposition and develop coho salmon and steelhead escapement calibration curves for central California coastal streams.
3. PIT tag smolts and monitor out-migration timing, age, size, abundance, and freshwater survival with downstream migrant traps, relative to fluctuating environmental conditions and population densities in the watershed
4. Monitor in-stream movements and habitat utilization of PIT-tagged juveniles with in-stream PIT tag readers relative to fluctuating flow conditions throughout the year.
5. Monitor ocean survivorship (%) and growth of returning adults that were PIT tagged as emigrating smolts.
6. Estimate genetic effective population size and number of breeders for each year class of wild and hatchery coho salmon and steelhead in Scott Creek.
7. Monitor differences between hatchery-produced and naturally spawned fish for the above objectives and the degree of hatchery fish introgression into wild stocks.
8. Enhance broodstock collection for the Monterey Bay Salmon and Trout Project (MBSTP) Kingfisher Flat Hatchery and NOAA Fisheries captive coho salmon broodstock program.
9. Determine source populations of coho salmon re-colonizing previously extirpated streams in Santa Cruz and San Mateo counties through genetic assessment tests.
10. Monitor, through snorkel surveys, the biological recovery of coho salmon being reintroduced to area streams by NOAA Fisheries and MBSTP.

The adult and juvenile counting components of the Station on Scott Creek are not intended to address all of the listed objectives, but are used to complement other research studies collectively aimed at meeting all the objectives. For example, most fish counters cannot provide biological samples that are important to achieve certain objectives (e.g., determining source populations), but these goals can still be achieved by sub-sampling the counts using an additional upstream fyke trap and/or complementing these data through the carcass surveys, required as part of any CMP Station.

Since the sampling objectives concern both juveniles and adults, Steps 1 through 5 were conducted separately for each life stage. The life stage and fish handling filters were used to sort the techniques in the Parameter Table based on the Scott Creek monitoring station objectives and constraints. Of the five (5) sampling techniques listed under the juvenile monitoring list in Table 1, all of the techniques satisfy the Scott Creek monitoring objectives and constraints. Of the seven (7) sampling techniques (and 3 supporting techniques) listed in Table 1 under adult monitoring, all sampling techniques and supporting techniques were determined to meet monitoring objectives, and be within constraints for use in Scott Creek.

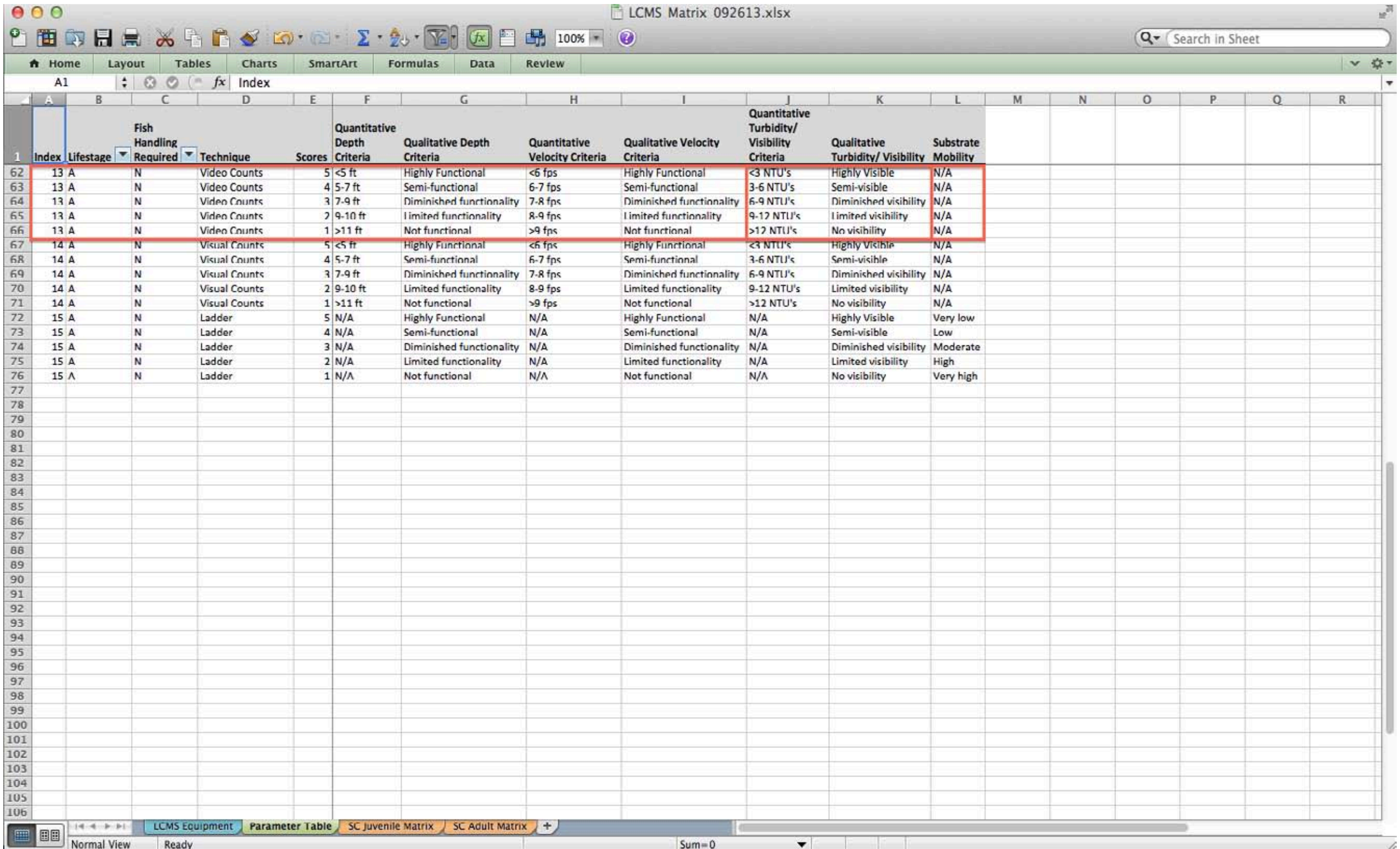
Step 2: Collect Site-Specific Data. Based on the site specific data collected during the characterization of the Scott Creek watershed (see previous section titled *Physical and biological characterization of the Scott Creek Watershed*), we developed a range of values for each relevant parameter. The flow during the reconnaissance survey was approximately 20 cfs, which is lower than the average of daily average flows for the monitoring period, thus, we adjusted our scores accordingly to accommodate the likelihood of higher average flows.

- Depth: Based on the range of maximum depths measured during the survey (1.1-2.5 ft), 3-4 feet was used as the depth range, recognizing that depth would be much higher during winter storm events that are typically the monitoring periods that create the most nuances.
- Velocity: Based on the range of maximum velocities measured during the survey (0.4-1.1 fps), 2-3 fps was used as the velocity range, recognizing that velocity would be much higher during winter storm events.
- Turbidity: The turbidity values obtained during the Scott Creek survey were 0.55 and 1.38 NTUs, but according to anecdotal information obtained from discussions with Dr. Hayes turbidity is relatively low during the majority of the monitoring period, but there are high levels of turbidity during freshet events. Thus, turbidity values obtained during the Scott Creek survey did not reflect the upper range in the turbidities at Scott Creek, which likely occur during freshet winter storm events when fish passages may be occurring. Peer reviewed literature, such as Klein et al. (2012) and Cafferata and Reid (2013), suggests that turbidity commonly exceeded 40 NTU’s during freshets in flow on various Northern California streams; therefore, 40 NTUs was treated as a common turbidity value for this case study.
- Substrate Mobility: Based on pebble counts and discussions with Dr. Hayes the substrate mobility was defined as “high”. Pebble counts alone would not have provided enough information, but discussions with Dr. Hayes indicated that the lightweight mudstone is highly mobile.

Step 3: Populate the Decision Matrix. The remaining techniques from the reduced Parameter Table that was created in Step 1 were listed in the appropriate Decision Matrix (Adult or Juvenile). Four adult sampling techniques required supporting equipment and were paired accordingly into composite techniques. Electronic fish counters (resistivity or infrared), the upstream fyke trap, and video systems require a supporting structure to guide fish into the counting area, which in this case can either be a fixed weir, portable resistance board weir (PRBW), or a ladder. These were combined into twelve (12) composite techniques for the ranking: 1) electronic resistivity counts and a PRBW, 2) electronic resistivity counts and a fixed weir, 3) electronic resistivity counts and a ladder, 4) electronic infrared counts and a PRBW, 5) electronic infrared counts and a fixed weir, 6) electronic infrared counts and a ladder, 7) video camera and a PRBW, 8) video camera and a fixed weir, 9) video camera and ladder, 10) upstream fyke trap and fixed weir, 11) upstream fyke trap and PRBW, and 12) upstream fyke trap and ladder. Thus, the final adult Scott Creek Matrix Template had a total of five (5) juvenile sampling strategies and fifteen (15) adult sampling strategies, including visual, tower and hydroacoustic techniques.

By using the site-specific information collected in Step 2 and the reduced Parameter Table created in Step 1, the score for each parameter was determined for every technique in the matrix. For example, using only the higher measured turbidity value of 1.38 NTUs referenced against the scores for the video count technique in the Parameter Table a score of five (5) would have been assigned for this technique based on quantitative criteria < 3 NTUs ("Highly visible") (Figure 12). However, knowing that Scott Creek turbidity can increase to very high levels rapidly, a common value of 40 NTUs was selected, which would render the video counts ineffective ("No Visibility" = 1) during crucial migration periods.

If the technique is a composite technique the lower score between the two combined techniques is entered in to the Decision Matrix. For example, when an upstream fyke trap is combined with a resistance board weir, then the weir would score a 5 using the range of 2-3 fps for the parameter velocity, but the upstream fyke trap would score a 4 under those conditions; thus, the composite score would be a 4, because the upstream fyke trap is the more limiting factor technique.



Index	Lifestage	Fish Handling Required	Technique	Scores	Quantitative Depth Criteria	Qualitative Depth Criteria	Quantitative Velocity Criteria	Qualitative Velocity Criteria	Quantitative Turbidity/ Visibility Criteria	Qualitative Turbidity/ Visibility	Substrate Mobility
13	A	N	Video Counts	5	<5 ft	Highly Functional	<6 fps	Highly Functional	<3 NTU's	Highly Visible	N/A
13	A	N	Video Counts	4	5-7 ft	Semi-functional	6-7 fps	Semi-functional	3-6 NTU's	Semi-visible	N/A
13	A	N	Video Counts	3	7-9 ft	Diminished functionality	7-8 fps	Diminished functionality	6-9 NTU's	Diminished visibility	N/A
13	A	N	Video Counts	2	9-10 ft	Limited functionality	8-9 fps	Limited functionality	9-12 NTU's	Limited visibility	N/A
13	A	N	Video Counts	1	>11 ft	Not functional	>9 fps	Not functional	>12 NTU's	No visibility	N/A
14	A	N	Visual Counts	5	<5 ft	Highly Functional	<6 fps	Highly Functional	<3 NTU's	Highly Visible	N/A
14	A	N	Visual Counts	4	5-7 ft	Semi-functional	6-7 fps	Semi-functional	3-6 NTU's	Semi-visible	N/A
14	A	N	Visual Counts	3	7-9 ft	Diminished functionality	7-8 fps	Diminished functionality	6-9 NTU's	Diminished visibility	N/A
14	A	N	Visual Counts	2	9-10 ft	Limited functionality	8-9 fps	Limited functionality	9-12 NTU's	Limited visibility	N/A
14	A	N	Visual Counts	1	>11 ft	Not functional	>9 fps	Not functional	>12 NTU's	No visibility	N/A
15	A	N	Ladder	5	N/A	Highly Functional	N/A	Highly Functional	N/A	Highly Visible	Very low
15	A	N	Ladder	4	N/A	Semi-functional	N/A	Semi-functional	N/A	Semi-visible	Low
15	A	N	Ladder	3	N/A	Diminished functionality	N/A	Diminished functionality	N/A	Diminished visibility	Moderate
15	A	N	Ladder	2	N/A	Limited functionality	N/A	Limited functionality	N/A	Limited visibility	High
15	A	N	Ladder	1	N/A	Not functional	N/A	Not functional	N/A	No visibility	Very high

Figure 12. A screenshot of the Parameter Table with red boxes highlighting the video sampling technique and the parameter Turbidity/Visibility. In this case, a score of 1 was given to this technique because it cannot operate in high turbidities (>12 NTUs) with low visibilities, which is likely to be encountered during peak migration periods on Scott Creek.

Step 4: Rank the Alternatives. Once the Decision Matrix was complete, the scores were averaged to calculate an overall score for each alternative technique. The matrix was then ranked to determine the top scoring techniques for Scott Creek (Tables 5 and 6).

Table 5. Scott Creek juvenile Decision Matrix table ranked by average score.

Sampling Techniques	Channel Depth	Water Velocity	Turbidity/ Visibility	Substrate Mobility	Average Score
5' Rotary screw trap	4	2	N/A	4	3.33
Fyke net	3	4	N/A	2	3.00
8' Rotary screw trap	1	2	N/A	4	2.33
Incline screen trap	1	4	N/A	2	2.33
Incline plane trap	1	2	N/A	2	1.67

Table 6. Scott Creek adult Decision Matrix table ranked by average score.

Sampling Techniques	Channel Depth	Water Velocity	Turbidity/ Visibility	Substrate Mobility	Average Score
Electronic - Infrared counts (e.g., Riverwatcher) & Resistance Weir	5	5	5	2	4.25
Electronic - Infrared counts (e.g., Riverwatcher) & Rigid Weir	5	5	5	2	4.25
Hydroacoustic (e.g., DIDSON)	5	5	5	2	4.25
Electronic - Infrared counts (e.g., Riverwatcher) & Ladder	5	5	5	2	4.25
Electronic - Resistivity counts (e.g., Logie) & Ladder	5	5	5	2	4.25
Electronic - Resistivity counts (e.g., Logie) & Resistance Weir	4	5	5	2	4.00
Electronic - Resistivity counts (e.g., Logie) & Rigid Weir	4	5	5	2	4.00
Visual counts	5	5	1	N/A	3.67
Video Counts & Resistance Weir	5	5	1	2	3.25
Video Counts & Rigid Weir	5	5	1	2	3.25
Video Counts & Ladder	5	5	1	2	3.25
Tower Counts	3	5	1	N/A	3.00
Upstream Fyke Trap & Resistance Weir	3	4	N/A	2	3.00
Upstream Fyke Trap & Rigid Weir	3	4	N/A	2	3.00
Upstream Fyke Trap & Ladder	3	4	N/A	2	3.00

Step 5: Identify Preferred Alternative. The highest scoring techniques were examined in context of the factors that are not represented by the Decision Matrix parameters. Thus, the preferred technique was derived from the highest scoring technique that best fit monitoring objectives and

site conditions. For the purposes of this Case Study budget, permitting, and timeline constraints were not considered.

Juvenile Migration

Based on information gathered for Scott Creek and using our Decision Matrix approach, the top two ranked sampling strategies for juveniles were: 1) 5' rotary screw trap, and 2) fyke net. After considering the site conditions at the survey reach, we suggest a 5' rotary screw trap as the best sampling technique for juvenile outmigration monitoring (Table 7). Generally, a fyke nets could be used during extremely low flow conditions; however, the 5' rotary screw will allow for monitoring a broader range of flows.

Table 7. Scott Creek Decision Matrix ranking notes for the top two juvenile salmonid monitoring sampling strategies.

Sampling Technique	Ranking Notes
5' Rotary Screw Trap	1) Can be operated in a wide range of flows 2) Insufficient depth and water velocity can be problematic; however, protocol and design specific attributes can increase the ability of the trap to monitor at very low depths and velocity 3) The trap will likely scour a hole in highly mobile substrate below the cone, thereby increasing the ability to operate at very low depths 4) Equipment is very portable and permitting is not an issue since there are minimal impacts to the surrounding environment 5) Cost can be kept to a minimum by following the appropriate protocols
Fyke Net	1) Does not operate well in a deep channel 2) Does not operate well in moderate to high water velocities 3) Cannot accommodate a wide range in flow 4) Prone to failure in highly mobile substrate due to scouring 5) Turbidity is not a factor and the equipment is easily portable 6) Permitting should be relatively easy to obtain 1) There is extra effort to this strategy due to the possibility of failure and the constant manipulation of equipment to adjust to the substrate mobility which translates to a relatively moderate cost

Although the current fyke net sampling on Scott Creek provides adequate data during years with relatively low flows, the technique is problematic during moderate to high water years. A fyke trap is highly susceptible to failing at moderate to high flows and at water velocities that do not pose operating limitations for a 5' rotary screw trap. However, fyke traps can be operated in very low flows (i.e. <20 cfs), when it could be impractical to operate a 5' rotary screw trap. Both, 5' rotary screw traps and fyke traps, are fairly portable and easily installed/removed, therefore, the two strategies could be used in conjunction with one another to allow sampling over a much broader range of flows. Similar to the Noyo River (Figure 13) and Pudding Creek (Figure 14), a 5' rotary screw trap would give researchers the ability to monitor continuously during periods of higher flow, and would likely provide more efficient data collection at all flows. Although the low flow periods at the Scott Creek Survey Reach provide very minimal water depths and velocities in the thalweg, flow diversions panels can be used to increase velocity at the trap location. This should provide sufficient flow into the trap to maintain cone rotation, and increased current velocity under the cone of the trap will likely scour a depression in the mobile mudstone gravel and cobble substrate, further facilitating unimpaired trap function (Figure 15). Based on flow data obtained during the watershed characterization, it is reasonable to expect that a 5' rotary screw trap with flow diversion panels could be operated in higher flows than the current fyke net configuration.

Figure 13. The Noyo River 5' rotary screw trap at low flows with diversion panels.

Figure 14. The Pudding Creek 5' rotary screw trap at low flows with diversion panels.

Figure 15. The Pudding Creek 5' rotary screw trap at low flows with the flow diversion panels.

<u>Adult Migration</u>

Based on information gathered for Scott Creek and using our Decision Matrix approach, five sampling strategies were tied for the top rank for adult migration monitoring: 1) infrared counter (e.g., Vaki Riverwatcher) paired with a PRBW, 2) infrared counter paired with a rigid weir, 3) hydroacoustic (e.g. DIDSON) system, 4) infrared counter and ladder, and 5) resistivity counts and ladder (Table 8). Under consideration of site characteristics of the Survey Reach, we suggest the best sampling technique for adult migration monitoring is a PRBW and infrared counter and a camera. Depending on design and implementation, this particular sampling technique has the ability to monitor in a wider range of flows than a rigid weir, under high velocities, in a relatively deep channel, and has the ability to monitor in very high turbidity. This technique is relatively portable, since the weir can be installed or removed within a 6-hour period as has been demonstrated on the San Joaquin Basin tributaries (see Appendix C; FISHBIO unpublished data).

The hydroacoustic system (i.e. DIDSON) and resistivity counter (i.e. Logie) and ladder strategies are not ideal for Scott Creek based on species identification considerations. Hydroacoustic system species identification can be very difficult, especially in streams with both coho and steelhead (Adams et al. 2011, pg 65) and Resistivity counters cannot effectively differentiate between species and determine origin of stock, which are integral factors for life cycle monitoring. Investigations into the use of hydroacoustic systems, such as the DIDSON, have led us to theorize that many researchers are falsely identifying the DIDSON as a tool that can be easily installed in a river to conduct salmonid life cycle monitoring. We obtained assurances to our theories, during the California/Nevada American Fisheries Society conference (Old Town Sacramento 2014) where researchers participating in a DIDSON symposium panel discussion were all having varying degrees of difficulties with species differentiation, kelt differentiation, and origin of stock identification when using the DIDSON for salmonid monitoring.

Although we did not identify the lagoon as a possible installation site it might be more suitable for a resistivity counter and resistance weir due to the morphology of the site being more conducive to less variation in depth and velocity at varying flows. However, the resistivity counters effectiveness during multiple fish passage events, high salinity due to tidal influences, of detecting smaller fish (< 500 mm), and during wave action and wind turbulence is insufficient to warrant a recommendation of this sampling technique for Scott Creek.

Although the infrared counts and ladder technique would provide the most accurate and consistent data, the supplemental ladder technique would require a engineered design plan that gives the technique a much higher cost for relatively similar benefits that a infrared counter and PRBW provides.

Table 8. Scott Creek Decision Matrix ranking notes for the top three adult salmonid monitoring sampling techniques.

Sampling Technique	Ranking Notes
Infrared Counter & Resistance Weir	1) Can be operated in a wide range of flows 2) Design specific attributes could increase the effectiveness of the weir at deeper channel depths and higher water velocities 3) Substrate mobility may be an issue; however, design specific attributes have the potential to increase the ability of a weir to handle the substrate 4) Infrared Counter can allow remote monitoring in turbidities < 100 NTU's 5) Infrared Counter can reduce fish stress related to handling 6) Infrared Counter can decrease the data management efforts, thereby decreasing the overall cost of monitoring 7) Infrared Counters & Resistance Weirs can be designed to be portable
Infrared Counter & Rigid Weir	1) Similar infrared counter attributes as list above 2) Does not handle changing flows or pulse flows as well as a resistance board weir 3) Design changes that increase the functionality of a rigid weir in high flow and velocities typically make it a more permanent structure that can significantly increase the cost and permitting constraints
Hydroacoustic (DIDSON)	1) This technique handles high velocity, a high range of flow, and deep channel depths

	2) Species identification is very difficult unless passage objects are within range (< 15 meters) and migration timing does not overlap. 3) Very high cost since it requires at least 8 hours to process 24 hours of imagery, regardless of auto-process capabilities
Infrared Counter and ladder	1) Similar Infrared counter attributes as list above 2) The permanent nature of this type of structure significantly increases the costs and permitting constraints
Resistivity Counter and ladder	1) Resistivity counter can reduce fish stress related to handling 2) Resistivity counter is not good for species differentiation and origin of stock 3) The permanent nature of this type of structure significantly increases the costs and permitting constraints

Adult coho and steelhead escapement data obtained from Hayes et al. (2011) indicates that an infrared counter has the ability to collect the pertinent data under the historical passage rates and densities. Under high rates of migration, the infrared counter may underestimate fish counts when multiple fish enter the scanner unit at the same time (Baumgartner et al. 2010, Sharlow and Hyatt 2004). According to a study conducted in the Big Qualicum River, Canada, the fish counter was 95% accurate for migration rates less than 500 fish per hour, but accuracy declined to 76% at rates exceeding 1,500 fish per hour (Shardlow and Hyatt 2004). Cuthbert and Fuller (2011) indicates that accurate counts of up to 100 fish/hour are achievable, which is well within the range of passage rates expected during peak upstream migration in Scott Creek.

Furthermore, recent technology improvements to the Riverwatcher infrared counter has increased confidence in species identification, as well as, improved differentiation between salmonid species. Historically, an optional camera has been available to use with the Riverwatcher (Camera Riverwatcher) to assist with the differentiation of salmonid species however this had limited functionality in turbid conditions. A few years ago Vaki designed an air filled chamber camera housing for the Camera Riverwatcher that significantly improved the camera imagery in turbid conditions; thereby, increasing the ability of the Riverwatcher to differentiate salmonid species in turbid conditions (Figure 16). Although the threshold for effective camera imagery in turbid conditions is unknown, Cuthbert and Hellmair (2012) effectively identified adult steelhead in the Salinas River with turbidity that was typically greater than 20 NTU's using a Camera Riverwatcher with the air filled chamber camera housing.

Figure 16. Air-filled chamber camera housing for the Camera RiverWatcher. Example of the air-filled chamber camera Riverwatcher installed in a River in South Korea (left photo) and view of the inside of the Riverwatcher camera tunnel depicting the glass lens of the air filled chamber camera housing (right photo).

Although a resistance board weir is already in place on Scott Creek, there is opportunity for minor modifications to increase functionality during high flows (see Cuthbert and Fuller 2011 for examples). For example, the operators of the Nisqually River weir use an anchor chain (Figure 17) to pull the weir in and out of the river during high flows, and an air bladder (Figure 18) to provide extra buoyancy to the weir during periods of elevated discharge (Bill St. Jean, personal communication Nisqually Indian Tribe, Olympia, Washington). Although an anchor chain may not be a suitable configuration for Scott Creek, an air bladder could allow the weir to operate at higher flows and to clear the weir of mudstone more efficiently by temporarily lowering the weir (deflating the air bladder) to clear off rocks and debris. Similarly, the Scott Creek weir could benefit by extending the panels to 20 feet in length and adding an infrared (e.g., Vaki Riverwatcher) camera system, which would increase the functionality and data collection efficiency at high flows and high turbidity. Additionally, an upstream fyke trap could be used in conjunction with the infrared camera to provide trapping opportunities (Figure 19). Based on flow data from 2010 to 2013, obtained during the watershed characterization, it is reasonable to suggest that the modifications to the existing weir outlined above would allow continuous weir operation throughout the majority of the migration season, with the exception of a few, very limited time periods (i.e., <24 hours) each season when high flows temporarily exceed the operational range of the weir.


Figure 17. The Nisqually Weir anchor chain substrate rail. Photo courtesy of Nisqually Indian Tribe.


Figure 18. The Nisqually Weir air bladders filled with compressed air. Photo courtesy of Nisqually Indian Tribe.

Figure 19. Example of an upstream fyke trap previously used in conjunction with the Stanislaus River Weir and Riverwatcher monitoring project.

Summary and Recommendations for Scott Creek

Results of the Decision Matrix tool recommend that smolt outmigration monitoring should be conducted with a 5' rotary screw traps for the following reasons:

- A rotary screw trap can operate under a higher range of depths and velocities than a fyke net and is less likely to be damaged or rendered dysfunctional during high flows, thereby reducing effort.
- A rotary screw trap will give researchers the ability to operate under high flows, which is typically when the majority of steelhead smolts migrate.
- Although rotary screw traps require a substantial initial investment (high first year cost), they likely will save money in the long run due to their increased durability and decreased effort to maintain and operate in comparison to fyke nets.
- Fyke nets can continue to be used during very low flow conditions when a rotary screw trap would not operate.

A portable resistance board weir is already in use at Scott Creek to monitor adult passage, and the results of the Decision Matrix confirm that this is the ideal sampling technique for Scott Creek. Based on the results, the following modification to the Scott Creek weir could be made to further enhance its functionality:

- Resistance panels could be extended from 15 ft. to 20 ft. long.
- An air bladder floatation device could be designed and installed to the downstream end of the weir to increase buoyancy. In conjunction with the air bladder device, the resistance weir panels could be adjusted by changing the incline of the panel to decrease the hydraulic force on the weir.

- An anchor chain portable substrate rail (or a design that accomplishes the same objective) could be used to make the installation and removal process easier, and allow researchers to more quickly respond to changes in flow.
- An infrared camera unit could be added to the passage chute at the weir to reduce effort and fish handling. An infrared camera can also provide continuous migration data during high flow periods when a weir trap is deemed unsafe for technicians to operate.
- An upstream fyke trap could be used in conjunction with the infrared camera to provide trapping opportunities.

Although the infrared counter and portable resistance board weir technique appears to be the most logical solution for salmonid life cycle monitoring on Scott Creek the infrared counter and ladder technique has the potential to provide more consistent data during peak pulse flows. If researchers are interested in pursuing this technique further, then a detailed cost/benefit analysis should be conducted to identify if this technique is warranted in comparison to the infrared counter and portable resistance board weir. In order, to understand the costs associated with this technique the ladder would have to be engineered to the site/river conditions (hydrology, substrate, etc…), which would have a significant cost as well. It is also important to note that more specific and detailed engineering to portable weirs can be done to mitigate limiting factors, such as, substrate mobility; however, as described above, the engineering would be very costly and have a negative effect on the cost/benefit analysis. For example, a portable resistance weir could be designed with hydraulic or air bladder rams that can adjust (raise or lower) rigid weir panels during changes in flow and periods of high substrate mobility (i.e weir panels are lowered to clear/pass mobilized substrate).

The data collection efforts for the Scott Creek Case Study were limited to a snapshot in time, and the Decision Matrix tool was informed by existing life-cycle monitoring experience. Future monitoring projects, especially new projects, would greatly benefit from collecting more detailed site characteristic information on the range of values experienced at the site for the parameters found in the Parameter Table. Such information would allow for a more objective ranking of the parameters in an effort to maximize the effectiveness of the Decision Matrix to produce the best recommendations for life-cycle monitoring in coastal coho and steelhead streams.

CONCLUSIONS AND FUTURE DEVELOPMENTS OF THE DECISION MATRIX TOOL

Due to the paucity of information available in literature on quantitative criteria for the sampling techniques, the development of the life-cycle monitoring station Parameter Table relied heavily on a the experience of a group of knowledgeable biologists. The Scott Creek Case Study demonstrated the effectiveness of the Decision Matrix in its current form, but the Decision Matrix will benefit from experienced Station operators providing feedback regarding the criteria in the Parameter Table. Based on this feedback, modifications and additions can be made to increase the accuracy of the criteria or to encompass more information, such as parameters that were not originally considered.

The Decision Matrix was developed to assist resource managers, researchers, and other professionals working on identifying optimal sampling techniques for CCC coho salmon and steelhead populations. However, the optimal technique will depend on many site-specific factors and not all factors could be addressed using this tool. The Decision Matrix was designed to be flexible and allow for modifications. Additional factors not considered by the matrix, which could be added include, conductivity, aquatic vegetation, and fish abundance, which could affect the accuracy of some techniques. Furthermore, researchers in other salmonid watersheds outside of the CCC can modify this tool beyond its current focus on fixed station monitoring, to assist in developing a general monitoring plan. For example, if a Decision Matrix user is interested in considering aerial survey counts as an alternative, they could include them as a sampling technique, but would need to add an additional parameter to surmise how effective sampling techniques would be under varying percentages of riparian canopy or cover.

The adaptability of the matrix should provide researchers with the ability to adjust (insert, remove, combine, re-categorize, etc..) the techniques, adjust the parameter criteria based upon new information, and adjust the parameter inputs collected from the field to custom tailor the matrix for different magnitudes of rivers and site conditions. For example, a similar decision process was used to determine the feasibility of life cycle monitoring in the Salinas River and it's tributaries in 2009 which resulted in annual life cycle monitoring of adult steelhead at one location in the Salinas River and juvenile steelhead monitoring at three locations in the Salinas River, Nacimiento River, and Arroyo Seco River, respectively (Krafft et al. 2014).

The Decision Matrix could be developed into a more user friendly and accessible tool, with a web-based platform that would be interactive and driven by user feedback. This would provide a valuable forum for Station operators to share their experiences and benefit from a shared knowledge base. As new sampling techniques are developed and current techniques are improved with technology, the Decision Matrix can be expanded and improved upon over time.

LITERATURE CITED

Adams, P.B., L.B. Boydstun, S.P. Gallagher, M.K. Lacy, T. McDonald and K.E. Shaffer. 2011. California Coastal Salmonid Population Monitoring: Strategy, Design and Methods. Fish Bulletin 180. State of California, Natural Resources Agency, Department of Fish and Game.

Baumgartner, L., M. Bettanin, J. McPherson, M. Jones, B. Zampatti, and K. Beyer. Assessment of an infrared fish counter (Vaki Riverwatcher) to quantify fish migrations in the Murry-Darling Basin. Narrandera Fisheries Centre, Narrandera NSW, Australia. 2010.

Bond, M.H. 2006. Importance of estuarine rearing to Central California steelhead (*Oncorhynchus mykiss)* growth and marine survival. M.A.Thesis. University of California, Santa Cruz.

Boydstun, L. B., and T. McDonald. 2005. Action Plan for Monitoring California's Coastal Anadromous Salmonids. A Joint Planning Effort of the California Department of Fish and Game and NOAA Fisheries. Santa Cruz, CA.

Cafferata, P. H., and L. M. Reid. 2013. Applications of long-term watershed research to forest management in California: 50 years of learning from the Caspar Creek experimental watersheds. California Forestry Report No. 5 by the State of California Natural Resources Agency Department of Forestry and Fire Protection.

California Department of Fish and Game. 2004. Recovery Strategy for California Coho Salmon. Species Recovery Strategy 2004-1 Report by The California Department of Fish and Game to the California Fish and Game Commission.

California Department of Fish and Game. 2012. Instream flow recommendations: Scott Creek, Santa Cruz County. Prepared by The California Department of Fish and Game Water Branch, Instream Flow Program, Sacramento, CA.

Cuthbert, R., and A. Fuller. 2011. Fall/winter migration monitoring at the Tuolumne River Weir. 2010 Annual Report prepared by FISHBIO for Turlock Irrigation District and Modesto Irrigation District, Oakdale, CA.

Cuthbert, R., A. Fuller, and S. Snider. 2010. Fall run Chinook salmon and Spring Predator migration monitoring using an infrared counting system at the Stanislaus River Weir. 2008/09 Annual Report prepared by FISHBIO for Oakdale Irrigation District and South San Joaquin Irrigation District, Oakdale, CA.

Cuthbert, R. and M. Hellmair. 2012. Salinas River Basin Adult Steelhead Escapement Monitoring. 2012 Annual Report prepared by FISHBIO for Monterey County Water Resources Agency, Oakdale, CA.

Duffy, W.G. 2005. Protocols for Monitoring the Response of Anadromous Salmon and Steelhead to Watershed Restoration in California - Draft. Prepared for the California Department of Fish and Game Salmon and Steelhead Trout Restoration Account, Agreement No. P0210565, Arcata, CA. 12 April 2005.

Hayes, S.A. D. Frechette, D. Pearse, J.C. Garza and R.B. MacFarlane. 2011. DRAFT: Monitoring Life History Traits of ESA-listed Salmonids on the Central California Coast. Report submitted to the California Department of Fish and Game as part of the requirements of FRGP Award # P0830405. May 2011.

Hayes, S. A., M. H. Bond, C. V Hanson, E. V Freund, J. J. Smith, E. C. Anderson, A. J. Ammann, and R. B. MacFarlane. 2008. Steelhead Growth in a Small Central California Watershed: Upstream and Estuarine Rearing Patterns. Transactions of the American Fisheries Society 137:114–128.

Klein, R. D., J. Lewis, and M. S. Buffleben. 2012. Logging and turbidity in the coastal watersheds of northern California. Journal of Geomorphology published by Elsevier. 139-140 (2012) 136-144.

Kondolf, G.M. 1997. Application of the pebble count: notes on pupose, method, and variants. Journal of the American Water Resources Associated, Vol. 33, February 1997.

Krafft, E., C. Leal, and T. Voss. 2014. Salinas Valley Water Project Annual Fisheries Report for 2013. 2013 Annual Report prepared by Monterey County Water Resources Agency for National Marine Fisheries Service, Salinas, CA.

National Marine Fisheries Service (NMFS). 2007. 2007 Federal Recovery Outline for the Distinct Population Segment of Central California Coast Steelhead. Southwest Regional Office. May 2007.

National Marine Fisheries Service (NMFS). 2012. Final Recovery Plan for Central California Coast coho salmon Evolutionarily Significant Unit. National Marine Fisheries Service, Southwest Region, Santa Rosa, California.

Shardlow, T.F., and K.D. Hyatt. 2004. Assessment of the counting accuracy of the Vaki infrared counter on Chum salmon. North American Journal of Fisheries Management 24: 249-252.

Volkhardt, G., S. Johnson, B. Miller, T. Nickelson, and D. Seiler. 2007. Rotary Screw Traps and Inclined Plan Traps. Pages. 235-266 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.

Wolman, M.G. 1954. A method of sampling coarse river-bed material. Transactions, American Geophysical Union. Vol. 35, No. 6, December 1954.

APPENDIX A. ANNOTATED BIBLIOGRAPHY OF LIFE-CYCLE MONITORING STATION TECHNIQUES AND PARAMETERS

Electronic - Infrared counts

Baumgartner, L., M. Bettanin, J. McPherson, B. Zampatti, and K. Beyer. 2010. Assessment of an infrared fish counter (Vaki Riverwatcher) to quantify fish migrations in the Murray-Darling Basin. Industry & Investment NSW-Fisheries Final Report Series No. 116. ISSN 1837-2112.

1. Can be used to correlate fish migration with environmental factors.
2. Best at detecting fish with a body depth of 40mm or greater.
3. Can be operated by independent power sources (e.g. solar).
4. Can be installed in virtually any location where migratory fish can be directed through the device.
5. Is useful for collecting data on both up- and downstream migrants.

Santos, J. M., P. J. Pinheiro, M. T. Ferreira, and J. Bochechas. 2008. Monitoring fish passes using infrared beaming: a case study in an Iberian river. Journal of Applied Ichthyology 24:26-30.

1. Works best in low turbidities.

Shardlow, T. F. and K. D. Hyatt. 2004. Assessment of counting accuracy of the Vaki infrared counter on chum salmon. North American Journal of Fisheries Management 24:249-252.

1. IR counts are most accurate when migration rates are low. Accuracy has been shown to drop substantially when the machine has to count more than one fish at a time.
2. IR counts have been shown to be accurate up to 1500 fish/hr as long as fish are passing one at a time.

Electronic - Resistivity counts (e.g. Logie)

Alaska Department of Fish and Game. 2006. Southeast habitat information tools. Alaska watershed dataset through the SEAK GIS Library Project. http://gisdev.sf.adfg.state.ak.us/SEAKFISH/viewer.htm.

1. Inexpensive.
2. Less intrusive than traditional weirs
3. No handling of fish.

4. Good in remote areas.

McCubbing, D. and D. Ignace. 2000. Salmonid escapement estimates on the Deadman River, resistivity counter video validation and escapement estimates. MEOLP Project Report number 2000, Vancouver, British Columbia, Canada.

1. Successfully used for steelhead.
2. Often needs some kind of validation such as video review.
3. High turbidities make video difficult.
4. 95.9% efficient for upstream steelhead (results may vary dramatically).
5. Highly variable conductivities affect counter efficiency more negatively than continuously high conductivities

McCubbing, D. and D. Gray. 2004. Logie 2100C resistivity fish counter training manual. Instream Fisheries Research, Inc., Vancouver, British Columbia, Canada.

1. Flash flows, high debris, low water level, and animal activity can negatively impact counter efficacy.
2. Manufacturer recommends conductivities less than 300µs.
3. Best in clear streams with minimal flow variation.

McCubbing, D., B. Ward, and L. Burroughs. 2000. Salmonid escapement on the Keogh River: a demonstration of a resistivity counter in British Columbia. Province of British Columbian Fisheries Technical Circular Number 104:25 p.

1. 88% efficient for coho.
2. Most accurate for larger fish

Nicholson, S.A. and M.W. Aprahamian. 1993. Field Validation of the 'Logie' Fish Counter at Forge Weir on the River Lune, 1992. National Rivers Authority, North West Region, FTR/93/5. April 1993.

1. As water level increase a fish of a given length will displace proportionally less water above the electrode resulting in reduced signal size.
2. Figure 11 ("The influence of water level on the relationship between peak signal size and fish length") indicates that peak signal size decreases with increasing water level.
3. Table 6 indicates that for fish under 25 cm, counting efficiency decrease with increasing water level (e.g., poor accuracy at water levels between 50 and 70 cm).

<u>Fyke net</u>

DFG. 1995. Studies on the downstream migration of young salmon in the Feather River 1955. Sacramento, CA: California Department of Fish and Game.

1. At low flows fyke nets are notoriously selective for smaller juveniles.

Fresh, K., 2000. Juvenile Chinook migration, growth, and habitat use in the lower Green River, Duwamish River, and nearshore of Elliot Bay. Prepared for King County Department of Natural Resources and Parks, Water and Land Resource Division, Seattle.

1. Larger mesh fyke nets are best used for larger fish; conversely, smaller meshed nets are more efficient at catching smaller fish.
2. Can easily clog with debris

Hubert, W. A. 1996. Passive capture techniques. Pages 157-192 in B. R. Murphy and D. W. Willis, editors. Fisheries techniques, 2nd edition. American Fisheries Society, Bethesda, Maryland.

1. Good for capturing juvenile salmon and steelhead.
2. Good in virtually all substrate types.
3. Very large substrates can allow small fish to escape.

Milner, A. and L. Smith. 1985. Fyke nets used in southeastern Alaskan stream for sampling salmon fry and smolts. North American Journal of Fisheries Management 5:502-506.

1. Relatively inexpensive, portable and easy to operate.
2. Proven technique in flowing water.
3. Bows at high flow
4. Selects against larger smolts at low flows and velocities.

Fyke trap

Zimmerman, C. E. and L. M. Zabkar. 2007. Weirs. Pages 385-398 in D. H. Johnson, B. M. Shrier, J. S. O'Neal, J. A. Knutaen, 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.

1. Upstream fyke traps are very dependent on other structures such as resistance weirs or rigid weirs to direct the fish into the trap
2. It becomes very difficult to operate the trap at high flows

3. Requires significant labor to monitor the trap for fish health.

Hydroacoustics - DIDSON

Brandt, S. B., 1996. Acoustic assessments of fish abundance and distribution, Pages 385-432 in B. R. Murphy and D. W. Willis, editors. Fisheries Techniques, 2nd edition. American Fisheries Society, Bethesda, Maryland.

1. Useful in turbid waters.
2. Useful in streams with low target species populations or infrequent passages.
3. Useful for larger life stages.
4. No disruption to the environment.
5. Well suited to assess mid-water fishes.
6. Cost effective.
7. Cannot directly identify fish.
8. Efficiency is lost in shallow water due to the equipment having difficulty-detecting fish near the bottom or surface.

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.

1. High frequency multi-beam sonar useful in streams with high passage (200 fish/hr or greater).
2. Waters with high debris densities may give deceiving results.
3. Low portability.

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

1. Dual frequency sonar useful for streams with high fish passage.
2. Good in most habitat and substrate types.
3. Good in remote locations.
4. Excellent in turbid, light debris waters.
5. DIDSON could image a sphere at to 800 NTU up to 16.5 m away

Pipal, K., M. Jessop, G. Holt, and P. Adams, 2010. Operation of a dual-frequency identification sonar (DIDSON) to monitor adult steelhead (Oncorhynchus mykiss) in the central California coast. NOAA Technical Memorandom NMFS Southwest Fisheries Science Center, Fisheries Ecology Division, Santa Cruz, California.

1. Requires significant effort to reposition during freshets.
2. Unless the stream is narrow, operation requires a weir type structure.
3. Requires a significant power source.
4. Does not adequately handle milling behavior.
5. Requires a relatively consistent channel depth and width to sufficient cover the passable area with the view of the DIDSON.

Xie, Y., T. J. Mulligan, G. M. W. Cronkite, and A. P. Gray. 2002. Assessment of potential Bias in Hydroacoustic estimating of Frasier River sockeye and pink salmon at Mission, B. C. Pacific Salmon Commission Technical Report No. 11, Vancouver, British Columbia, Canada.

1. Preferable to intrusive methods such as nets and traps.

Inclined Plan Traps (IPT)/Incline Screen Traps (IST)

Volkhardt, G., S. Johnson, B. Miller, T. Nickelson, and D. Seiler, 2007. Rotary Screw Traps and Inclined Plan Traps. Pages. 235-266 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.

1. Fry < 50 mm FL may be captured at relatively low velocities
2. Larger migrants (such as steelhead smolts <250 mm) generally require velocities >2 m/s (6.5 fps)(i.e. faster than a large smolts swimming speed) to be sampled efficiently
3. Less constrained by shallow depths than RSTs
4. ISTs can handle higher velocities. Water velocities of at least 1 m/s are desirable for scoop trap operation; for most steelhead smolts, velocities greater than 2 m/s (3.3 fps) may be required for capture and retention. For Humphreys traps, a minimum water velocity of 0.9 m/s (3 fps) was recommended, with best efficiency at 1.5–2 m/s (4.9 – 6.6 fps).
5. A traveling screen can be motorized to render ISTs more effective in low flow/low velocity conditions.

Ladder

Faulds, P. and J. McDowell. Fish passage operations at the Landsburg Dam Fish Passage Facilities on the Cedar River from July 2008 through June 2009. Annual Report prepared by the Seattle Public Utilities District, Seattle, Washington.

1. A trap can be used in a ladder to remove fish for hatchery broodstock.
2. A Vaki Riverwatcher can be used to passively monitor the fish ladder.

Massa, D., J. Bergman, and R. Greathouse. Lower Yuba River Accord Monitoring and Evaluation Plan Annual Vaki Riverwatcher Report, March 1, 2008 through February 28, 2009. Annual Report prepared by Pacific States Marine Fisheries Commission for The Lower Yuba River Accord Planning Team.

1. Demonstrated a passive monitoring technique in a two fish ladders for counting salmonids.
2. Collected very detailed size and migration timing information passively under very turbid conditions.

Resistance Weir

Cuthbert, R. and M. Hellmair. 2012. Salinas River Basin Adult Steelhead Escapement Monitoring. 2011 Annual Report prepared by FISHBIO for Monterey County Water Resources Agency, Salinas, California. 22 pp.

1. Demonstrated the use of a resistance weir in a tidal environment.
2. Demonstrated the use of a resistance weir anchored to a sand substrate.
3. Demonstrated the use of a Weir and Riverwatcher to effectively enumerate adult steelhead in very turbid conditions without handling them.

Zimmerman, C.E. and L.M. Zabkar. 2007. Weirs. Pp 385-398. *In* Johnson, D.H., B.M. Shrier, J.S. O'Neal, J.A. Knutzen, X. Augerot, T.A. O'Neil, T.N. Pearsons, Eds. Salmonid Field Protocols Handbook. Techniques for Assessing Status and Trends in Salmon and Trout Populations. Amer. Fish. Soc., Bethesda, MD. 497p

1. Can be designed to incorporate boat passage.
2. Can be very labor intensive when not combined with a passive fish counter (i.e. infrared counter, resistivity counter, time-lapse video, DIDSON)
3. Works well in stream with highly variable flow.

Rigid Weir

Portz, D. E., E. Best, and C. Svoboda. 2011. Evaluation of Hills Ferry Barrier effectiveness at restricting Chinook salmon passage on the San Joaquin River. Report by The Bureau of Reclamation Technical Service Center to The San Joaquin River Restoration Program.

1. Demonstrated the failure of a rigid weir to properly function in a sand substrate, even in low flow
2. DIDSON, acoustic telemetry, and bathymetry data were collected demonstrating compromised portion of the weir and fish passing the weir and being detected upstream.

Zimmerman, C.E. and L.M. Zabkar. 2007. Weirs. Pp 385-398. *In* Johnson, D.H., B.M. Shrier, J.S. O'Neal, J.A. Knutzen, X. Augerot, T.A. O'Neil, T.N. Pearsons, Eds. Salmonid Field Protocols Handbook. Techniques for Assessing Status and Trends in Salmon and Trout Populations. Amer. Fish. Soc., Bethesda, MD. 497p.

1. Rigid weirs work best in waters that have minimal variation in flow.
2. Can be very labor intensive when not combined with a passive fish counter (i.e. infrared counter, resistivity counter, time-lapse video, DIDSON)

Rotary Screw Traps (RST)

Cuthbert, R., S. Ainsley, and D. Demko. 2011. Salinas Basin Juvenile *O. mykiss* Outmigration Monitoring. 2011 Final Report prepared by FISHBIO for Monterey County Water Resources Agency, Salinas, California. 29 pp.

1. Demonstrated steelhead smolt capture at low depths and velocities using flow diversion structures
2. Traps can be damaged at 14-15 rpm

Volkhardt, G., S. Johnson, B. Miller, T. Nickelson, and D. Seiler. 2007. Rotary Screw Traps and Inclined Plan Traps. Pages. 235-266 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.

1. Reduced trap cleaning relative to tradition IPT's (due to traveling screen).
2. Generally more efficient at capturing larger smolts than an IPT.

3. Less-size selective with respects to steelhead; however, coho have a more equal capture probability, most likely due to differences between swimming velocities of the two species.
4. Water velocities of 0.8–2 m/s (2.6 - 6.5 fps) work well for screw traps operated in Oregon coastal streams
5. Steelhead smolts captured at speeds as slow as 1.67 rpm (Cuthbert et. al. 2011 suggests even slower speeds can capture RBT smolts).
6. Stilts can be used to raise the whole trap in the event that water depth is not sufficient.
7. Motors can used to rotate the trap in the event that water velocities are too low.

Tower Counts

Cousens, N. B. F., G. A. Thomas, C. G. Swann, and M. C. Healey. 1982. A review of salmon escapement estimation techniques. Canadian Technical Report of Fisheries and Aquatic Science 1108.

1. Limited to low turbidities
2. Lower cost than weirs and aerial counts.
3. Good for most salmonid species.
4. Steelhead migration rates may be too low for reliable counts.

Edwards, M. R. 2005. Comparisons of counting tower estimates and digital video counts of coho salmon escapement in the Ugashik Lakes. U.S. Fish and Wildlife Service, Alaska Fisheries Technical Report No 81, King Salmon Fish and Wildlife Office, King Salmon, Alaska.

1. Tower counts are consistent with digital video counts.

Rietze, H. L. 1957. Western Alaskan salmon investigations; field report on the evaluation of towers for counting salmon in Bristol Bay, 1956. Mimeo report to the U.S. Department of the Interior, U.S. Fish and Wildlife Service, Bureau of Commercial Fisheries, Juneau, Alaska.

1. Similar accuracy to a weir but with less migrational disruption.
2. Best in areas with low glare and wind.

Thompson, W. F. 1962. The research program of the Fisheries Research Institute in Bristol Bay, 1945-1958. In T. S. Y. Koo, editor. Studies of Alaskan red salmon. University of Washington Press, Seattle.

3. Low maintenance.
4. Easily mobilized.

5. Low technology.
6. Low equipment cost.
7. High labor cost.
8. May require a partial weir to concentrate fish in a viewable area.

<u>Video Counts</u>

Esteve, M. 2005. Observations of spawning behavior in salmoninae: *Salmo, Oncorhynchus* and *Salvelinus*. Reviews in Fish Biology and Fisheries 15:1-21.

1. Excellent for viewing specific spawning behaviors of various members of the family salmonidae.

Hatch, D. R., J. K. Fryer, M. Schwartzberg, D. R. Pederson, A. Wand. 1998. A Computerized Editing for Video Monitoring of Fish Passage. North American Journal of Fisheries Management 14:626-635.

1. Excellent alternative to manual counts.
2. Best in low turbidities

Newcomb, T. J. and T. G. Coon. 1997. Evaluation of alternate methods of estimating numbers of outmigrating steelhead smolts. Report # Fisheries Research Report No. 2045. Michigan Department of Natural Resources, Fisheries Division.

1. Low labor requirements.
2. Low cost.
3. High turbidities decrease accuracy and can require additional trapping.
4. Review of video can be labor intensive since it typically requires 8 hours to review 24 hours of passage video.

Otis, E. O., and M. Dickson. 2002. Improved salmon escapement enumeration using remote video and time-lapse recording technology. Alaska Department of Fish and Game, Division of Commercial Fisheries. Restoration Project 00366 Final Report, Homer.

1. Extremely successful in remote areas where man power may be limited.
2. Excellent in variable river conditions and habitat types.

Mueller, R. P. 2005. Deepwater spawning of fall Chinook salmon (*Onchorhynchus tshawytscha*) near Ives Pierce Island of the Columbia River. 2004-2005 Annual Report, Project No. 199900301. Booneville Power Administration, DOE/BP-00000652-28, Portland, Oregon.

1. Excellent for assessing deep water spawning behaviors.
2. Infrared lighting has been best in low light conditions including high turbidities.

Pearson, W. H., R. P. Mueller, S. L. Sargeant, and C. W. May. 2005. Evaluation of juvenile salmon leaping ability and behavior at the experimental culvert test bed. Final Report of the Washington State Department of Transportation, Battle Pacific Northwest Division, WSDOT Agreement No. GCA2677, Richland.

1. Excellent in assessing movement of juvenile coho salmon (including leaping ability).
2. Low portability.

Visual Counts

Dolloff, A. C., and M. D. Owen. 1991. Comparison of aquatic habitat survey and fish population estimation techniques for a drainage basin on the Blue Ridge Parkway, Completion Report. U. S. Department of the Interior, National Park Service, Cooperative Agreement CA-5000-3-8007, Bethesda, Maryland. 39-48.

1. Visual surveys techniques are best in low turbidities.
2. Visual techniques are best for adult fish. Juvenile and larval fish are difficult to spot.
3. Better in low velocities

Flosi, G., and F. L. Reynolds. 1994 California salmonid stream habitat restoration manual. California Department of Fish and Game, Technical Report, Sacramento.

1. Highly portable.
2. Most costs associated with labor.
3. Effective in most habitat types.
4. Densely vegetated habitats reduce efficiency.

Griffith, J. S., D. J. Schill, and R. E. Gresswell. 1984. Underwater observations as a technique for assessing fish abundance in large rivers. Proceedings of the Western Association of Fisheries and Aquatic Sciences 45:834-844.

1. Can be effective in high flows as long as turbidities are low and depths are reasonable.
2. Accuracy subject to high levels of variability due to observer bias.

APPENDIX B. LIFE-CYCLE MONITORING STATION PARAMETER TABLE

Please see the accompanying Excel spreadsheet for the life-cycle monitoring station Parameter Table.

APPENDIX C. PHOTOS AND DESCRIPTION OF THE STANISLAUS RIVER WEIR REMOVAL.

A team of eight technicians removes a portable resistance board weir in less than six hours. A time-lapse video recording of this event is available at http://youtu.be/Mgyvrh-6bIY.

Beginning at 7:00 am a team of eight begin removing bulkheads and disassembling the weir passing chute.

Panels are unhooked from the substrate cable and floated across the channel where they are separated and removed from the river.

Technicians work in teams of four to carry weir panels up the bank to be stored for next season.

By noon the last of the safety buoys are removed and the weir removal is complete.