Sonar estimation of adult salmonid abundance in Redwood Creek, Humboldt County, California 2011-2012.

U.S. Geological Survey, California Cooperative Fish and Wildlife Research Unit

Humboldt State University

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ABSTRACT

Dual frequency identification SONAR **(**DIDSON) was used to estimate escapement of adult coho salmon, Chinook salmon, and steelhead entering Redwood Creek to spawn between 9 November 2011 and 14 March 2012. Sonar assessment of adult salmonids in Redwood Creek began in 2009 as part of a pilot study to determine if and how DIDSON technology could be used to produce estimates of escapement for the basin. Observations from spawning surveys in the basin were used to model species apportionment of the DIDSON counts. The estimate for unidentified salmonid passage when multiple species were present (9 November 2011 to 28 February 2012) was 2393 +/- 876 fish. Chinook salmon estimates ranged from 1223-1849, coho salmon estimates ranged from 456-1040, and steelhead estimates ranged from 220-297.

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INTRODUCTION

The acronym DIDSON stands for dual frequency identification SONAR. It provides high resolution underwater video and has been effectively used by management agencies to count migrating adult salmon in rivers (Holmes et al. 2005, Cronkite et al. 2006, Maxwell et al. 2007, Melegari 2008, Johnson et al. 2009). A DIDSON has been deployed on Redwood Creek for three consecutive migration seasons starting in 2009-2010, with some success. Dangerously high stream flows and species identification of the DIDSON images have been identified as limitations in the use of this technology on Redwood Creek (Metheny 2012).

The primary objective of this study was to estimate escapement for three species of anadromous salmonids in Redwood Creek. The average run timing and body length these species differs, but each also overlaps with at least one other species. Use of DIDSON to estimate escapement has proven challenging on rivers supporting multiple species of anadromous salmonids (Faulkner and Maxwell 2008, Melegari and Osborne 2008). Resolution of images from DIDSON video is such that fish length can be accurately determined, but details of morphology (and thus species) cannot. Therefore, in streams supporting multiple species, a distinction should be made between DIDSON counts of total fish when no attempt is made to assign individuals to a particular species, and fish passing the camera that have been assigned to a species.

Apportionment of salmonid species with overlapping run times and sizes for DIDSON escapement estimates has typically been derived from sampling with seines (Pfisterer 2002, McKinley 2003, English et al. 2011) or fish wheels (Westerman and Willette 2006). A basin-wide regime of spawning surveys commenced on Redwood Creek in 2009-2010 (Ricker 2011), offering a means of modeling the species apportionment for the Redwood Creek DIDSON. Specifically, in-stream observations of known salmonid species can be used to assign species probabilities to observations of individual fish from the DIDSON.

Additionally, escapement assessments from redd expansion methods provide an opportunity to compare estimation techniques for agreement.

SITE DESCRIPTION

Redwood Creek flows into the Pacific Ocean near the town of Orick about 56 km north of Eureka, California (Figure 1). The watershed covers an area of 738 km^2, is long, narrow and oriented northwest-southeast. Redwood Creek is about 108 km long, but with tributaries contains 192 km of habitat accessible to anadromous fish. The largest tributaries to Redwood Creek are Prairie Creek, located just upstream of Orick and Lacks Creek, located in the middle part of the watershed. The watershed has been identified as a high priority for restoration activities to improve water quality and recover anadromous salmonid populations (Canata et al. 2006).

The Redwood Creek watershed supports four species of anadromous salmonids, of which Chinook salmon *(Oncorhynchus tshawytscha)*, coho salmon *(O. kisutch)* , and steelhead (*O. mykiss*) are listed under the ESA (United States Office of the Federal Register 1997, 1999, 2000). Coastal cutthroat trout (*O. clarkii clarkii*) and Pacific lamprey (*Lampetra tridentata*) also migrate into Redwood Creek, and resident fish species also inhabit the watershed (Redwood National and State Parks 1997).

The deployment site for the Redwood Creek DIDSON has been at the same location in the town of Orick for three migration seasons, starting in 2009-2010. The camera was situated immediately downstream of the U. S. Geological Survey gauging station 11482500 located 5.9 km from the Pacific Ocean (lat 41^{o} 17’ 58” long 124^{o} 03’ 00” NAD83). This site was about 100 m downstream of the confluence of Prairie Creek, the first major spawning tributary in the watershed.

The landowner adjacent to the site on the east side of Redwood Creek, Orick Rodeo Association, allowed the use of a secure trailer with electricity to power the unit and to house the topside computer components. At this site, the deepest part of channel is against the west bank, which is nearly vertical and consists of rip-rap. On the east bank, a gravel bar slopes gradually down from the levee toe to the channel thalweg. Approximately 100 m of channel is contained between the two levees at the site.

MATERIALS AND METHODS

Deployment of the DIDSON

The DIDSON deployment on Redwood Creek is described in detail in Metheny 2011. A standard model DIDSON (SN 392) was used, which can detect salmon at distances of up to 30 m (Burwen et al. 2007, Matthews and Baillie 2007). The DIDSON was deployed in typical side-facing position, described by Maxwell (2007), and mounted on an adjustable H-frame constructed of 5.08 cm aluminum tubing. The DIDSON was housed in a custom-made aluminum enclosure to protect it from damage. The enclosure fit snugly around the camera with only the lens and camera cable exposed.

When deployed, the H-frame mount and camera was stabilized with T-posts driven into the river bottom and lashed to the mount with 1 cm diameter nylon line. For security, 1 cm diameter nylon line was attached to the camera box, mount, and to T-posts anchored on shore. To protect from abrasion, the DIDSON data cable was strung through 2.5 cm diameter PVC conduit where it crossed the levee and wrapped with vinyl tubing between the levee and camera.

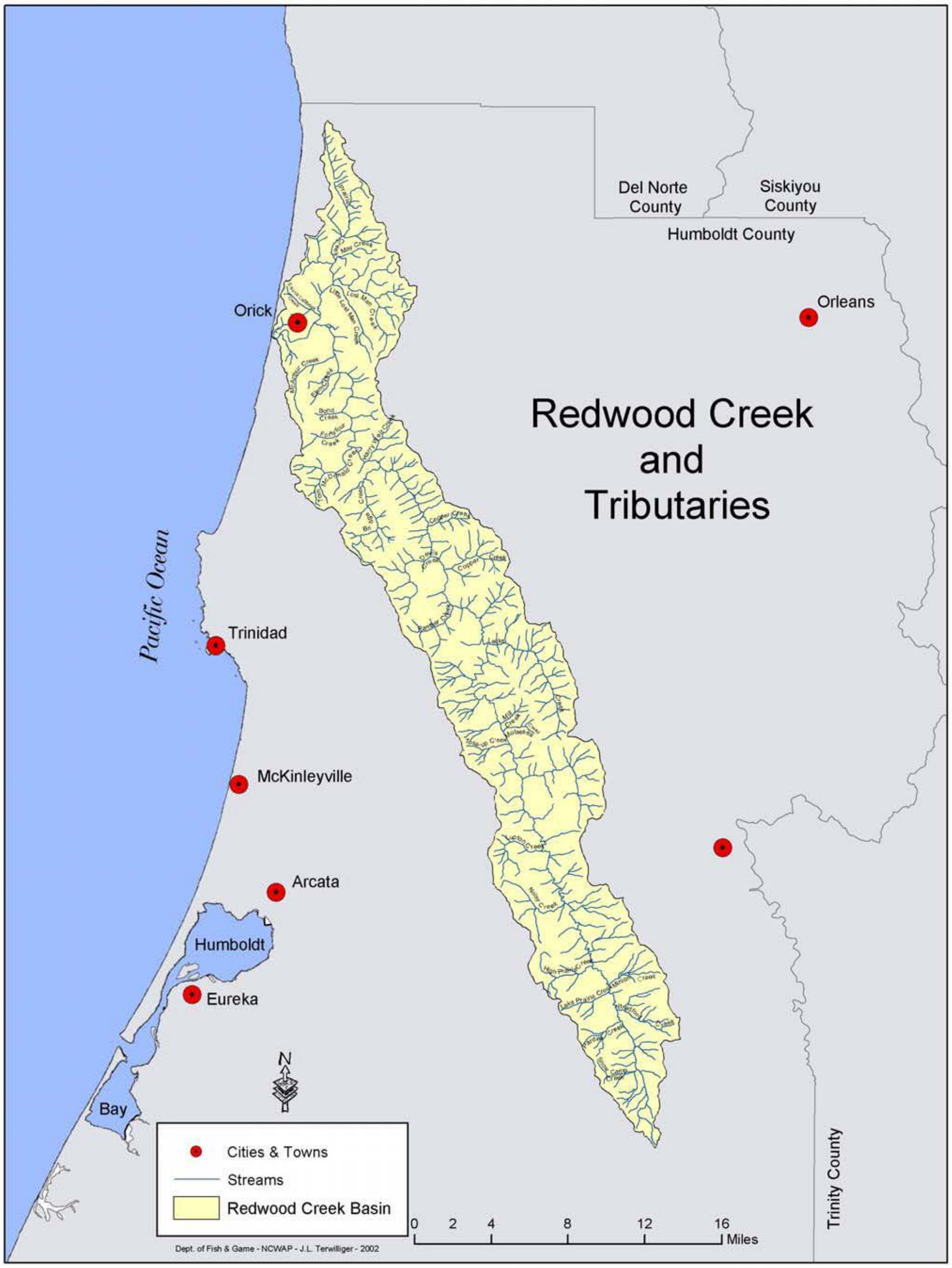


Figure 1. Map of Redwood Creek showing its location in northern California.

The camera was maintained in a position where it could safely ensonify as much of the channel as possible. The channel cross section changed frequently, so I used visual aiming methods similar to those described by Maxwell and Gove (2007), who recommend positioning the DIDSON close to bottom substrate and angling the beam along the angle of the river bottom. This angle was typically between -1° and -5°.At moderate to high flows, the camera stand was positioned as close to the deepest part of the channel as flows allowed, 25-45 m from the west bank. At flows less than 1000 f^3/s, the camera was kept in the shallow water close to the east bank to keep fish from swimming behind the camera, about 18 m to the west bank.

To keep the camera stand in the appropriate water depth, the study site was checked at least once a week and the camera was moved if discharge had changed from the previous week. During rain events, stage height was monitored remotely using the nearby USGS gage to ensure the camera could be moved before flows increased to hazardous levels. The camera was checked after storms or every two weeks for silt and algal buildup, and was rinsed as needed, as accumulations of either diminish video quality.

Estimating escapement to Redwood Creek

DIDSON video must be reviewed and interpreted to produce estimates of fish passage, which can be time consuming. The review methods used for analyzing Redwood Creek DIDSON video data are described in detail in Metheny 2012. Two means of reducing the time required for video analysis in 2011-2012 were used: (1) sub-sampling and (2) time-condensed video footage.

A non-replicated systematic sample of the first 10 minutes of each hour was employed to estimate escapement into Redwood Creek for the bulk of the salmon migration (87 out of 93 days). For each 10-minute file, net movement was defined as the sum of positive upstream movements and negative downstream movements (Xie et al. 2002). Net movement over 10 minutes was multiplied by a factor of six to derive hourly estimates of fish passage. Net movement of fish for a day was treated as the sum of hourly net movements.

When analyzing DIDSON data with sub-sampling, unprocessed video files were played back at one to eight times faster than recorded speed. Increasing fish densities required slower playback rates, as described by Faulkner and Maxwell (2008). Tallies of upstream and downstream movements, along with corresponding lengths were recorded for each 10-minute file.

The CSOT (Convoluted Samples Over Threshold) feature processes video files and retained moving objects larger than a certain threshold size, while video that had no moving objects was discarded. Suitable days with few fish and low image noise were selected for review using a CSOT census. These video files were compressed using default settings, combined into a single file, and then reviewed.

The V2 and V5 estimators of variance and resulting 95% confidence intervals were calculated when sub-sampling was employed (Reynolds 2007, Wolter 1984, 1985). The V5 estimator was used when multiple species were present. The V2, which is better suited for low sample sizes (Wolter 1985), was used when only steelhead were migrating, after 28 February 2012. When a CSOT census was used, it was assumed that no sampling error existed. For simplicity, it was assumed at all times that the camera detected all adult fish passing the site in either direction.

When measuring the length of fish, I used a method similar to the one described by Pippal et al. (2010). With this method, footage was replayed after a fish is observed, and a frame showing the entire length of the fish was selected. The software was then used to obtain a minimum of two length measurements, and the average was recorded. This length was assumed to represent the fish's total length.

A cutoff of 40 cm was used to differentiate adult salmonids from jacks, cutthroat trout, and resident fish. This cutoff was based on the 40.64 cm minimum length for adults used by the California Department of Fish and Wildlife Steelhead Report Card. For each day, the proportion of observed fish above and below the 40 cm cutoff was applied to the daily escapement estimate. All fish over 40 cm were assigned to a species using models based on spawning survey observations. Individual fish under 30 cm were generally ignored to simplify and speed up the review process, while groups of 10 or more were noted.

Steelhead migrating back to ocean after spawning present a challenge to enumerating steelhead runs, especially if down-running steelhead are present when other species are migrating upstream. Methods outlined by Pipal 2010 were used to distinguish down-running steelhead from milling fish. With this method, fish traveling in the downstream direction after the peak of the steelhead run were counted as down-runners, rather than milling fish.

An attempt was made to differentiate fish from other swimming animals detected by the DIDSON in 2011-2012. The analysis of Redwood Creek video data did not address this issue in previous years, i.e. almost all swimming targets were assumed to be fish. However, the orientation and movement of the acoustic shadow cast by non-fish differs from the shadows cast by fish when viewed on the DIDSON display. Specifically, up and down movement of an acoustic shadow was used as evidence of a non-fish swimming past the camera.

Species Models for Overlapping Runs

Observations of live fish made by the California Department of Fish and Wildlife and the U. S. Geological Survey, Cooperative Fish and Wildlife Research Unit during spawning surveys in Redwood Creek during 2010-2011 were used to model species abundance of fish over 40 cm (Chinook salmon, coho salmon, and steelhead). Carcass observations were not considered, due to increased uncertainty in determining date of migration past the DIDSON into spawning reaches. Four methods of assigning Redwood Creek DIDSON counts to species were used: (1) logistic regression using individual assignment; (2) logistic regression using summed probabilities; (3) ratios of spawning survey observations and (4) normalized distributions of run times. These methods are described in detail in Metheny 2012.

General Assumptions

Several assumptions were made in using live fish observations to inform models of species abundance. The first was that spawning survey observations reflected the true mixture of species present in the basin. Second, no effect was assumed of sub-basin upon the frequency of species observation. The third assumption was that there were no differences in probability of detection among the three species over all spawning reaches. It was assumed that the length measurements taken from DIDSON video files and spawning surveys were congruent. Finally, the assumption was made that fish were not observed on multiple surveys.

Logistic Regression

Logistic regression was used to estimate the possibility of a fish target being Chinook salmon, coho salmon, or steelhead, based on fish length and date. Dates were transformed to 'water year day' representing the number of days since the start of the water year, 1 October. I adjusted date values, assuming that fresh fish migrated past the DIDSON site 10 days prior to the date of observation on the spawning grounds and spawned-out fish 15 days prior for all species. Adjustments were based on residency times calculated for Prairie Creek salmon (Wright 2011).

The multinomial logistic regression was interpreted in two different ways. For one method, the highest predicted probability was used to classify individual fish as coho or Chinook salmon or steelhead. For each day, the number of predicted fish for each species was then used to calculate daily estimates of species proportions. Alternatively, the predicted species probabilities for all observed individuals were summed to derive species proportions for the season.

Spawning survey observations by interval

For this method, spawning survey observations were used to calculate the species ratio of fish observed over a given time interval. Intervals were created from a single survey or surveys conducted on consecutive days, and were applied to all preceding days extending back in time to the previous survey. The calculated species ratio over each interval was applied to the corresponding escapement estimate.

Normalized distributions of run times

With this method, the seasonal migration pattern of each species was treated as normally distributed over time. A normal distribution was fit to the spawning survey observation dates for each species, and probability distributions were generated for each of the three normal distributions. The areas of the probability distribution curves were then scaled to the number of observations of that species, and used to predict the expected species ratio for each day.

RESULTS

For 2011-2012, a total of 2119 fish targets were detected by the DIDSON (1257 upstream and 862 downstream). There were 20 days of downtime, mostly in January and February, for which no adjustments were made. The expanded estimate of unclassified fish passing the DIDSON from 9 November 2011 to 28 February 2012 was 2393 (+/- 876) fish. Steelhead passage from February 28 to 14 March 2012 was mostly downstream with 132 (+/- 62) fish estimated migrating upstream and 237 (+/- 85) fish migrating back toward the ocean post-spawning.

Fish passage was concentrated around two storm events in 2011 on 23 November and 30 December (Figure 2). In both instances, fish were migrating on both ascending and descending limbs of the hydrograph, while fewer fish were detected at peak flows (Figure 2). Fish passage rates were highest at 0700-0800 hours, with distinct peaks in both upstream and downstream directions (Figure 3). Fish lengths taken from the DIDSON video ranged from 15-155 cm, with the bulk of the fish in the 60-80 cm range (Figure 4).

Recording tallies of up and downstream movements has made it possible to quantify milling behavior in 2011-2012. Milling behavior at the Orick Rodeo Ground deployment site varied by day from 100% upstream to 100% downstream (Figure 5). Milling behavior decreased and movement became predominantly upstream when fish passage peaked around the two storm events on 23 November and 30 December 2011 (Figure 5, 2).

Comparison of Redwood Creek DIDSON estimates across years revealed an increase in migratory behavior in late November detected in all three migration seasons (Table 1). This peak in fish passage is most likely associated with Chinook salmon, based on observations throughout the basin. A second, larger peak in fish passage was detected around New Year's in the two years when data were collected at that time (Table 1). Spawning survey observations indicate that this peak is comprised of multiple salmonid species.

Acoustic shadows from non-fish were detected mostly in February and March. Differentiation using acoustic shadow characteristics was not attempted in previous years on Redwood Creek, so the steelhead estimates for those years may be biased high.

Fewer fish under 40 cm were recorded in 2011-2012 than in previous years, since fish under 30 cm were usually ignored in 2011-2012, while fish down to 20 cm were enumerated in 2009-2010 and 2010-2011. Fish in the 40-50 cm range could be Chinook jacks, rather than adult coho or adult steelhead. However, relatively few fish were measured between 40 and 50 cm (Figure 4).

Results of species models for 2011-2012 are presented in Table 2, with 2009-2010 results for comparison. Observations of live coho salmon into the end of February 2012 prolonged the length of the multi-species migration period compared to 2009-2010. The extension of the coho migration, combined with fewer overall observations of steelhead resulted in much lower estimates for steelhead escapement in 2011-2012 than in 2009-2010.

DISCUSSION

The main challenges to a successful DIDSON deployment on Redwood Creek continue to be high flows and validation of the species apportionment models. High flows prevent data collection, but an equal number of days were missed due to computer malfunctions. The need for a remote internet connection to the topside computer would minimize loss of data from computer malfunctions, but has not yet been addressed due to budgetary constraints. Milling at the current deployment site complicated video review, but did not prevent estimation of escapement.

More spawning survey observations were available from 2011-2012 than in 2009-2010. Using more information to create the species models should result in more realistic population estimates. However, the accuracy of the species models at any level of input remains to be determined, and is a difficult prospect with existing budgets and technology on Redwood Creek. The ultimate objective is to develop confidence intervals around the single-species estimates which account for uncertainty in both: 1) sub-sampling on the un-apportioned count, and 2) using models to approximate the species mixture in the basin.

Steelhead estimates depend on the length of the deployment, the amount of video which is reviewed, and how kelts are accounted for. Reviewing video data into the months of May and June may inflate steelhead population estimates, and alter post-spawning survival estimates. Treatment of the steelhead run as a single normal distribution with one date to separate milling fish from down-runners may be a necessary oversimplification. In reality, the steelhead population on Redwood Creek may have multiple migratory peaks throughout the winter and spring. This scenario could put down-running steelhead in front of the camera at the same time that coho, Chinook, and steelhead are migrating upstream.

Steelhead may be under-represented in spawning survey data, and thus under-apportioned on the DIDSON counts. Surveys targeting the observation of salmon while simultaneously targeting steelhead with angling could increase the proportion of steelhead to salmon observations. An attempt was made in 2012-2013 to increase the number of live fish observations in Redwood Creek for species modeling using a combination of snorkeling, walking surveys, and angling.

A large number of fish under 40 cm entered Redwood Creek early in 2009, and were assumed to be coastal cutthroat trout. This early run of smaller fish has not been detected by the DIDSON in other years, perhaps due to deployment date. Cutthroat trout are difficult to enumerate using DIDSON in Redwood Creek due to their life-history traits, body size, and a lack of information relative to other salmonids in the basin.

The extent of coastal cutthroat trout anadromy in Redwood Creek is unclear, and cutthroat passing the DIDSON may simply be migrating within the freshwater environment. Body shape, color, and spotting patterns may be used to distinguish sea-run cutthroat from resident cutthroat in Redwood Creek; but these metrics are subjective, and not visible on the DIDSON. Larger size in cutthroat trout is not necessarily an indicator of anadromy, since resident cutthroat up to 45 cm are present in Redwood Creek.

Coastal cutthroat trout are smaller on average than the other migratory adult salmonids in Redwood Creek, often overlapping in size with resident trout. Attempts to enumerate fish measuring 15-30 cm with the DIDSON were abandoned in 2010 to simplify the video review process. The mean size of coastal cutthroat trout observed on spawner surveys is 29 cm, but very few cutthroat are observed by ground crews in Redwood Creek, averaging only seven detections per year from 2009-2011. It is also unclear whether cutthroat observed on spawner surveys represent anadromous or resident forms. Due to these numerous uncertainties, coastal cutthroat trout were not considered by DIDSON species models for 2011-2012.

A combination of information from DIDSON and spawning surveys will likely provide better information on the status of Redwood Creek salmonids than either method would alone. The DIDSON likely provides a better total count of all salmonids in a basin than sporadic spawning surveys do, but it provides little biological information. On the other hand, spawning surveys give excellent information on fish species when live fish and carcasses are observed, but characteristics such as pot depth or substrate size to model species is equally questionable as using date and length to assign species to DIDSON images.

Comparison of DIDSON estimates with redd abundance estimates in 2009-2010 appears to indicate agreement for coho salmon and steelhead (Table 2). An expansion of two fish per redd results in similar estimates for these species. In contrast, an expansion of nine fish per redd is required for the two Chinook estimates to match up. Chinook salmon may in fact spawn nine fish at a time on Redwood Creek. The difference could also be a result of using redd-based estimation techniques which were designed specifically for coho and steelhead in smaller coastal streams (like Prairie Creek, Pudding Creek), rather than for Chinook salmon in larger mainstem reaches (like mainstem Redwood Creek).

Table 1. Comparison of weekly DIDSON estimates of adult fish, missed hours and flows for three migration seasons on Redwood Creek. The "sum cfs" column represents the sum of the mean daily discharge values in cubic feet per second at the USGS gage in Orick (value of 700 would be 7 days at 100 cfs per day). Estimates are based on within-hour expansions only, no estimates were made for missed hours. An "x" indicates no data available for estimation. An "a" indicates that DIDSON video data is available for review, but has yet to be analyzed. A "*" indicates an eight day julian week, a"**" indicates an eight day julian week during leap years only (2012 was a leap year).

	2009-2010			2010-2011			2011-2012		
Dates	Estimate	Missing hrs	Sum cfs	Estimate	Missing hrs	Sum cfs	Estimate	Missing hrs	Sum cfs
10/1-10/7	x	168	19	x	168	193	7	165	688
10/8-10/14	x	168	174	x	168	165	x	168	1,203
10/15-10/21	x	168	545	x	168	141	x	168	477
10/22-10/28	x	168	162	2	166	4,715	x	168	323
10/29-11/4	x	168	121	287	58	3,200	x	168	276
11/5-11/11	x	168	619	67	96	5,632	44	110	691
11/12-11/18	x	168	864	280	18	2,968	119	58	515
11/19-11/25	343	47	2,894	108	78	11,105	348	58	4,139
11/26-12/2	197	0	2,070	x	168	14,090	229	22	2,356
12/3-12/9	91	0	680	0	65	12,340	29	92	1,120
12/10-12/16	132	12	2,279	24	111	17,900	141	0	906
12/17-12/23	980	3	6,300	x	168	23,300	-102	70	796
12/24-12/31*	248	8	4,085	30	123	36,180	601	24	6,584
1/1-1/7	244	33	13,910	x	168	13,260	617	0	4,571
1/8-1/14	84	44	9,141	0	101	8,828	158	44	2,092
1/15-1/21	6	120	14,730	96	0	10,020	30	106	26,433
1/22-1/28	18	60	20,830	288	0	5,587	12	134	32,880
1/29-2/4	72	0	10,430	156	38	4,050	-6	9	11,960
2/5-2/11	71	72	8,501	240	66	3,199	60	0	6,020
2/12-2/18	132	0	8,127	90	101	10,233	84	24	6,678
2/19-2/25	253	11	6,095	-6	73	7,650	13	112	5,211
2/26-3/4**	-23	18	20,420	132	14	8,098	-34	30	10,461
3/5-3/11	-15	24	9,270	0	157	24,380	-12	0	7,732
3/12-3/18	-72	0	12,150	0	145	28,690	-36	125	27,460
3/19-3/25	a		6,020	x	168	32,480	a		24,960
3/26-4/1	a		13,700	6	111	33,550	a		43,450
4/2-4/8	a		22,400	-36	14	11,760	a		29,320
4/9-4/15	a		13,600	-18	51	7,993	a		15,050
4/16-4/22	a		9,800	0	87	21,710	a		12,520
4/23-4/29	a		19,163	-30	0	10,830	a		9,300

Table 2. Comparison of results from four methods of species classification for DIDSON escapement estimates over two migration seasons. Insufficient data prevents species modeling for 2010-2011 (see Table 1). The number of live spawning survey observations of steelhead includes fish observed after the last live salmon (Chinook or coho) was observed.

2011-2012 up to last salmon (+/-876 fish)				After Feb 28
Method	Coho	Chinook	Steelhead	steelhead >40 cm
Logistic regression – individual assignment	1040	1223	130	132 (+/- 62)
Logistic regression - summed probabilities	788	1440	165	steelhead <40 cm
Survey intervals	456	1849	88	6
Normalized distributions	928	1307	158	
Live spawning survey observations	172	283	33	237 kelts (+/- 85)

2009-2010 up to last salmon (+/- 780 fish)				After Jan 23
Method	Coho	Chinook	Steelhead	steelhead >40 cm
Logistic regression – individual assignment	321	2488	12	550
Logistic regression - summed probabilities	490	2318	12	steelhead <40 cm
Survey intervals	368	2444	8	225
Normalized distributions	314	2500	6	
Live spawning survey observations	33	99	38	100 kelts
Redd abundance estimate	191	260	218	

Figure 2. Mean daily discharge is cubic feet per second at the USGS gauging station in Orick and estimated passage of fish over 40 cm from 9 November 2011 - 14 March 2012. A white box indicates no data. Mean daily discharge peaked at 12,100 cfs on 21 January 2012.

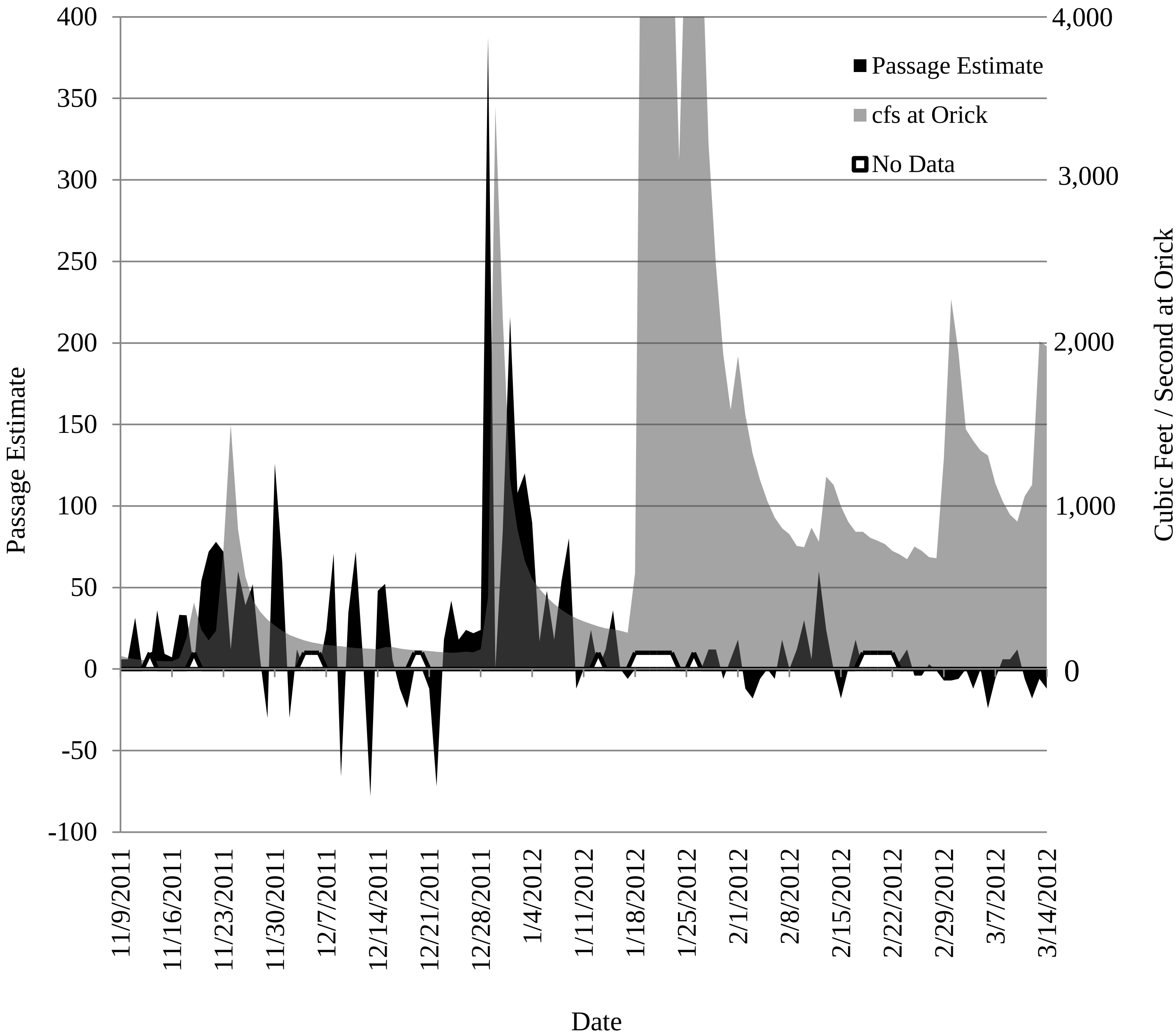


Figure 3. Hourly distributions of upstream (n=1003) and downstream (n=673) moving fish throughout the 2011-2012 migration season on 71 days where all 24 hours were recorded. Days with less than 24 hours recorded were not considered.

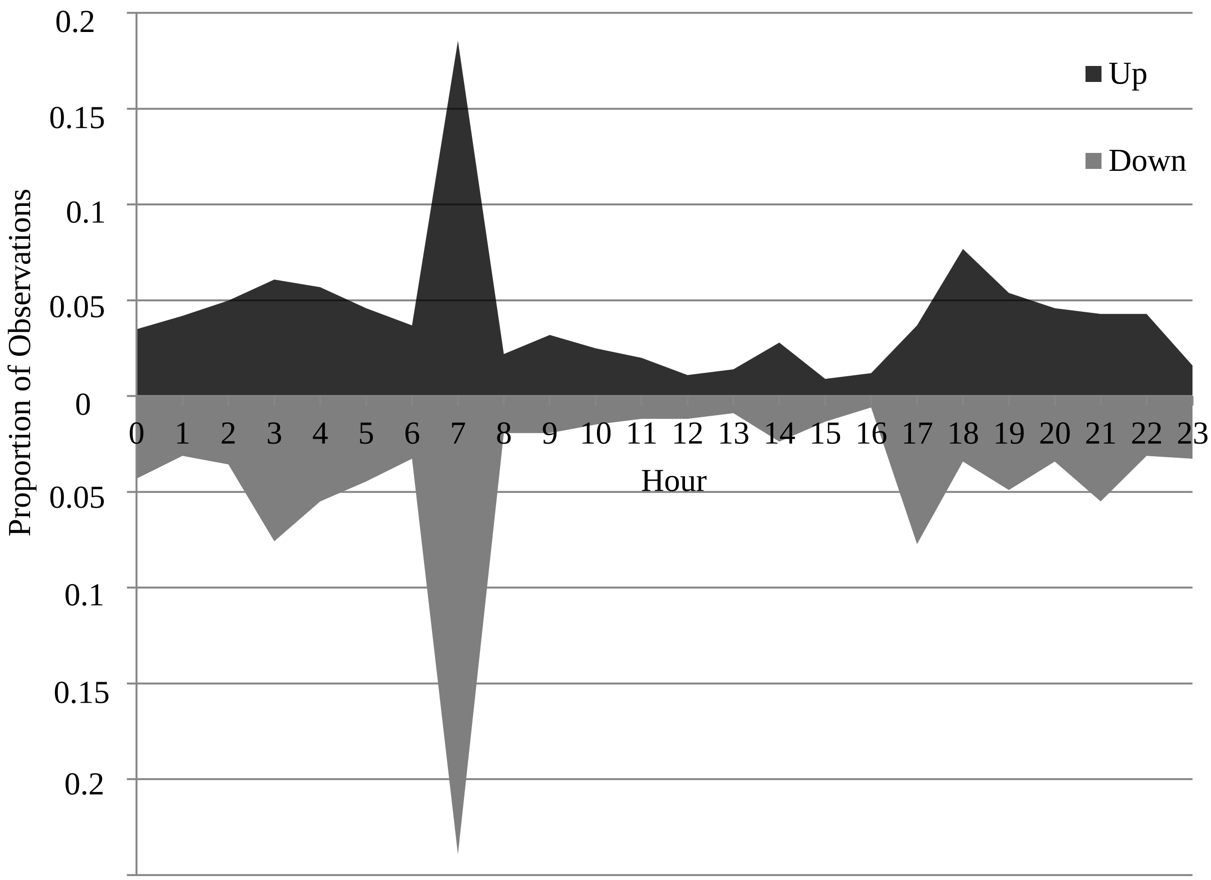


Figure 4. Distribution of upstream (n=1004) and downstream (n=465) fish lengths taken from Redwood Creek DIDSON video from 9 November 2011 - 2 March 2012. Non-fish targets are excluded. A student's t test detected no difference between sets of upstream and downstream lengths over 30 cm.

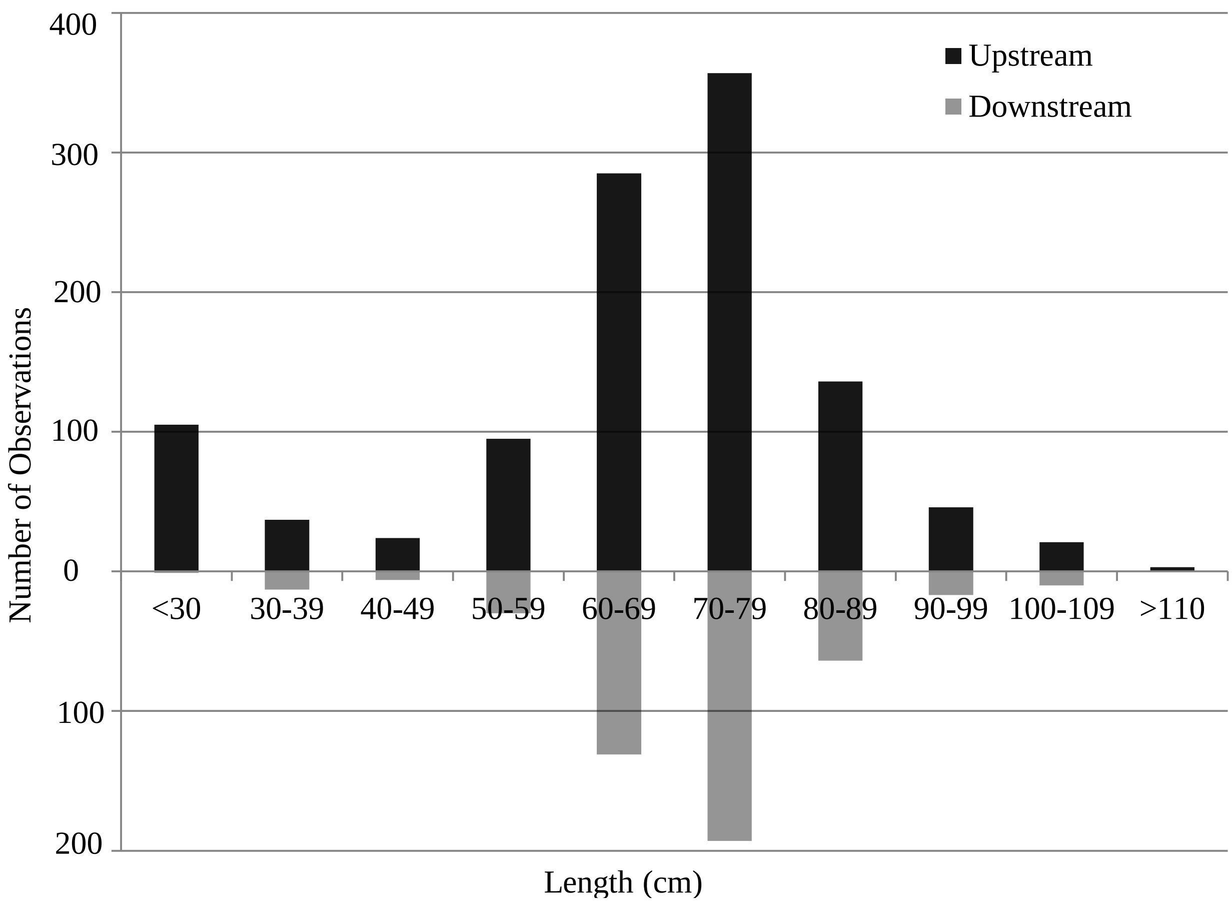
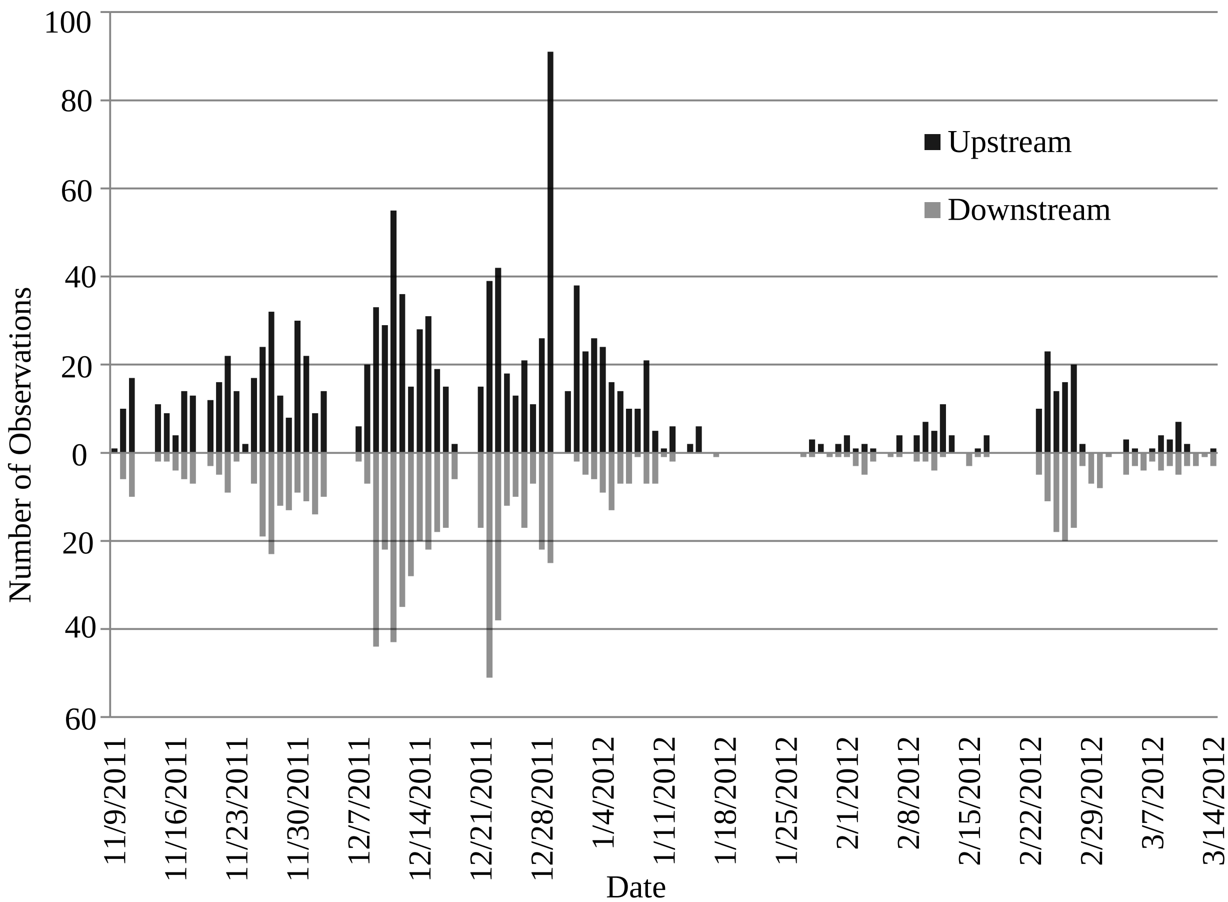


Figure 5. Milling behavior at the Redwood Creek DIDSON deployment site, shown as raw daily upstream and downstream counts for fish over 30 cm.



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