Sonar estimation of adult salmonid abundance in Redwood Creek, Humboldt County, California 2012-2013.

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

Humboldt State University

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Prepared by

Matthew Metheny

Walt Duffy

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ABSTRACT

Dual frequency identification SONAR **(**DIDSON) was used to estimate an escapement of 5,479 (+/- 637) adult salmonids entering Redwood Creek to spawn between 22 October 2012 and 18 March 2013. Observations from California Department of Fish and Wildlife spawning surveys in the basin as well as snorkel surveys were used to model species apportionment of the DIDSON counts. Of the 5,479 fish passing the DIDSON, 747 were estimated as coho salmon, 3,401 as Chinook salmon, and 1,331 as steelhead.

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INTRODUCTION

The acronym DIDSON stands for dual frequency identification SONAR. It provides underwater video in dark, turbid conditions and has been effectively used by management agencies to count migrating adult salmon in rivers throughout the Pacific northwest (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. 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, 2013).

The primary objective of this study was to estimate escapement for three species of ESA listed anadromous salmonids in Redwood Creek, Chinook salmon *(Oncorhynchus tshawytscha)*, coho salmon *(O. kisutch)* , and steelhead (*O. mykiss*) (United States Office of the Federal Register 1997, 1999, 2000). The run timing and body length these species overlap with one another, and DIDSON images lack the resolution to identify species. Thus, when considering Redwood Creek DIDSON counts, a distinction was made between counts of total fish when no attempt was made to assign individuals to a particular species, versus fish passing the camera that have been assigned to a species. Migratory coastal cutthroat trout (*O. clarkii clarkii*) and lamprey (*Lampetra tridentata*) are also detected by the DIDSON camera. The body size of cutthroat and the swimming motion of lamprey differentiate these fish from adult salmon and steelhead.

Apportionment of salmonid species with overlapping run times and sizes for sonar escapement estimates has typically been derived from sampling where fish are trapped and handled (Pfisterer 2002, McKinley 2003, Westerman and Willette 2006, English et al. 2011). 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, live observations of known salmonid species can be used to assign species probabilities to observations of individual fish from the DIDSON.

In addition to informing DIDSON species models, redd expansion methods used on Redwood Creek provide an opportunity to compare estimation techniques for agreement. The California Coastal Salmonid Monitoring Plan supports the task of formulating a redd expansion factor by comparing redd counts with census values from a counting station (Adams et al. 2011). Determining the number of adults per redd detected on Redwood Creek in an important task given the plan's emphasis on monitoring via redd surveys.

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. Much of the watershed is in a state of recovery from industrial logging which took place in the 1970's. Salmonid life cycle monitoring in the pristine Prairie Creek sub-watershed as well as the rest of the basin has intensified since 2009.

The deployment site for the Redwood Creek DIDSON has been at the same location in the community of Orick since 2009. The camera was situated 100 m 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 120 m downstream of the confluence of Prairie Creek, the first major spawning tributary in the watershed.

The Redwood Creek estuary forms a lagoon which is closed to the ocean during summer low-flow conditions. The DIDSON deployment is timed to coincide with rain-driven flows which breach the lagoon and provide salmonids with the opportunity to migrate up Redwood Creek. Depending on the water year, the DIDSON is operated from November until May.

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 house the topside computer components. The site has the proper channel configuration, which is key to a successful DIDSON operation (Maxwell 2007). On the east bank, a gravel bar slopes gradually down to the nearly vertical west bank and channel thalweg. Approximately 100 m of channel is contained between two flood levees at the site.

METHODS

Deployment of the DIDSON

A standard model DIDSON (SN 392) was used, which can detect salmon at distances of up to 30 m in clear water (Burwen et al. 2007, Matthews and Baillie 2007), and to 28 m in turbid Redwood Creek. The DIDSON was deployed in the same fashion as previous years, using an H-frame camera stand in the typical side-facing position described by Maxwell (2007). The DIDSON camera was housed in a custom-made aluminum enclosure to protect it from damage.

The H-frame camera mount was stabilized with rebar driven into the river bottom. For further security, 1 cm diameter nylon line was attached to the camera box, mount, and to T-post anchors on shore. The DIDSON data cable was strung through 2.5 cm diameter PVC conduit where it crossed the levee to prevent damage.

The camera was maintained in a position where it could safely ensonify as much of the channel as possible. The channel cross section on Redwood Creek changed after high flows, requiring visual aiming methods similar to those described by Maxwell and Gove (2007). They 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 -3°. The camera was kept in shallow water close to the east bank to keep fish from swimming behind the camera, since deflection weirs are socially prohibited at the site. Distance from the camera to the opposite bank ranged from 12 to 38 m, depending on flow.

Maintaining the camera stand in the appropriate water depth (about 0.7 m) was imperative for proper imaging and safety. The deployment was moved the deepest water possible (about 1 m) when flows were dropping. Conversely, the camera was moved into the shallowest water possible (about 0.5 m) when flows were rising. 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

Playback of DIDSON video and documentation of fish passage requires a human reviewer. Two means of reducing the time required for video analysis for 2012-2013 were used: (1) sub-sampling and (2) time-condensed video footage.

As in previous DIDSON studies on Redwood Creek, a non-replicated systematic sample of the first 10 minutes of each hour was employed to estimate escapement of total fish with no species designation. 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 and tallies kept of upstream and downstream movements. Increasing fish densities required more review time and slower playback rates, as described by Faulkner and Maxwell (2008). For counts of fish not assigned to a species, the V5 estimator of variance and associated 95% confidence intervals were calculated for times when sub-sampling was used (Wolter 1984, 1985, Reynolds 2007). For simplicity, it was assumed at all times that the camera detected all adult fish passing the site in either direction.

The CSOT (Convoluted Samples Over Threshold) software feature processes DIDSON video files and retained moving objects over a size threshold. Video that had no moving objects was discarded, thus reducing time needed for review. 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. When a CSOT census was used, it was assumed that no sampling error existed.

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 and Restoration Card. 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. Because a student's t-test detected no difference between up and downstream lengths in 2011-2012, only upstream lengths were recorded in 2012-2013.

In an attempt to speed up the review process, a different approach to gathering lengths was used in 2012-2013 than previous years. An initial review of video files was used to estimate escapement of fish over 40 cm, while ignoring exact fish lengths. I then sampled upstream fish lengths at a rate of 15% of the daily escapement values. For each day, a random starting point was selected, and upstream lengths were gathered until 15% of the day's escapement estimate had been collected. This method was especially helpful on days when fish were milling to a high extent. On days when fish passage was predominantly upstream, this method required going back and measuring nearly every fish, since lengths and hours are sampled at approximately the same rate.

Steelhead migrating back to ocean after spawning present a challenge to enumerating steelhead runs, especially if down-running steelhead are present while other species are migrating upstream. Methods outlined by Pipal et al. 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 2012-2013. The analysis of Redwood Creek video data did not address this issue during 2009-2010 and 2010-2011. 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.

Shadows of fish passing between the camera lens and the start of the sonar view (first 1-5 m) were documented in 2012-2013, and applied to escapement estimates. Only shadows of adult-sized fish were counted, and only shadows with a distinct fish-shape were counted. Video of fish that appeared both as shadows and within full view of the sonar were used to establish a standard of how fish shadows appear on the sonar.

Species Models for Overlapping Runs

Observations of live fish made by the California Department of Fish and Wildlife during spawning surveys in Redwood Creek during 2012-2013 were used to model species abundance of fish over 40 cm (Chinook salmon, coho salmon, and steelhead). The dates of carcass observations were not considered, due to increased uncertainty in determining date of migration past the DIDSON into spawning reaches. Lengths from fresh carcasses were selected at random and paired with live fish observation dates lacking an associated length.

Three methods of assigning Redwood Creek DIDSON counts to species were used: (1) logistic regression using individual assignment; (2) ratios of spawning survey observations and (3) normalized distributions of run times. These methods are described in further 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.

Steelhead collected by hook and line (22 fish) for a Redwood Creek genetic study were considered by species models for the first time in 2012-2013. Anecdotal evidence suggests that coho salmon are more easily observed than steelhead during spawning surveys. These additional observations were included in an attempt to prevent steelhead from being under-apportioned by the DIDSON species models.

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). In 2012-2013, the sonar camera's focus control malfunctioned, resulting in blurry images for 15 days. On these days, accurate lengths could not be measured, and logistic regression analysis used only date of observation.

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

Spawning survey observations were used to calculate the species ratio of fish observed over multiple time intervals. Interval endpoints were placed in between survey rounds, immediately after surveys conducted on consecutive days. The calculated species ratio over each interval was then 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

Salmonid Escapement to Redwood Creek

For 2012-2013, a total of 4,817 adult size fish were detected by the Redwood Creek DIDSON (3,025 upstream and 1,792 downstream). An estimated 5,479 fish migrated upstream past the camera, with no adjustments made for downtime. The camera did not record for 21 days during 2012-2013, consisting of nine days due to high flows and 12 days because of computer issues. Daily escapement peaked around 17 November 2012, when an estimated 1,200 fish migrated past the camera in 30 hours. This pulse in migration happened when flows rose above 300 f^3/s for the first time in the water year. Daily estimates, along with flows and equipment downtimes are presented in Figure 2.

Between 9 October and 15 November 2012, all fish passing the DIDSON camera were assumed to be Chinook salmon (1,519 fish). A mixture of Chinook and coho salmon and steelhead migrated past the sonar site between 16 November 2012 and 8 February 2013 representing 3,291 fish. After 8 February 2013, all fish passing the camera were counted as steelhead (668 fish), with 57 steelhead estimated returning to the ocean after 28 February 2013. Results of species modeling for 2012-2013 are presented in Table 1. A comparison of results across available years is presented in Table 2.

In 2012-2013, 100 fish shadows were counted passing between the camera lens and sonar window, representing an expanded estimate of 600 fish (10% of total estimate). Milling behavior at the Orick DIDSON site complicated review, but did not prevent estimation of escapement. Downstream fish were detected on 108 of 126 days recorded at the Orick sonar site (Figure 3). Fish passage showed a distinct increase from 0700-0800 hours in both directions, while fewer fish were detected during daylight hours (Figure 4). Fish lengths taken from the DIDSON video ranged from 45-119 cm, with a majority of fish in the 70-99 cm range (Figure 5).

Symposium on DIDSON - Acoustic Telemetry

A symposium on DIDSON technology was held in March 2014 as dictated by the grant funding for this project. The symposium took place as part of the 48th Annual Conference of the California-Nevada Chapter of the American Fisheries Society in Sacramento, California. The technical session entitled "Acoustic Telemetry" occurred on Saturday, March 29, 2014 and was attended by DIDSON experts from all over the state of California. Agency representatives, resource stakeholders, and students were present in addition to the 20+ DIDSON users at the symposium.

Russ Bellmer of California Department of Fish and Wildlife was the session moderator, and he presented the first comprehensive report on the use of DIDSON devices employed as part of the California Coastal Salmonid Monitoring Plan. The session was devoted to fish monitoring with DIDSON in California, and the results from this Redwood Creek study were presented and discussed. Presentations from the symposium will be posted on the California Department of Fish and Game website for educational purposes, including the presentation about this Redwood Creek study.

DISCUSSION

Comparison of Redwood Creek DIDSON estimates across years revealed a period of intense migration following the first fall rain event opening the estuary lagoon to the ocean. This initial peak in fish passage is almost entirely composed of Chinook salmon, based on multiple years of live fish observations. 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 10 detections per year from 2009-2012. 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.

The combination of fish milling behavior and a reviewing 10 minutes per hour resulted in negative daily escapement values on four days around early November (Figure 2). Net migration for these days is more likely to be zero than negative, considering an absence of down-running steelhead in November. Increasing the minutes sampled per hour would easily clarify net movement for these days.

Life cycle monitoring requires comparison of Redwood Creek DIDSON adult estimates with juvenile downstream migrant estimates. The downstream trap on lower Redwood Creek in Orick had a 0+ Chinook smolt estimate for the 2011-12 cohort (1800 adults) of around 100,000. In contrast, the age 0+ Chinook estimate of around 550,000 for the 2012-13 cohort (3401 adults) was the highest ever since monitoring began on Redwood Creek (Mike Sparkman, California Department Fish and Wildlife, Arcata, personal communication). Detection of a change in number of adult Chinook, followed by a detection of a corresponding change in number of Chinook smolts is good news for using DIDSON as part of life cycle monitoring. Estimation of survival for all available species will be a collaborative effort with Mike Sparkman at CDFW Arcata.

While results of the species models have not been validated, some DIDSON information can be used for single species management. For example, individual coho salmon cannot be positively identified by the sonar image. However, for the 2012-2013 migration season, 3,000 images on the DIDSON can be identified as non-coho by their body size and the observation date. The remaining 2,500 fish which could be coho salmon, Chinook salmon, or steelhead still falls short of the ESA de-listing goal of 3,000 adult coho spawners for Redwood Creek (National Marine Fisheries Service, 2012).

The DIDSON likely provides a better total count of all salmonids in a basin than expansion from sporadic spawning surveys does, but it provides little biological information. Knowledge of the total number of salmonids entering Redwood Creek can be used to calculate the number of adult fish contributing to each redd observed on a spawning survey. This information could be particularly useful in wet years when high flows can potentially obscure or remove evidence of redds (Jones 2012).

Table 1. Results of Redwood Creek DIDSON species models for 2012-2013. Multiple species were present between 16 November 2012 and 8 February 2013.

Method	Coho salmon	Chinook salmon	Steelhead
Logistic regression	645	3508	1326
Survey intervals	844	3414	1221
Normalized distributions	752	3280	1447
Average	747	3401	1331

Table 2. Comparison results for Redwood Creek DIDSON over four migration seasons. Deployment dates, number of days the camera was inoperative, and species estimates. Species estimates are presented as the mean of model results. Insufficient data prevents accurate estimation for 2010-2011.

Season	Date In	Date Out	Days Missed	Coho salmon	Chinook salmon	Steelhead
2009-2010	11/20/2009	5/31/2010	16	373	2438	560
2010-2011	10/29/2010	5/31/2011	40	322	768	695
2011-2012	10/9/2011	5/31/2012	12	803	1455	267
2012-2013	10/22/2012	5/31/2013	21	747	3401	1331

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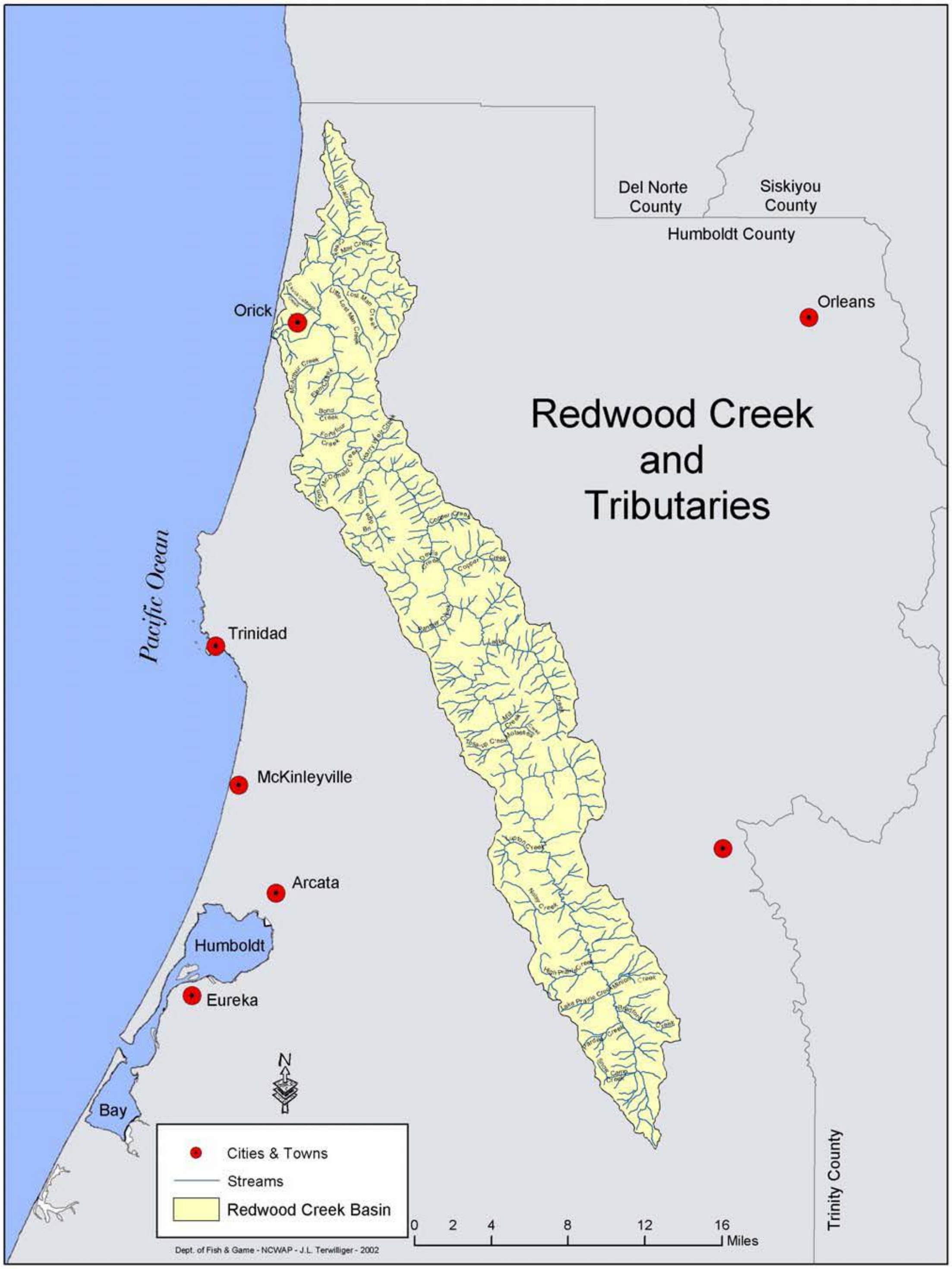

Figure 1. Map of Redwood Creek showing its location in northern California. The DIDSON deployment site is in the community of Orick.

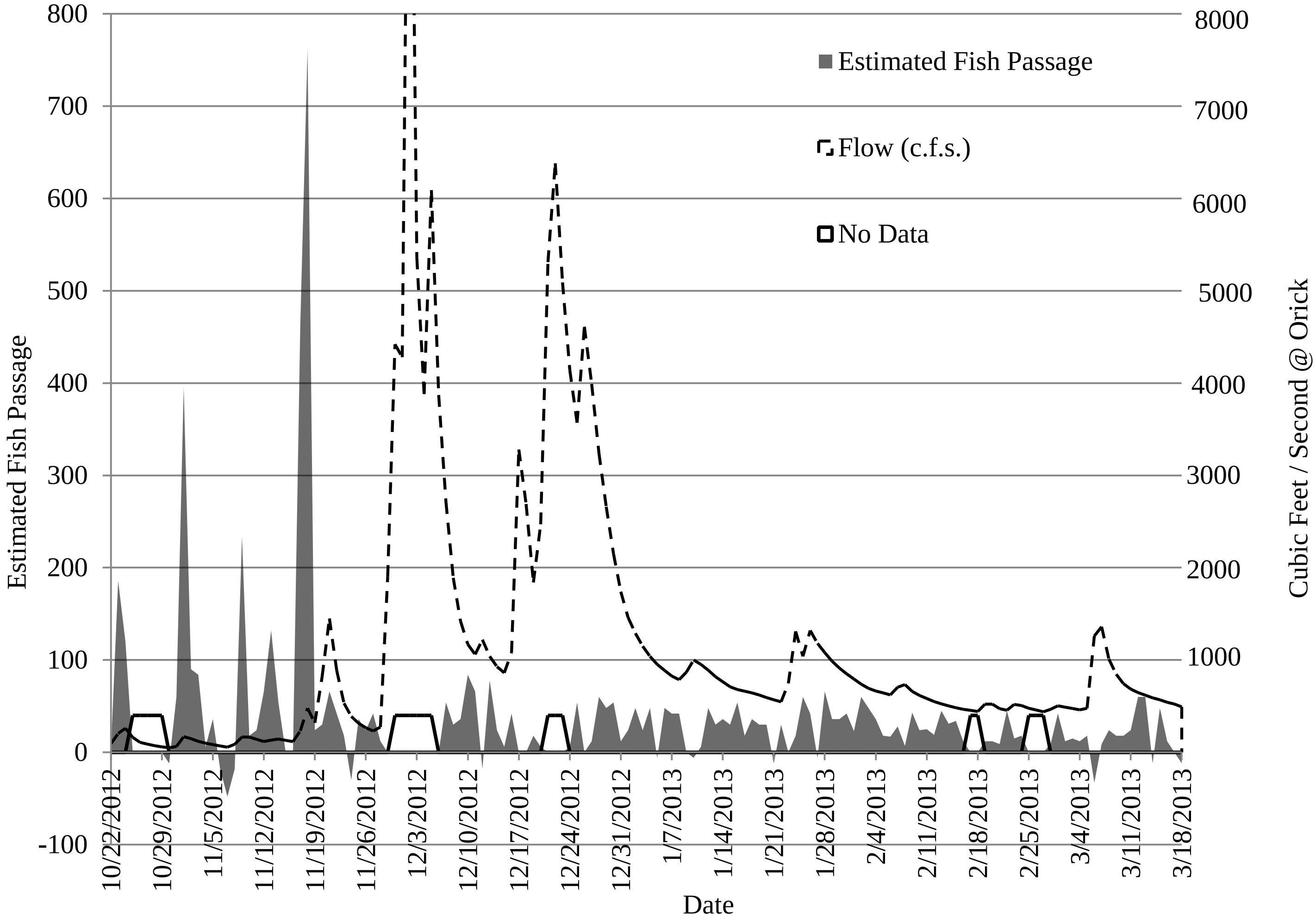

Figure 2. Mean daily discharge is cubic feet per second at the USGS gauging station in Orick and estimated passage of fish over 40 cm from 22 October 2012 - 18 March 2013. A white box indicates no data. Mean daily discharge peaked at 12,600 c.f.s. on 2 January 2012.

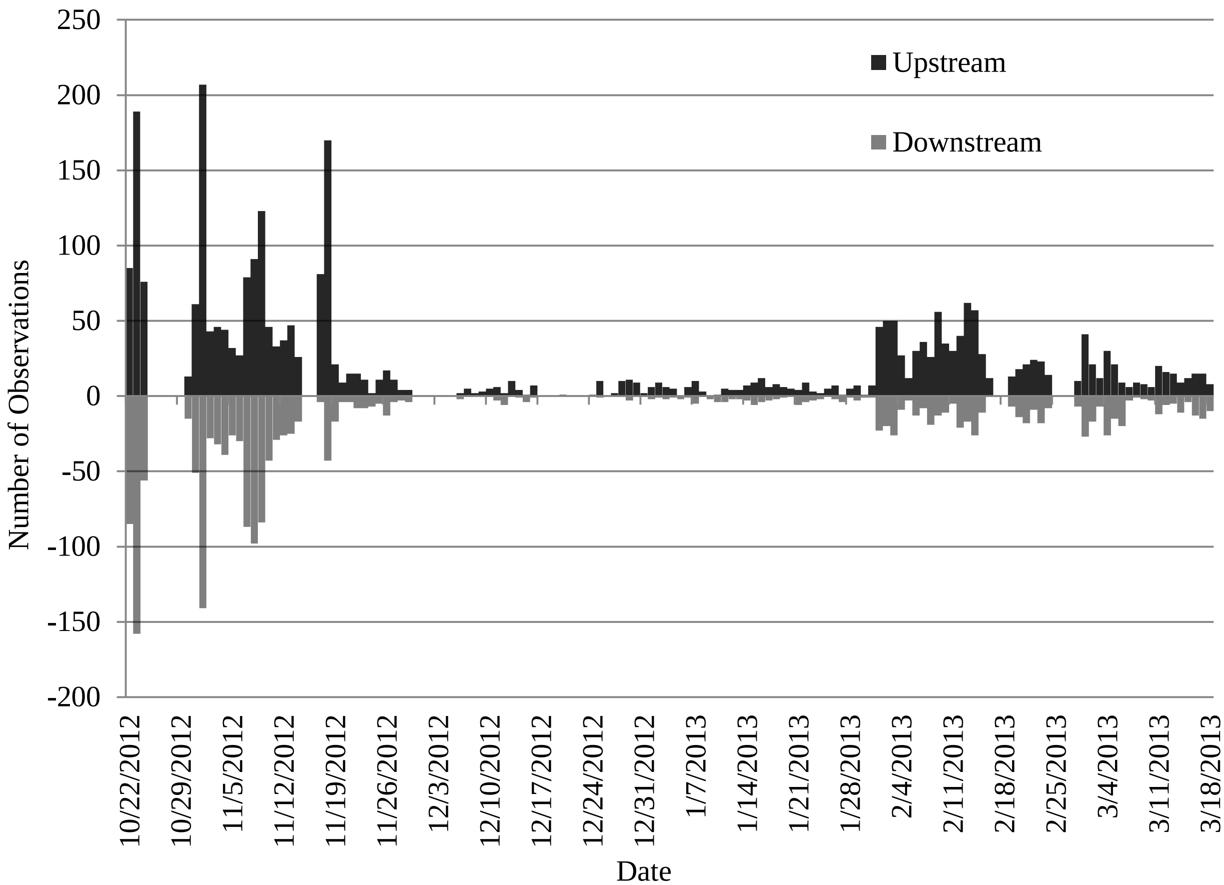

Figure 3. Milling behavior at the Redwood Creek DIDSON deployment site in Orick, shown as raw daily upstream and downstream counts for fish over 40 cm.

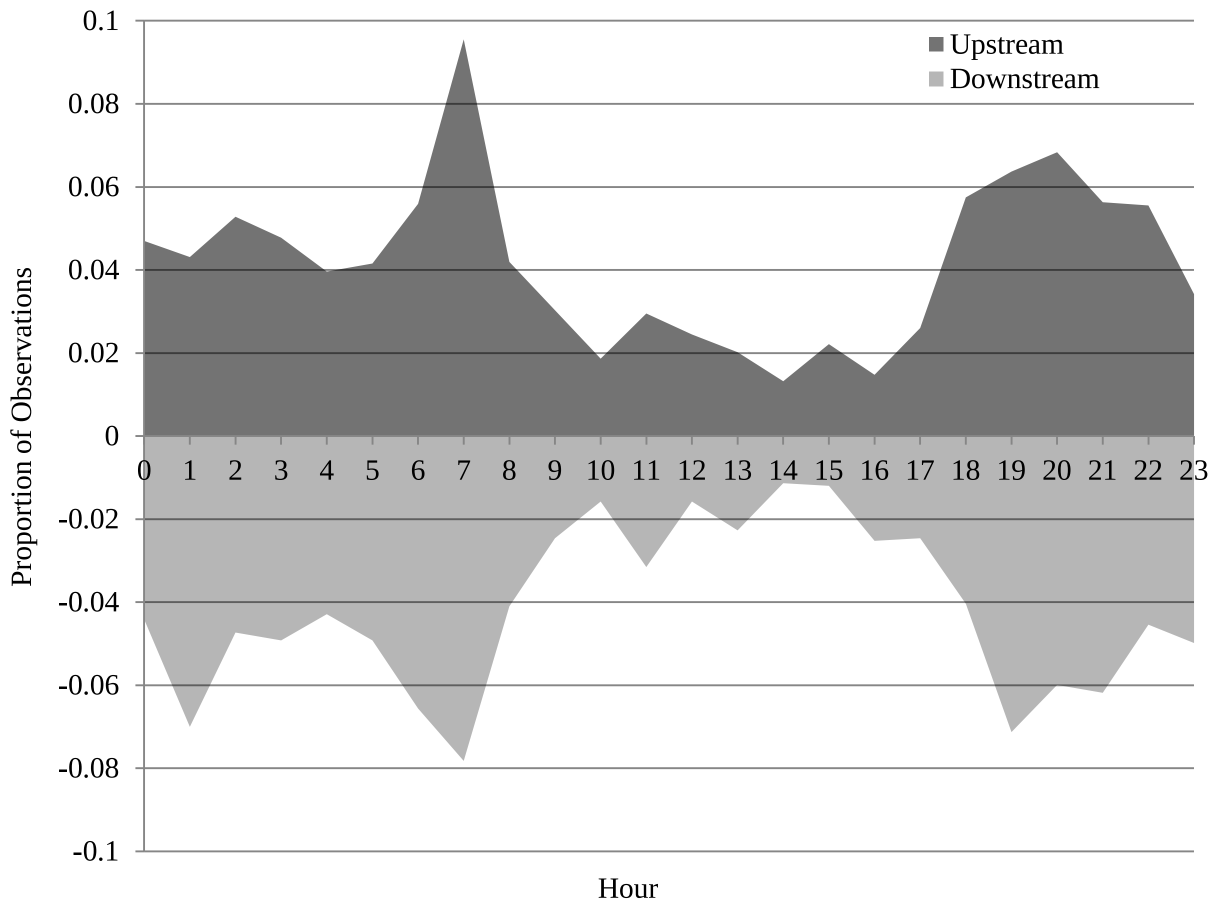

Figure 4. Hourly distributions of upstream (n=2575) and downstream (n=1585) moving fish throughout the 2012-2013 migration season on 111 days where all 24 hours were recorded. Days with less than 24 hours recorded were not considered.

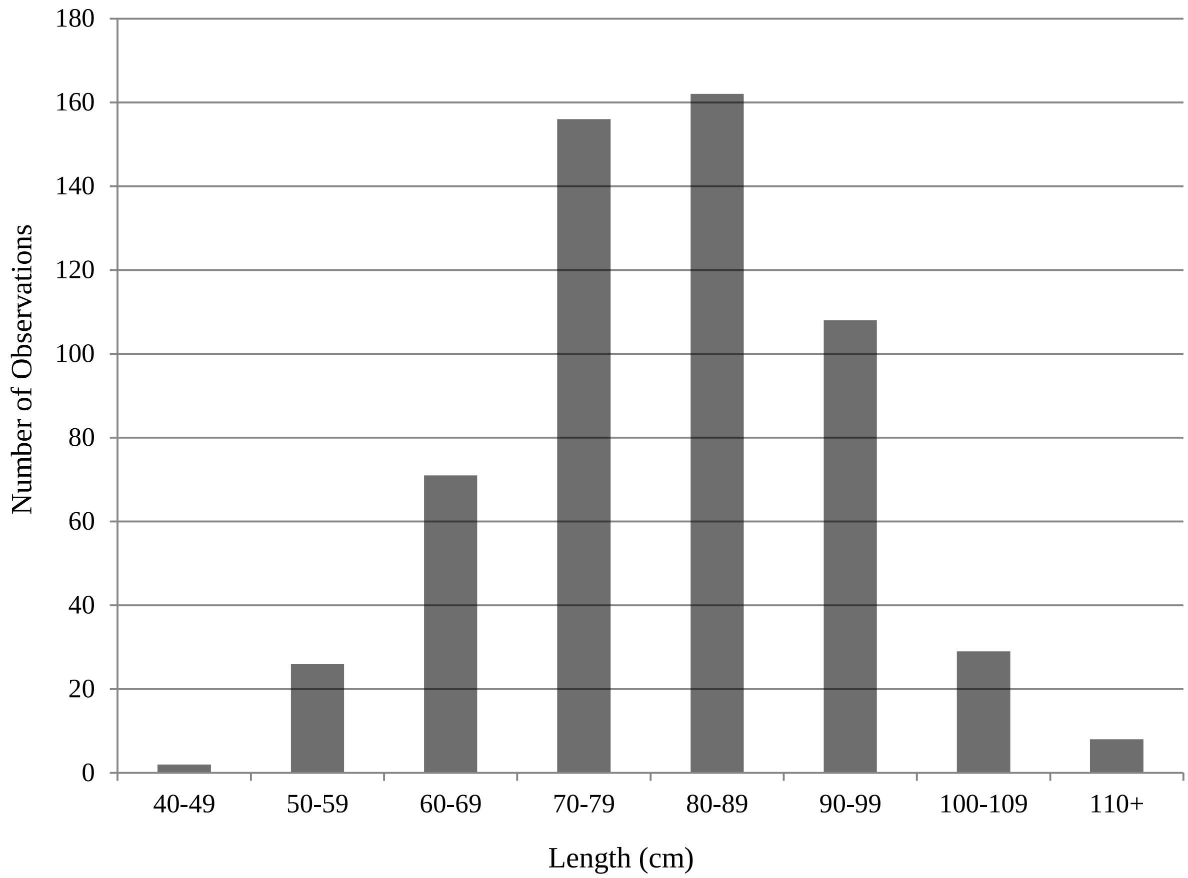

Figure 5. Distribution of upstream fish lengths (n=562) taken from Redwood Creek DIDSON video from 1 November 2012 - 31 January 2013.

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. California Department of Fish and Game Fish Bulletin 180.

Burwen, D. L., S. J. Fleishman, and J. D. Miller. 2007. Evaluation of a dual-frequency imaging sonar for detecting and estimating the size of migrating salmon. Alaska Department Fish and Game, Fishery Data Series No. 07-44, Anchorage, Alaska.

Cronkite, G.W., H. J. Enzenhofer, T. Ridley, J. Holmes, J. Lilja, and K. Benner. 2006. Use of high-frequency imaging sonar to estimate adult sockeye salmon escapement in the Horsefly River, British Columbia. Canada Department of Fisheries and Oceans, Canadian Technical Report of Fisheries and Aquatic Sciences 2647, Nanaimo, British Columbia.

English, K. K., T. C. Edgell, R. C. Bocking, M. R. Link, and S. W. Raborn. 2011. Fraser River sockeye fisheries and fisheries management and comparison with Bristol Bay sockeye fisheries. LGL Ltd. Cohen Commission Technical Report 7, Vancouver, British Columbia.

Faulkner, A. V. and S. L. Maxwell. 2008. Copper River hydroacoustic salmon enumeration studies, Miles Lake sonar project, 2005-2006. Alaska Department of Fish and Game, Fishery Data Series No. 08-37, Anchorage, Alaska.

Holmes, J. A., G. M. Cronkite, and H. J. Enzenhofer. 2005. Salmon enumeration in the Fraser River with the dual-frequency identification sonar (DIDSON) acoustic imaging system. Journal of the Acoustic Society of America 117: 2367-2368.

Johnson, P., D. Degan, M. Johnson, B. Olsom, C. H. Arrison, and D. Killam. 2009. Estimating Chinook salmon escapement in Mill Creek using acoustic technologies in 2008. Report submitted to United States Fish and Wildlife Service, Anadromous Fish Restoration Program, Red Bluff, California.

Jones, Edward C. 2012. Environmental stochasticity and the reliability of redd count data: a simulation study of redd construction, redd loss, and survey frequency in a small coastal stream in northern California. Master of Science Thesis. Department of Fisheries, Humboldt State University, Arcata, California.

Larson, Z. 2013. Use of dual frequency identification sonar to monitor steelhead escapement in the Smith River, California, 2012-2013. Report for California Department of Fish and Wildlife Steelhead Report and Restoration Card Program.

Matthews, I. P. and S. J. Baillie. 2007. Multi-species migration and improved escapement enumeration Cowichan River DIDSON project. Canada Department of Fisheries and Oceans. Nanaimo, British Columbia.

Maxwell, S. L. and N. E. Gove. 2007. Assessing a dual-frequency identification sonars' fish-counting accuracy, precision, and turbid river range capability. Journal of the Acoustical Society of America. 122: 3356-3377.

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

Maxwell, S. L., D. Degan, A. V. Smith, L. McKinley, and N. E. Gove. 2007. The feasibility of using a split-beam sonar to estimate salmon passage on the Nushagak River as a potential replacement for an echo-counting Bendix sonar. Alaska Department of Fish and Game, Fishery Data Series No. 07-11, Anchorage, Alaska.

McKinley, L. 2003. Sonar enumeration of pacific salmon escapement into the Nushagak River, 2002. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report No. 2A03-05, Anchorage, Alaska.

Melegari, J. L. 2008. Abundance and run timing of adult fall chum salmon in the Chandalar River, Yukon Flats National Wildlife Refuge, Alaska, 2007. United States Fish and Wildlife Service, Fairbanks Fish and Wildlife Field Office, Alaska Fisheries Data Series Number 2008-11, Fairbanks, Alaska.

Metheny, M. 2012. Use of dual frequency identification sonar (DIDSON) to estimate salmonid abundance in Redwood Creek, Humboldt County, California. Master of Science Thesis. Department of Fisheries, Humboldt State University, Arcata, California.

Metheny, M. 2013. Sonar estimation of adult salmonid abundance in Redwood Creek, Humboldt County, California 2012-2013. Report for California Department of Fish and Wildlife Fisheries Restoration Grants Program.

National Marine Fisheries Service. 2012. Public draft recovery plan for southern Oregon / northern California coast coho salmon (*Onchorhynchus kisutch*) Evolutionarily Significant Unit. National Marine Fisheries Service, Southwest Region, Santa Rosa, California.

Pfisterer, C. T. 2002. Estimation of Yukon River salmon passage in 2001 using hydroacoustic methodologies. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report No. 3A02-24, Anchorage, Alaska.

Pipal, K., M. Jessop, G. Holt, and P. Adams. 2010. Operation of dual-frequency identification sonar (DIDSON) to monitor adult steelhead (*Oncorhynchus mykiss*) in the central California coast. United States Department of Commerce, National Oceanographic and Atmospheric Technical Memorandum, NMFS-SWFSC-454, Santa Cruz, California.

Reynolds, J. H., C. A. Woody, N. E. Gove, and L. F. Fair. 2007. Efficiently estimating salmon escapement uncertainty using systematically sampled data. American Fisheries Society Symposium: Sockeye Salmon Evolution, Ecology, and Management 54: 121-129.

Ricker, S. Estimation of total observable anadromous salmonid redd construction in Redwood Creek and Humboldt Bay Tributaries, Humboldt County California, 2009-2010. 2011. California Department of Fish and Game Anadromous Fisheries Resource Assessment and Monitoring Program. 50 Ericson Ct. Arcata, California.

United States Office of the Federal Register. 1997. Endangered and threatened species; threatened status for southern Oregon / northern California coast evolutionarily significant unit (ESU) of coho salmon. Federal Register 62(117): 33038-33039.

United States Office of the Federal Register. 1999. Endangered and threatened species; threatened status for two Chinook salmon evolutionarily significant units (ESUs) in California; final rule. Federal Register 64(179): 50394-50415.

United States Office of the Federal Register. 2000. Endangered and threatened species; threatened status for one steelhead evolutionarily significant unit (ESU) in California; final rule. Federal Register 65(110): 36074-36094.

Westerman, D. L. and T. M. Willette. 2006. Upper Cook Inlet salmon escapement studies, 2004. Alaska Department of Fish and Game Fishery Data Series No. 06-49, Anchorage, Alaska.

Wolter, K. M. 1984. An investigation of some estimators of variance for systematic sampling. Journal of the American Statistical Association 79(388: 781-790.

Wolter, K. M. 1985. Introduction to variance estimation. Springer-Verlag. New York, New York.

Wright, K. 2011. Escapement, migration timing, and spatial distribution of adult Chinook and coho salmon in Prairie Creek, California. Master of Science Thesis. Department of Fisheries, Humboldt State University, Arcata, California.

Xie, Y., T. J. Mulligan, G. W. Cronkite, and A. P. Gray. 2002 Assessment of potential bias in hydroacoustic estimation of Fraser River sockeye and pink salmon at Mission, B.C. Pacific Salmon Commission Technical Report No. 11, Vancouver, British Columbia.

PERSONAL COMMUNICATIONS

Sparkman, M. 2012. Environmental Scientist, Anadromous Fisheries Resource Assessment and Monitoring Program, California Department of Fish and Game, 50 Ericson Court, Arcata, California 95521.