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Relationship between juvenile steelhead survival and winter habitat availability

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Abstract:

Wild salmonid populations in California are in steep declines. Poor smolt production resulting from anthropogenic degradation of freshwater rearing conditions is a major factor causing the losses. Anthropogenic effects include dam construction, hatchery effect, increased sedimentation, altered thermal regimes, channel incision, and loss of thermal and high flow refugia (e.g., direct removal of large woody debris from active channels). This last factor has likely caused juvenile salmonids to become increasingly dependent on coarse benthic substrates such as the interstitial spaces between cobble and boulder substrates for refugia during high-flow conditions. These habitats are often found in upstream portions of watersheds where colluvial deposition of coarse cobble and boulder substrates dominates the sediment transport processes. In this study, we compared the amount of cobble-boulder interstitial space habitat available at three locations dominated by colluvial processes with steelhead survey data describing the distribution of age classes at each reach. Results reported here indicate that there is a significant positive linear relationship between the amount of interstitial habitat (aka 'shelter') available (number of shelters per square meter) and an index of overwinter habitat survival (ratio of age 1+ to age 0+ steelhead), $R^2 = .996$, $F(1, 1) = 281.060$, $p = 0.038$. This highlights the potential

conservation importance of these areas in addition to the possible need to preserve connectivity between these and more profitable summertime rearing sites

Keywords: steelhead trout, California, winter habitat, survival, geomorphology, conservation

Introduction

Approximately 60% of existing anadromous Pacific salmonid taxa may become extinct within a century (Moyle et al. 2008). In the United States, 28 Evolutionary Significant Units (ESUs) of Pacific salmonids are currently listed as threatened or endangered under the Endangered Species Act (ESA). Ten of these are completely or partially located in California, which comprises the southernmost extent of Pacific salmonid ranges. Included on this growing list is California's Central Coast (CCC) coho salmon (*Oncorhynchus kisutch*: state and federally endangered), CCC steelhead trout (*O. mykiss*: federally threatened) and California Coastal Chinook salmon *(O. tshawytscha*: federally threatened). The threats to salmonids in this region are many and stem chiefly from interactions between freshwater habitat loss/degradation and variable oceanic conditions (e.g., fluctuations of upwelling strength and sea surface temperatures along coast, Pacific Decadal Oscillation, El Niño Southern Oscillation). Major threats to terrestrial systems include urbanization and agricultural development, deforestation, man-made barriers to migration, water diversions, mining, channelization, recreation, draining of wetland habitats, hatcheries, and introduced species. Associated with these impacts are elevated thermal regimes, sedimentation, modification of stream banks and channel morphology, reduced food resources, degraded water quality, loss of spawning and rearing habitat, reduced recruitment of large woody debris, and population fragmentation.

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Wild *O. mykiss* populations in California have declined 80%, with highest extirpation rates in the south, after once being found in nearly every ocean-accessible California river and stream from Mexico to the Oregon border (Busby et al. 1996). Since salmonids in this region typically spend at least a year in freshwater before migrating to the sea, proper overwinter habitat is critical to their survival. This is especially important in areas with Mediterranean-type climates, such as California's Central Coast region, where the majority of precipitation falls in the winter months and often results in very high discharge rates. Beneficial overwinter salmonid habitats include structures that moderate water velocity (e.g., large woody debris, coarse cobble and boulder substrate ("CoBo")) and portions of streams where velocity is reduced (e.g., off-channel habitats, deep pools). In addition to protecting fish from downstream displacement, these features also provide cover from predators and help improve bioenergetic performance during a period typically marked by poor growth. As a result of a decades-old policy of removing large woody debris from streams (incorrectly thought to prevent migrations of anadromous fish to spawning grounds), it is likely that the interstitial spaces provided by coarse cobble and boulder substrates have gained importance for overwintering salmonids.

The objective of our study is to determine the relationship CoBo shelter habitat and overwinter survival of *O. mykiss*. In order to accomplish this, we quantify CoBo shelter habitat in a reach dominated by colluvial transport processes where populations of wild steelhead trout are known to rear. We also take advantage of pre-existing data sets of CoBo shelter habitat for two other sites within the Pescadero basin (Peters Creek, Upper Pescadero Creek mainstem (UPM)) and compare the data to juvenile steelhead densities obtained previously by the California Department of Fish and Game (CDFG). We hypothesize that the density of CoBo shelters will be positively related to the ration of the density of age 1+ to age 0+ steelhead (an index of overwinter survival).

<u>Methods:</u>

Study Site

Our study includes data from three different sub-drainages (Oil Creek, Peters Creek, upper Pescadero Creek mainstem) located at the upper ends of the Pescadero Creek basin of the Pescadero-Butano Creek watershed (San Mateo County, CA, USA, 37.2291108°N 122.1919103°W, Figure 1). The Pescadero-Butano watershed's area is 81 mi^2. Mean annual precipitation and stream flow between 1954 and 1995 was 28.7 in and 43 ft^3/s, respectively (Sloan 2006). Approximately one third of the basin is timber land, one third agricultural preserve lands, and one-third protected land. The areas of the Oil and Peters Creek sub-basins are 4.9 mi^2 and 9.7 mi^2, respectively.

We collected data along a 150 m reach of Oil Creek, a low order tributary to Pescadero Creek (Figure 1). The region is characterized by has elevated geologic activity along the San Gregorio-Hungry Fault system and the Butano Fault system that thoroughly intersects the Pescadero-Butano watershed. The stream showed evidence of such activity, containing various geologic transects that influence flow and add to the complexity of juvenile salmonid overwinter refugia. The heavily forested area is privately owned by Redtree Properties, Ltd. which actively harvests Coast Redwoods (*Sequoia sempervirens*) and Douglas Fur (*Pseudotsuga menziesii*) throughout the drainage.

Determination of sediment transport processes

Montgomery and Buffington (1997) provide a means to predict where colluvial processes outweigh alluvial ones in mountainous streams and, therefore, where one might expect to find optimal salmonid overwintering habitat. Briefly, their method involves regressing channel slope (m/m) against upstream drainage area (m^2) in a log-linear fashion. The slope of the lines for upstream colluvial-dominated reaches differs in magnitude from ones dominated by alluvial forces lower in the watershed and the inflection point generated by the two relationships indicates where in the watershed the shift in sediment transport processes occurs (see Montgomery and Buffington 1997, Fig. 5). Study sites for this investigation were determined by Eric Donaldson (data in prep.) according to the techniques outlined by Montgomery and Buffington (1997).

Stream surveys: physical habitat

Study sites consisted of stream reaches of varying lengths (Oil Creek: 150 m, Peters Creek: 60 m, UPM: 33 m). We defined habitat units (step, step-pool, pool, riffle, run) along each reach according to the classification scheme of Montgomery and Buffington (1997). Bankfull widths were measured at the upstream and downstream ends of each habitat unit and areas of each unit were determined by multiplying average width by length. Channel slope was also measured for each habitat unit with a Laser Ace® 300 laser rangefinder with inclinometer .

We quantified overwinter habitat according to the methods of Finstad et al. (2007). This technique involved an initial visual inspection of the stream to identify coarse CoBo substrates. Next, we inserted a flexible PVC tube (15 mm width X 150 mm length) into interstitial spaces between the rocks. If the tube completely fit into the cavity, it was counted as a single shelter. If multiple tubes could fit into the interstitial space, it was recorded as multiple shelters. Also, if multiple entrances of adequate dimensions into the cavity existed, it was counted as multiple shelters (i.e., a Y-shaped cavity would be counted as three shelters).

Stream surveys: fish densities

In 1995, the CDFG measured fish densities for Oil Creek, Peters Creek, and the UPM as number of fish per average length and width of stream reach. They also provide size data which we use to classify fish ages: age 0+ fish were assumed to be less than 100 mm whereas age 1+ fish were assumed to be greater than 100 mm. We also assume that the shelter habitat data obtained in 2011 reflect conditions present in 1995. Since the study reaches were located in upstream portions of the watershed where alluvial transport of CoBo is limited, this assumption is justified: no major earthquakes occurred in the region between 1995 and 2011 so the likelihood for colluvial deposition into the study reaches is low.

The CDFG sampled fish by first placing block nets at the upstream and downstream ends of sample stations. A single upstream pass was made utilizing a Model 12 Smith-Root backpack electrofisher (Smith-Root, Inc., Vancouver, WA, USA). Steelhead were measured for total length and released back into the location of their collection. The CDFG sampled fish on Oil Creek from its confluence with the Pescadero mainstem upstream for 4 stream miles (9 stations total) from 4 October to 13 October 1995. The 150 m reach where shelters were quantified occurred along a reach approximately 2.1 miles from the confluence of Oil Creek with the Pescadero mainstem (Figure 1). CDFG sampled fish on Peters Creek from its confluence with the Pescadero mainstem upstream for 4.9 stream miles (11 stations total) from 16 October to 18 October 1995. The 60 m reach where shelters were quantified occurred along a reach approximately 0.6 miles from the confluence of Peters Creek with the Pescadero mainstem (Figure 1). CDFG sampled fish on UPM was surveyed from stream mile 9.7 (distance from coast) upstream 9.2 miles to the Trestle Creek confluence at stream mile 19.9 (8 stations total) on 5 October, 6 October, 30 October, 2 November, and 3 November 1995. The 33 m reach where shelters were quantified occurred at stream mile 13.0 (Figure 1).

Results

We found a significant positive linear relationship between total shelter density (average number of shelters per square meter for entire study reach) and the ratio of age 1+ steelhead density (in fish/area) to age 0+ steelhead density (an index of overwinter survival) at the 95% confidence level, $R^2 = .996$, $F(1, 1) = 281.060$, $p = 0.038$ (Figure 2). For the Oil Creek study site, the 'step' habitat unit possessed the highest average shelter density (0.69 shelters/m^2) followed by 'step-pool' (0.65 shelters/m^2), 'pool' (0.24 shelters/m^2), and 'run' (0.11 shelters/m^2) (Figure 3). We also found a significant positive linear relationship between local slope (i.e., slope of each habitat unit surveyed) and shelter density at the Oil Creek study reach at the 95% confidence level, $R^2 = 0.598$, $F(1, 14) = 20.844$, $p < 0.001$ (Figure 4).

Discussion

Our research supports a growing body of evidence suggesting that high flow refugia during winter months enhances the survival of juvenile salmonid fishes (e.g., Meyer and Griffith 1997, Finstad et al. 2007). The establishment and availability of interstitial spaces has been shown to correlate to significantly higher densities of juvenile salmonids compared to reaches lacking this spatial heterogeneity (Meyer and Griffith 1997). We observed a significant positive relationship between shelter densities and the age 1+ : age 0+ steelhead density ratios (Figure 2). This indicates that zones in the watershed that receive colluvial additions of coarse CoBo substrates may be important smolt producing areas. However, conclusions are limited due to the very low sample size (n=3 study reaches) used in the analysis. Also, geomorphologic data were gathered over a much smaller spatial scale than fisheries data and during different years. This is justified because salmonids are known to seek out and undergo migrations to profitable wintertime habitat refugia at distances approximating those necessary to move from fish sample sites to shelter sites in this study (Brown and MacKay 1995, Mellina et al. 2011). Also, since stream power is largely insufficient to transport the CoBo found in the upper reaches of the watershed, it is highly unlikely that any major re-working of the channel substrate has occurred between 1995 and 2011 (no major earthquakes occurred during that period as well).

The results of this study indicate that salmonid conservation might benefit from the protection of upper regions of watersheds where colluvial additions of material into stream channels dominate the sediment delivery processes. CoBo Shelter habitats appear to be especially important in step and step-pool units possessing relatively high local slopes (Figures 3, 4). Watershed managers should consider maintaining adequate migration corridors between profitable summertime and wintertime rearing areas, since the two are not necessarily the same (juvenile salmonids often migrate downstream during summer months, provided temperatures are not too high, where feeding opportunities are greater and upstream in the fall/early winter in order to avoid dangerous high flows, e.g., Miller and Sadro 2003). Restoration strategies should consider additions of CoBo to appropriate areas (i.e., areas of insufficient transport capacities) known to produce high densities of 0+ fish, especially in bottleneck areas where survival to older age classes is restricted.

Future studies should incorporate more study reaches and couple the geomorphology and fisheries data at finer spatial and temporal scales to better understand the relationships between sediment delivery processes and fish survival. Understanding threats to endangered and threatened salmonids in California's Central Coast region is of critical concern given their socio-economic importance and status as iconic symbols of California's native biodiversity. Faced with the reality of climate change and the detrimental effect it is expected to have on salmonid populations in the region (Boughton et al. 2005), the need for informed management of these imperiled species has never been greater.

Figures

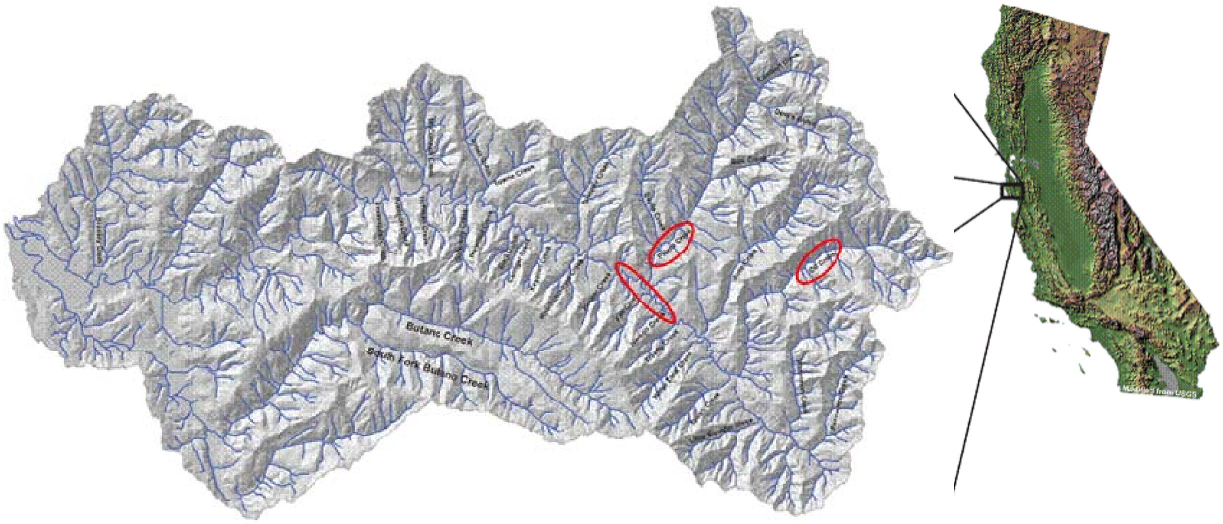

FIG. 1. Pescadero Creek watershed (San Mateo County, CA, USA, 37.2291108°N 122.1919103°W. Red circles indicate locations of study sites for this investigation (Oil Creek, Peters Creek, upper Pescadero Creek mainstem). Figure is from Dondaldson (in prep.).

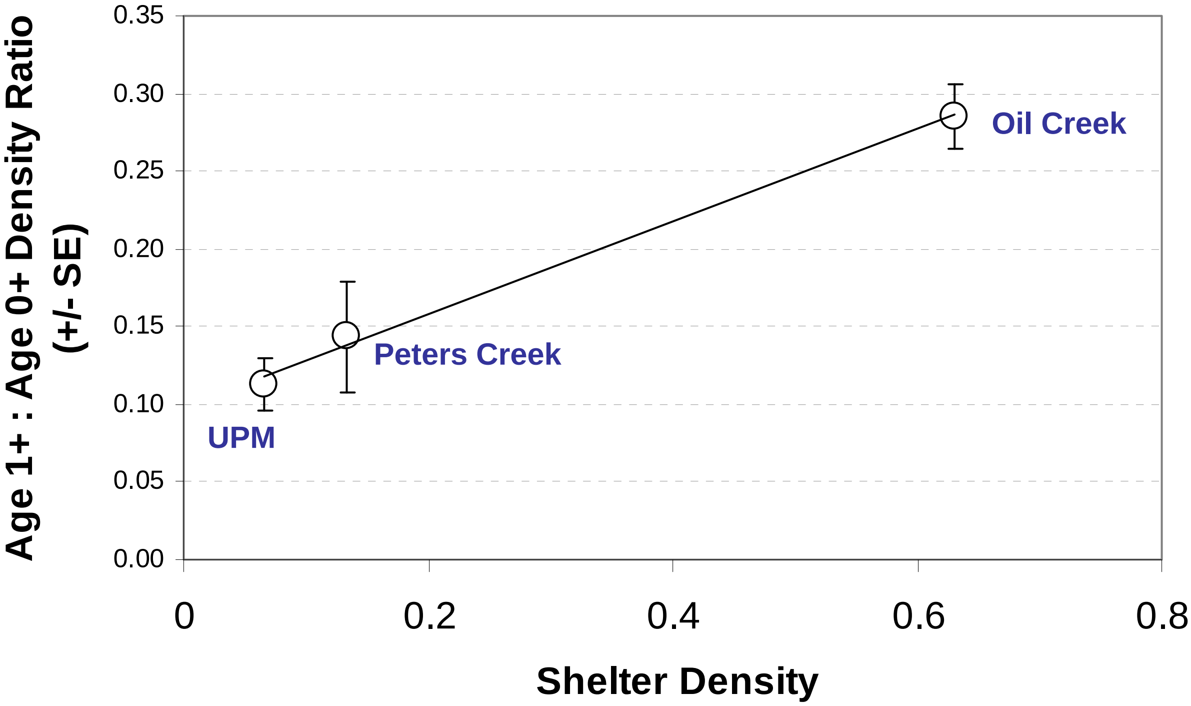

FIG. 2. Significant (α = 0.05) positive linear relationship between total shelter density (average number of shelters per square meter for entire study reach) and the ratio of age 1+ steelhead

density (in fish/area) to age 0+ steelhead density (an index of overwinter survival), $R^2 = .996$, $F(1, 1) = 281.060$, $p = 0.038$. Error bars indicate ± 1 standard error (SE).

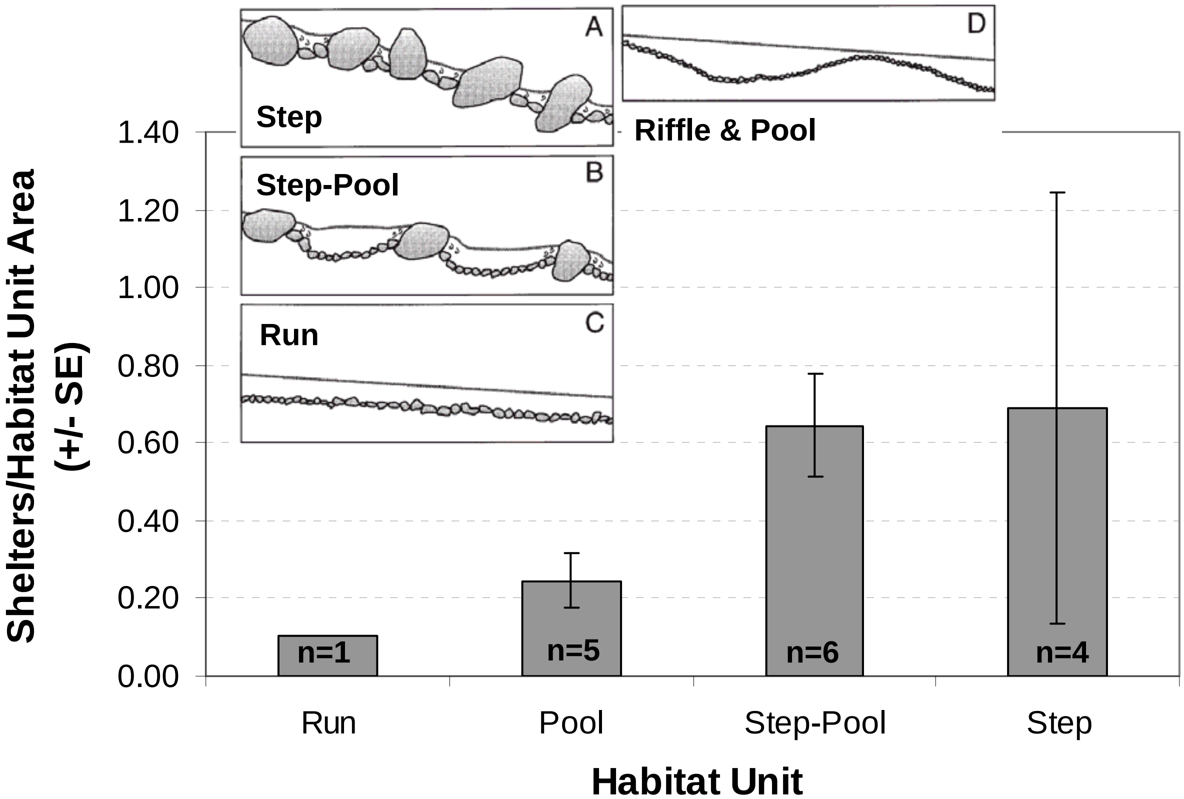

FIG. 3. Average shelter densities (no. shelters per square meter) per habitat unit at the Oil Creek study site. The total number of each habitat unit encountered in the 150 m study reach is indicated in each bar. Error bars indicate ± 1 standard error (SE). Cross section figure is modified from Montgomery and Buffington (1997).

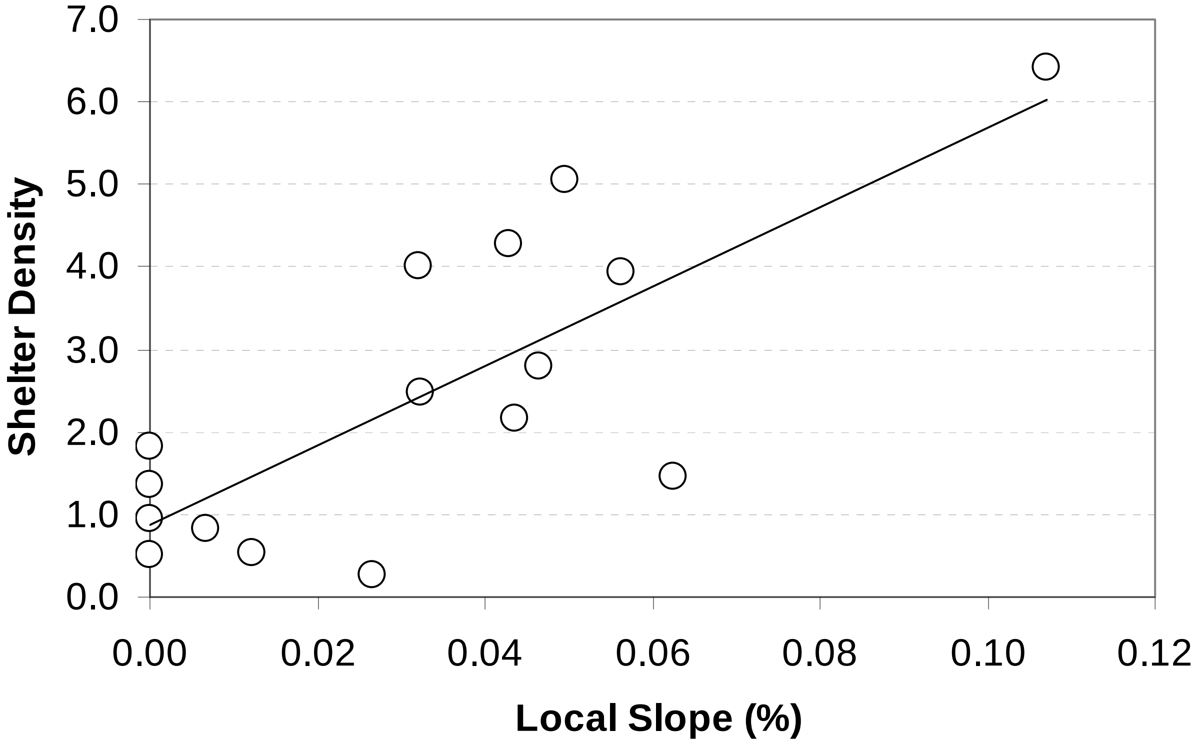

FIG. 4. Significant (α = 0.05) positive linear relationship between local slope (i.e., slope of each habitat unit surveyed) and shelter density (no. shelters per square meter) at the Oil Creek study reach, $R^2 = 0.598$, $F(1, 14) = 20.844$, $p < 0.001$.

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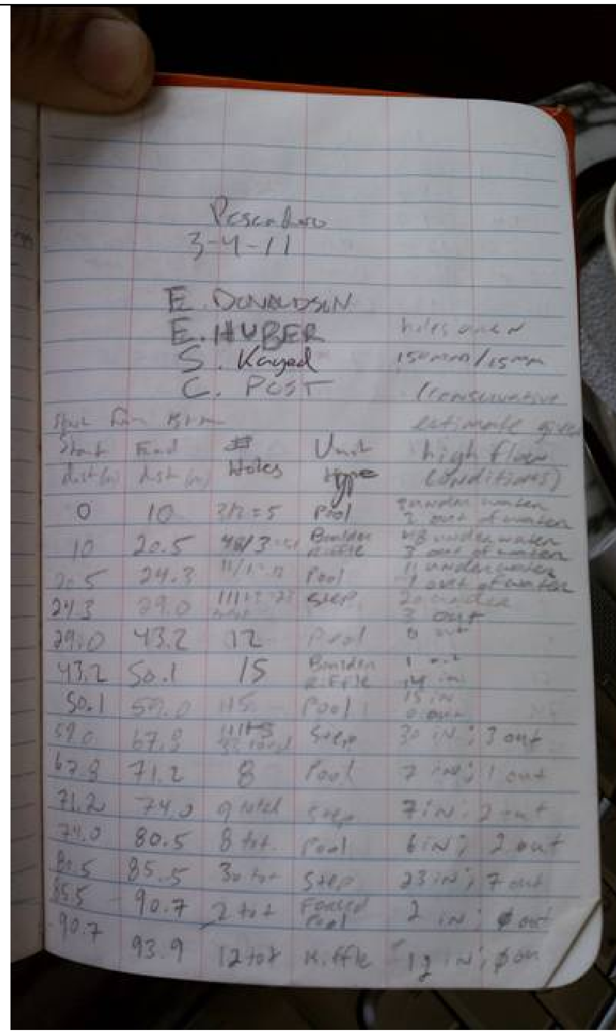
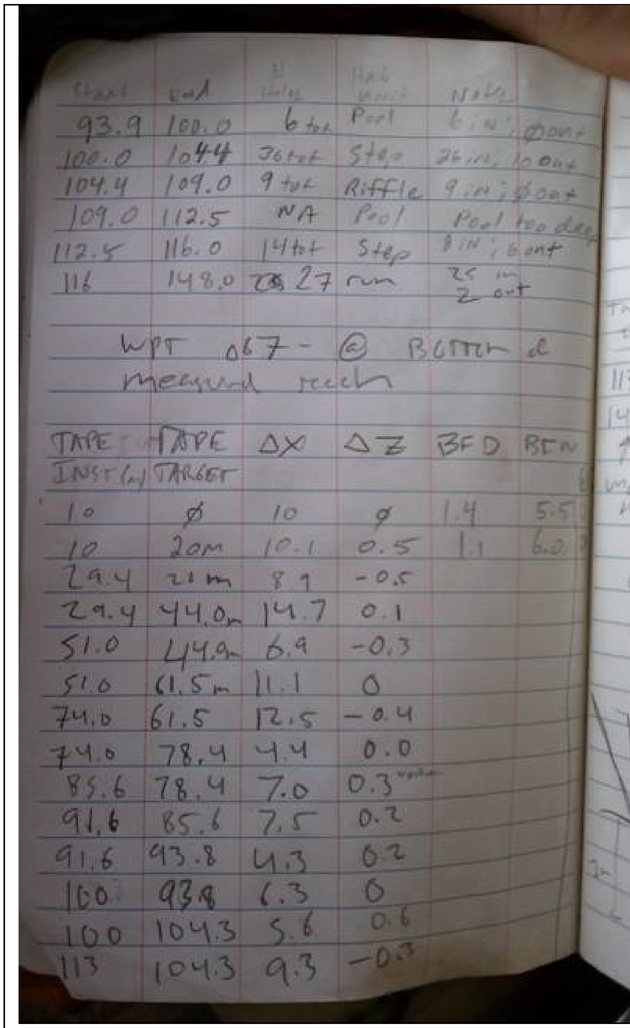
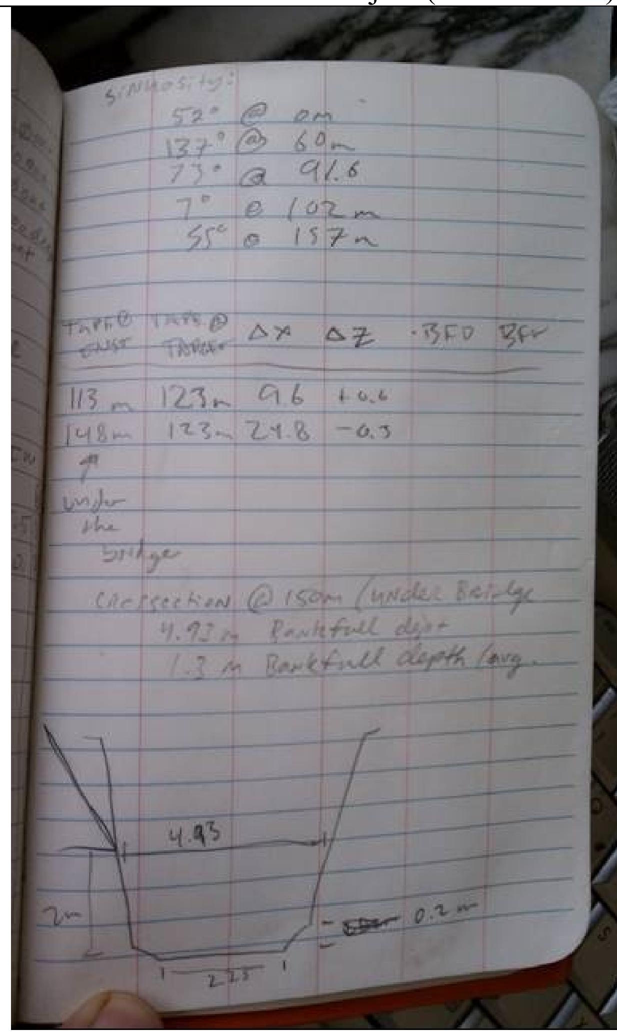
Appendix A: Field notes from trip to Oil Creek on 4 March 2011.	


93.9 100.0 6 tot Pool
100.0 104.4 Step
104.4 109.0 9 tot Riffle
109.0 112.5 NA Pool Pool too deep
112.5 116.0 14 tot Step
116 148.0 27 run
WPT 067 - @ Bottom of measured reach
TAPE INST (m) TAPE TARGET ΔX ΔZ BFD BFW
10 Ø 10 Ø 1.4 5.5
10 20m 10.1 0.5 1.1 6.0
29.4 21m 8.9 -0.5
29.4 44.0m 14.7 0.1
51.0 44.9m 6.9 -0.3
51.0 61.5m 11.1 0
74.0 61.5 12.5 -0.4
74.0 78.4 4.4 0.0
85.6 78.4 7.0 0.3
91.6 85.6 7.5 0.2
91.6 93.8 4.3 0.2
100 93.8 6.3 0
100 104.3 5.6 0.6
113 104.3 9.3 -0.3


Sinuosity:
52° @ 0m
137° @ 60m
73° @ 91.6
7° @ 102m
55° @ 157m
ΔX ΔZ BFD BFW
113m 123m 9.6 +0.6
148m 123m 24.8 -0.3
under the bridge
Cross section @ 150m (under Bridge)
4.93m Bankfull depth
1.3m Bankfull depth (avg)
4.93
2m
0.2m