Fall 2020

Habitat Monitoring for Salmonid Health at Headwaters Forest Reserve in Humboldt County, California

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Recommended Citation

Hutton, Allison Michelle; Buller, Jared; and Ayala, Lauren, "Habitat Monitoring for Salmonid Health at Headwaters Forest Reserve in Humboldt County, California" (2020). *Environmental Science & Management Senior Capstones*. 10.
https://digitalcommons.humboldt.edu/senior_esm/10

Habitat Monitoring for Salmonid Health at Headwaters Forest Reserve in Humboldt County, California

https://caltrout.org/article/recovering-the-elk-river-and-community/attachment/south-fork-elk-river

Prepared for:
Bureau of Land Management

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Applied Ecological Restoration (ESM 455)
Humboldt State University

December 2020

Abstract

The influx of fine sediment causes degraded habitat for salmonid species that are under federal monitoring protocols. Within Headwaters Forest Reserve, restoration efforts for salmonids such as road decommissioning have been conducted to reduce the influx of fine sediment into streams. Post-project monitoring of salmonid habitat in impacted streams is necessary to assess restoration effectiveness. Monitoring methods include assessing pool volume, large woody debris, and sediment particle size distribution in riffles. A one-kilometer study reach was examined to give indication of this progress. Thirty-one pools were counted along this study reach. A total of 149 large woody debris pieces were found. Of that, 86 were aggregate pieces and 63 were single pieces. Pieces of wood in aggregates decreased slightly from 2005-2020. Smaller length classes of LWD weren't observed until 2016 and longer length classes were no longer observed after 2013. Sediment size analysis showed that 98% of particles counted in this reach were considered gravels ranging from 2-90mm. The sediment size analysis also showed that there was no significant difference in the sediment size distribution from 2005-2020, indicating that the stream should be a suitable habitat for salmonid spawning. With the exception of a few outlier years, the dimension of streambed pools has been relatively consistent over the study period.

Introduction

Status of Salmonids in the Pacific Northwest and related Forest Impacts

Salmonids in the Pacific Northwest (Northern California to British Columbia) are in great decline, mainly due to the loss of freshwater habitat (Bisson et al., 2009), climate change, stream alterations, and overharvesting (Brown et al., 1994). Another large contributor to salmonid decline is land use and the creation of logging roads. Logging roads are a huge problem in the Pacific Northwest because there are many forests that are being logged (Flanagan et al., 2012). Logging roads increase the amount of sediment entering the stream systems nearby which makes streams shallower and warmer (Flanagan et al., 2012). Increased fine sediment impacts spawning areas for fish by changing the size of streambed particles and cementing areas where salmonids spawn (Flanagan et al., 2012). Two of the salmon species that are present in Pacific Northwest streams and listed as threatened species are Coho salmon (*Oncorhynchus kisutch*) and Chinook salmon (*Oncorhynchus tshawytscha*) (Brown, et al., 1994). It is estimated that there is only 6% of the Coho population remaining in California compared to the 1940's (Brown et al., 1994). Moreover, only 54% of streams previously containing Coho in the Pacific Northwest contain populations today (Brown et al., 1994).

Impact of Sediment Size to Salmonid Spawning Habitat

Logging practices can cause a multitude of negative effects on their surrounding environments. When logging roads are constructed and the vegetation is removed, it alters the nearby stream channels by changing the amount of wood, water and sediment inputted into the channels (Hendry et al., 1992). Logging practices can also increase the amount of erosion happening in the area; this erosion leads to smaller sediment sizes present in the river bed (Hendry et al., 1992).

When the sediment in the stream consists of primarily fine particles, it impairs the success rate of salmonid embryos (Hendry et al., 1992). Salmonids in the Pacific Northwest have been threatened by these effects of logging practices at least since the 1960s (Hendry et al., 1992).

Importance of Large Woody Debris as In-Stream Habitat

Most salmon and trout populations require stream habitat complexity. Stream complexity includes deeper pools mixed with shallow pools, meandering of the stream, and less wide pools (Fausch, 1992). More woody debris in the streambed helps make the stream more complex and therefore provides habitat for salmon production (Fausch, 1992). The woody debris creates deeper pools, which is very important for cover and habitat when there are storms (Hendry et al., 1992). Deeper water gives the fish area below the surface where they can hide since it has less turbidity and calmer waters (Hendry et al., 1992). These fish also need deeper water to survive because the deeper water contains colder water temperatures (Hendry et al., 1992).

Pool size

Pools serve a number of critical habitat functions for salmonids. They provide critical winter habitat for juvenile salmonids (Reeves et al., 1991), food, and rearing habitat (Clark and Gibbons, 1991). Pools are an indicator of channel complexity, are practical to measure compared to other forms of habitat, and their quality is inversely related to the disturbance within a watershed (Scholz and Booth, 1999). Deeper residual pool depth and lower frequency per channel width are associated with higher quality habitat for rearing salmonids (Washington Forest Practices Board, 1997).

Headwaters Forest Reserve

Headwaters Forest Reserve (hereafter Headwaters) is a nature reserve located near the cities of Eureka and Fortuna in Humboldt County (Figure 1) (Blom, 2017). It is managed cooperatively by the Bureau of Land Management (BLM) and California Department of Fish and Wildlife (CDFW) (Blom, 2017). Located within the Elk River watershed, large scale timber harvesting has been conducted since settlement by Europeans, with accelerated harvesting in the 1990s causing cumulative impacts to the watershed and streams contained within (NCRWQB, 2018). Restoration efforts in Headwaters consist of variable density thinning of second growth stands of trees, invasive plant removal, and decommissioning of logging roads to reduce high rates of sedimentation in the waterways (Blom, 2017). Most high impact roads closer to the streams have been removed, leaving lower impact roads that are located at higher elevations (Blom, 2017). High impact roads are those that have a strong possibility of dumping sediment in the watershed.

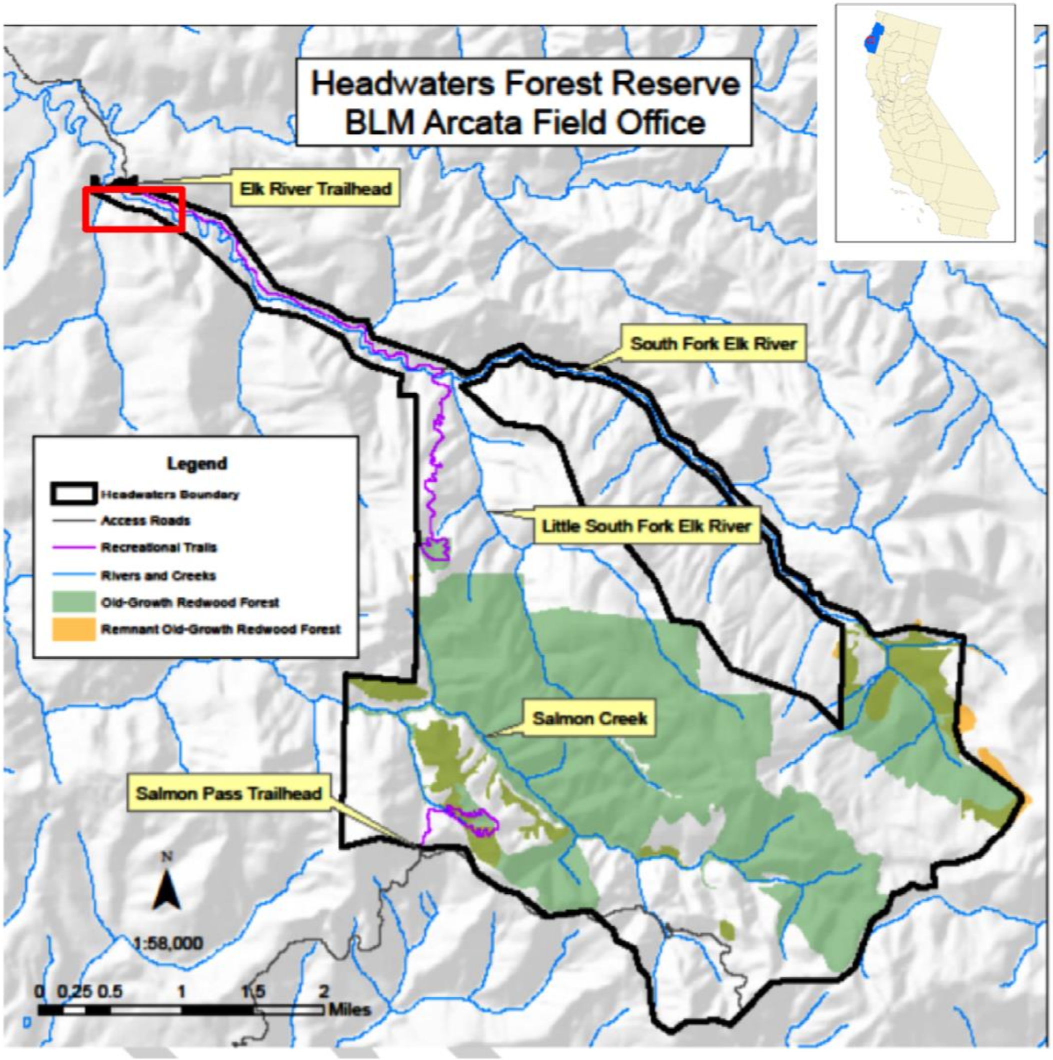


Figure 1. Map of Headwaters Forest Reserve showing location of Elk River Trailhead and areas of old-growth and remnant redwood forest. The 1-km study reach is contained in the red rectangle adjacent to the Elk River trailhead. Inset map in the top right shows the location of the Headwaters Reserve within Humboldt County, CA. (Source: Blom, n.d.)

Study Objectives

This study examined in-stream habitat conditions for salmonids in a 1-km reach of the South Fork Elk River located within the Headwaters Forest Reserve. Objectives for this study were to: a)

Collect data on habitat features for the BLM and compare with prior years' data to understand how habitat quality is changing in streambed pools, b) Document the changes in occurrence of LWD in the streambed, and c) Record the relative sizes of sediment in riffle sequences.

Methods

Site Description

This study took place in the South Fork Elk River, which is located in the Headwaters Forest Reserve near Loleta, California (shown in Figure 1). The survey reach was a 1-km section of the South Fork Elk River, beginning by the Elk River Trailhead (Figure 1). A flag and GPS coordinates indicated where the study reach ended. Some of the plant species present in the study area include red alder (*Alnus rubra*), bigleaf maple (*Acer macrophyllum*), coast redwood (*Sequoia sempervirens*), Himilayan blackberry (*Rubus armeniacus*), Coho salmon (*Oncorhynchus kisutch*), Chinook salmon (*Oncorhynchus tshawytscha*), and steelhead trout (*Oncorhynchus mykiss*) (Elk River Restoration Gets Boost, n.d.).

Pool Dimensions

Pool dimensions were measured for every pool within the 1-km study reach. The upstream and downstream boundaries of each pool were visually determined. Once boundaries were established, a meter tape was used to measure the full length of the pool. In instances where the pool was too long or had too many bends to complete in one measurement, multiple measurements were taken end to end and added together for the total length.

The width of each pool required multiple measurements because the width of a pool varied over its length. Three measurements were taken at each pool with a meter tape, with two being measured at the upstream and downstream extent and the third measurement in the middle of the pool length. These three measurements were averaged to calculate average pool width. Max pool depth was found at each pool by using a metric stadia rod at the deepest point, and recorded to the nearest tenth of a meter. Average depth for each pool was determined by taking a multitude of pool measurements and averaging them together to the nearest tenth of a meter. The amount of measurements for average depth varied situationally depending on the size of the pool and apparent variance in depth over its length, but was between 10-20 measurements per pool.

Sediment Size Characterization

Pebble counts were conducted to identify the average size of the river-bed's substrate and compare it to previous year's data. A random number generator was used to pick four riffles within the study reach on which to conduct a pebble count. Once a riffle was randomly identified, 100 particles were counted in that riffle. To count the particles, a person reached into the riffle and grabbed the first particle their fingers touched in order to prevent bias. After identifying the size of that particle using a gravelometer, it was placed back and then one step was taken in front of the last spot and a new particle was chosen, so then at the end 10 particles in a straight line were selected. After 10 particles in a straight line were selected, a step to the left or right was taken and then another 10 particles were picked up in a new line and measured. A total of 10 lines were traversed until to end with a total of 100 particles measured in a riffle. A total of 400 particles were measured and recorded within the 1-km reach. The substrate size categories listed on the gravelometer were defined as fines (<2mm), gravel (2-90mm), cobbles (90-256mm) and boulders (256-512mm).

Large Woody Debris

Large woody debris within the study reach was only counted if the piece was >3 meters in length and >0.2 meters in diameter. Three meters in length was chosen as the minimum length because it was half the average bankfull width of the channel. To be counted, the wood also had to be downed (not alive) and lying within the bankfull width of the creek. Once the requirements were met, the large woody debris was tallied according to size classes. Size classes were split by diameter and length classes. Diameter classes included 0.1-0.2 m, 0.2-0.4 m, 0.4-0.8 m, 0.8-1.6 m, and >1.6 m. Length classes included <1 m, 1-2 m, 2-4 m, 4-8 m, 8-16 m, 16-32 m, and >32 m. Large woody debris were also tallied according to whether they were single pieces or aggregates. Aggregates were defined as four or more pieces of wood in contact with each other and each group of aggregates was summed. Single pieces were counted when there were three or less pieces. Root wads were also tallied. Root wads were only counted when the root mass diameter was larger than the length of the tree trunk.

Results

Pool Dimensions

A total of 31 pools were measured within the 1-km study reach. This is a slightly higher count than any previous year of data collection, where the largest number of pools counted was 30. The pool count in all years is mostly consistent, with 2011 appearing to be an outlier for pool counts (Figure 2). This could be partially explained by a lower than average precipitation amount in 2011 (Table 1). However, 2013 was by far the lowest precipitation on record of all the relevant study years, and the pool count in 2013 was on the higher end of the pool count totals.

Annual precipitation amounts can provide context and evidence for why the measured pool dimensions in a study year are a particular size. Of particular interest is the low precipitation in 2013 and high precipitation in 2005, 2006, 2010, 2012, 2016, and 2017 (Table 1).

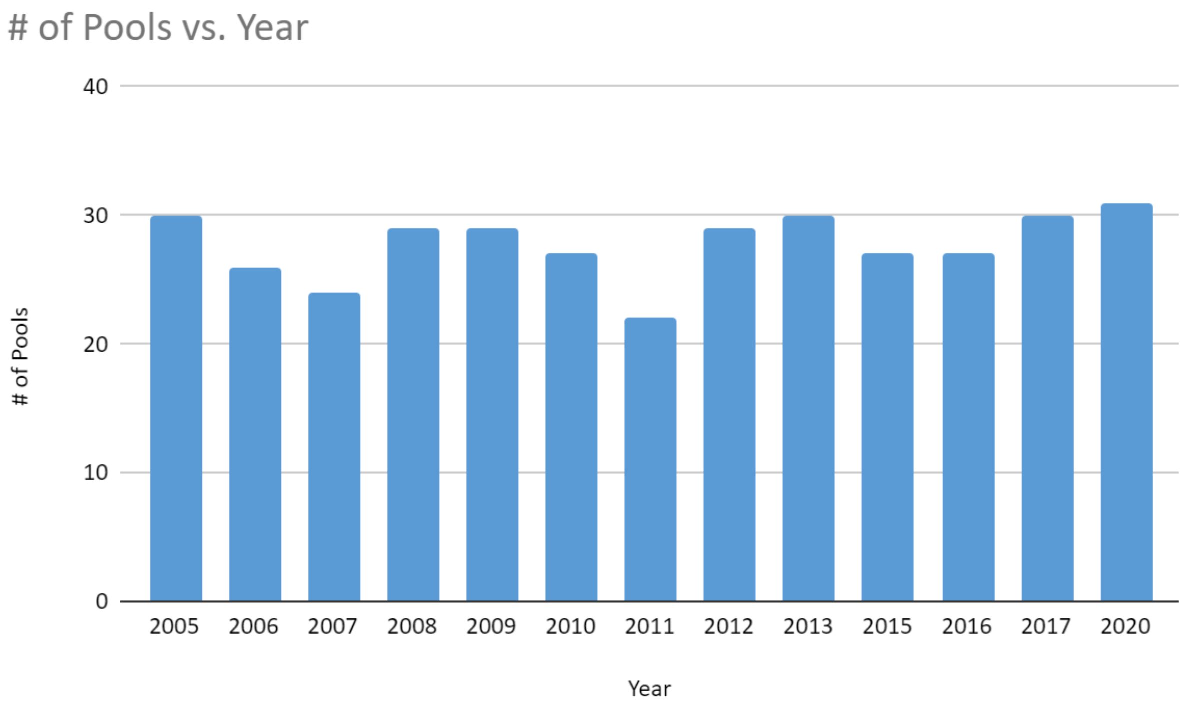
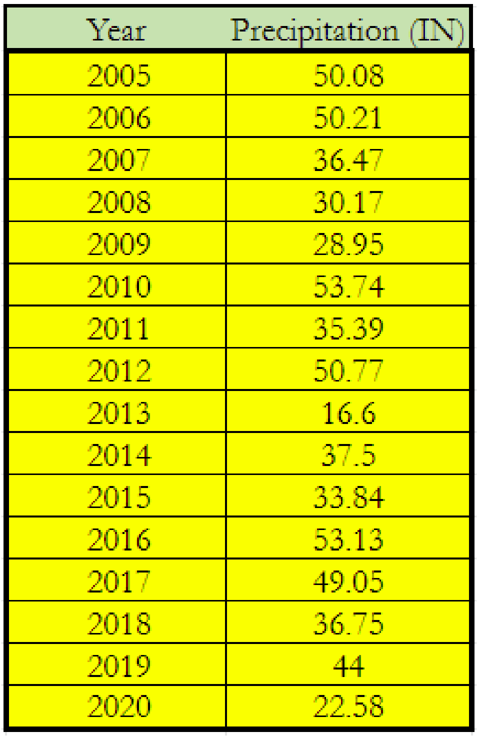


Figure 2: Number of pools measured in each study year within the 1-km study reach along the South Fork Elk River between 2005 and 2020.

Table 1: Annual precipitation at Eureka Woodley Island rain gauge in inches from 2005 to 2020 (source: Western Regional Climate Center).



Year	Precipitation (IN)
2005	50.08
2006	50.21
2007	36.47
2008	30.17
2009	28.95
2010	53.74
2011	35.39
2012	50.77
2013	16.6
2014	37.5
2015	33.84
2016	53.13
2017	49.05
2018	36.75
2019	44
2020	22.58

Higher depth at RF in 2009 and 2010 but lower residual depth in the same years could amount to differences in measurement methods, as 2009 was a low precipitation year and so greater depths in riffle sequences could not be explained by a higher presence of water. Average depth (Depth) is mostly consistent over the study period, whereas variations in max depth could at least partially be justified in an inconsistent methodology for determining max depth (number of measurements, location in pools of measurements), there does appear to be at least some consistency in low precipitation years yielding a lower max / average depth measurement (Figure 3).

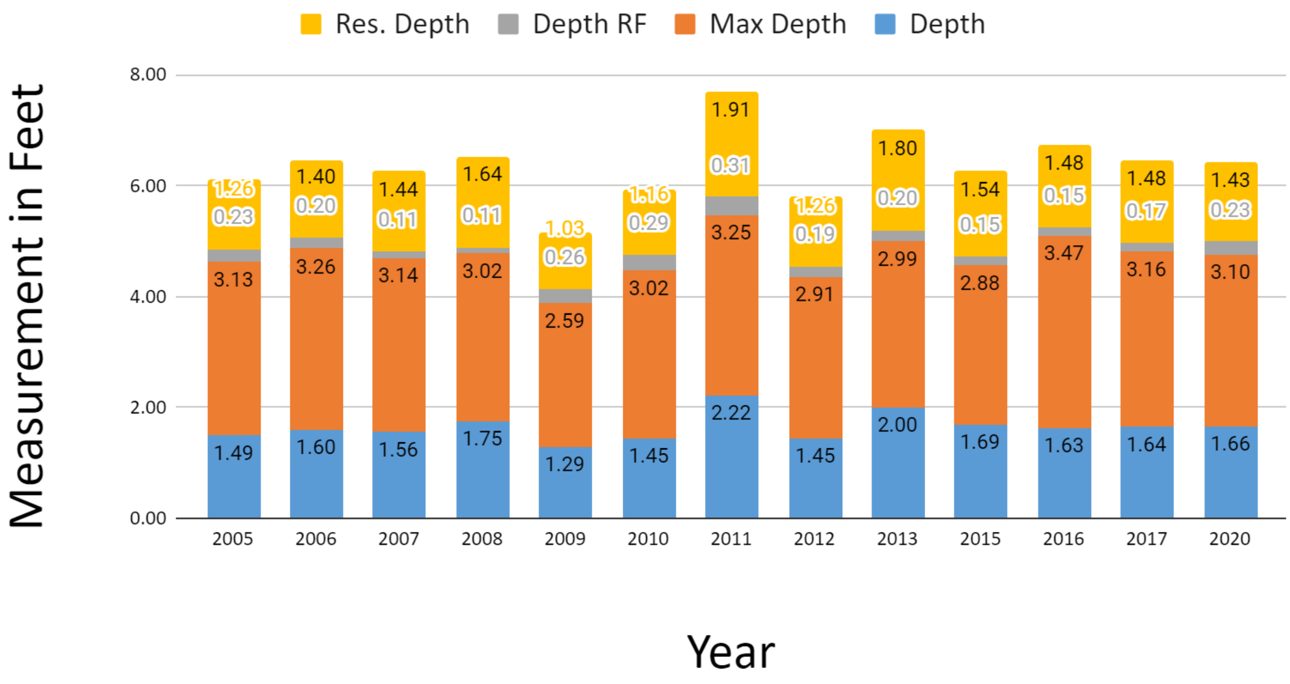


Figure 3: Pool & Riffle Variations in Max and Average Depth by Study Year along the 1-km study reach in the South Fork Elk River between 2005 and 2020.

There was pronounced variation in the pool length and average width among study years. Of particular interest were the conspicuously low values of pool length and average width in 2006 and 2016. These were both heavy precipitation years and resultantly lower measurements do not make much sense, but perhaps a different measurement standard was used (imperial rather than metric) (Figure 4). Similarly, the highest average pool length in 2011 does not make much sense either since this was among the lower precipitation years (Table 1).

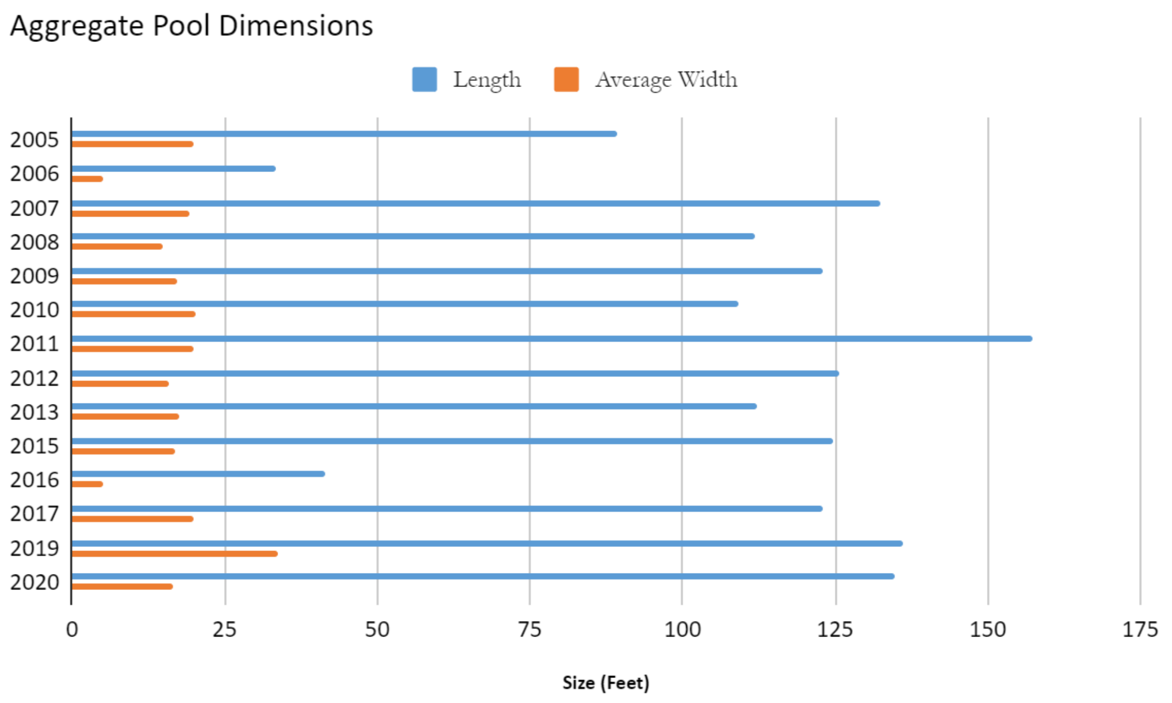


Figure 4. Comparison of average pool length & pool width in each study year within the 1-km study reach on the South Fork Elk River.

The highest residual pool depth was measured in 2011. Among the lower years for residual depth measurements were 2009, 2010, and 2012. Residual depth is an indicator for the differentiation between pools. Note that even though 2011 was a relatively low precipitation year (Table 1), the amount of pools in 2011 was the lowest count of all (Figure 2), which is in line with the high residual depth measured in this particular year (Figure 5).

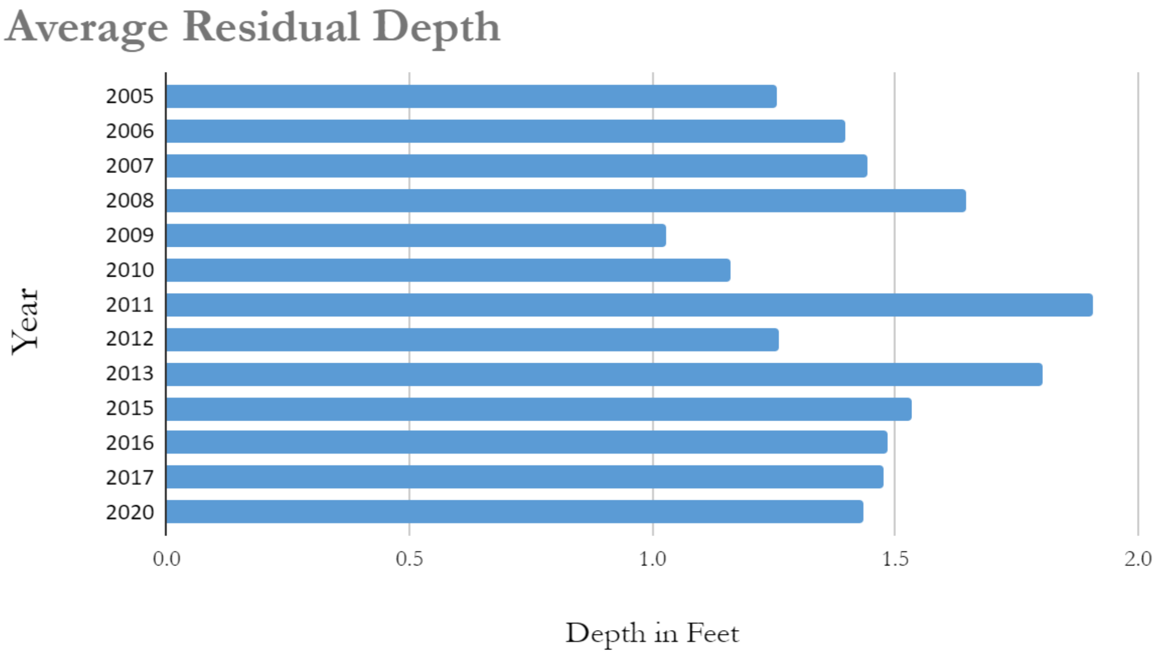


Figure 5. Average residual pool depth measured in each study year.

Depth appears to be relatively consistent over the past 15 years (Figure 6). The low depth in 2009 is justified since the precipitation in both 2008 and 2009 was on the lower end (Table 1). The low depth in 2020 is also consistent with low amounts of rainfall.

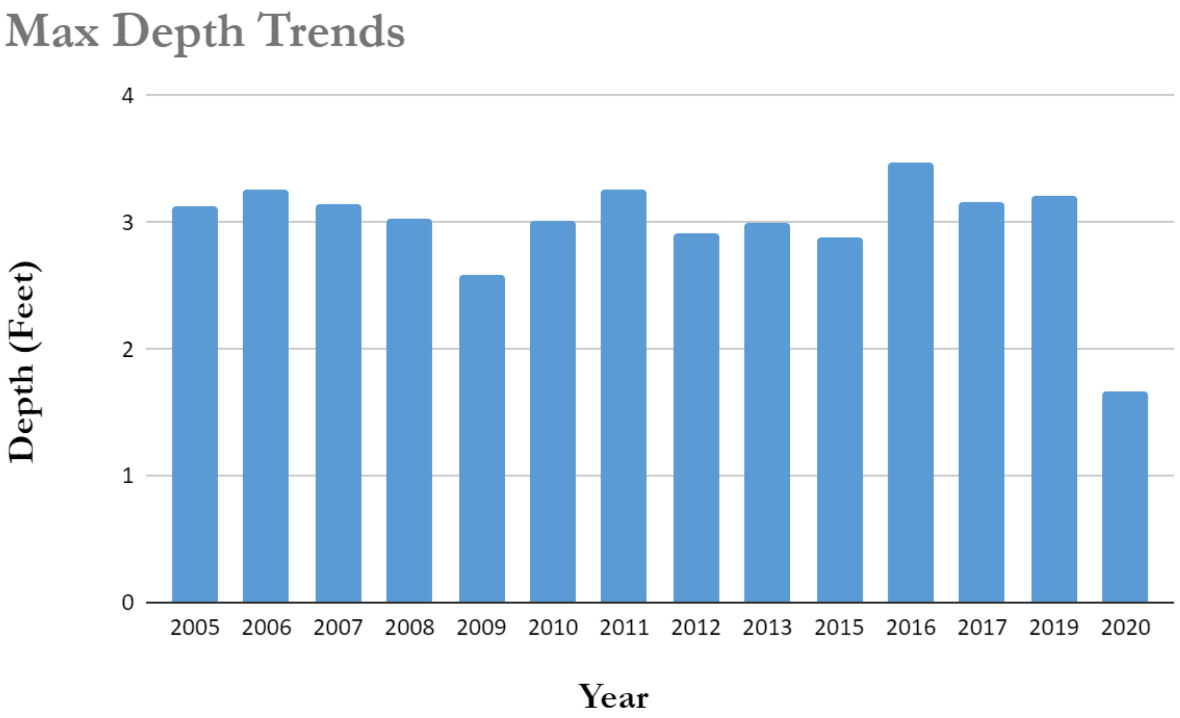


Figure 6. Visual trend of max pool depth & variance in pool depth over lifetime of study.

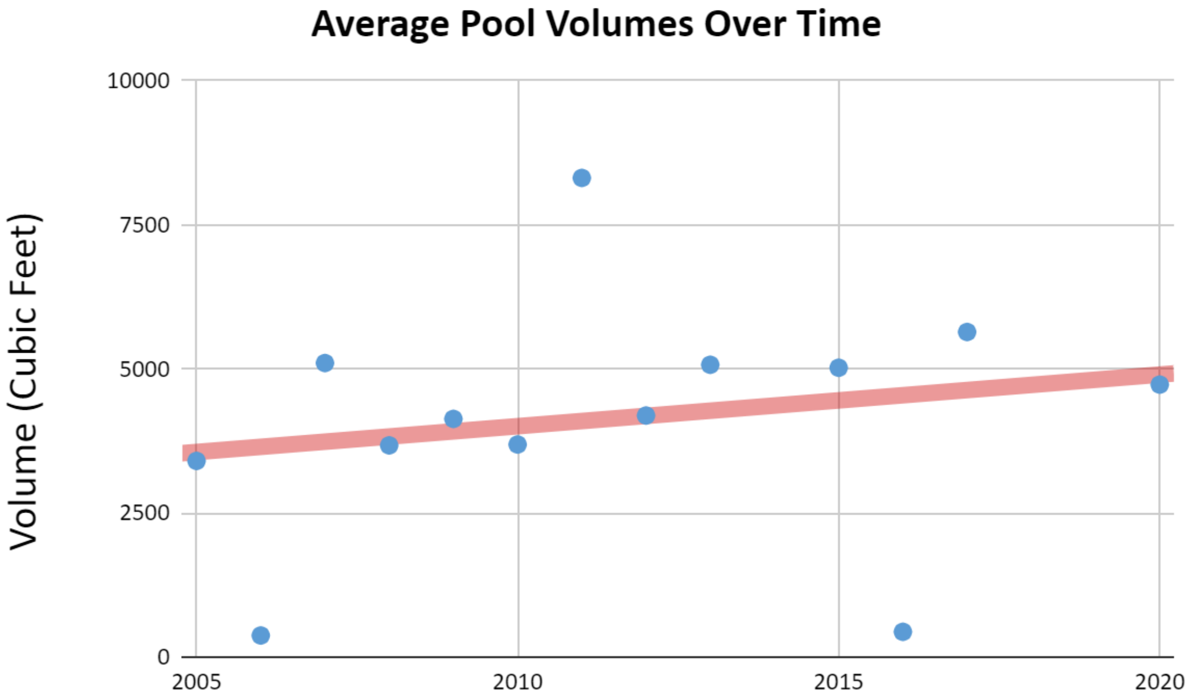


Figure 7. Visualization of changes in average pool depth over study period.

Large Woody Debris

There were 2 root wads and 149 pieces of large woody debris counted within the 1-km study reach. Of those large pieces, 86 were aggregates. There were 7 total groups of aggregates containing 4, 7, 11, 5, 7, 42, and 10 pieces in each aggregate. The total number of aggregate pieces was compared to past data since 2005 (Figure 8). A regression line was drawn on the chart and an R-squared value of 0.353 was found as well as a P-value of 0.070282. This means the data is not very statistically significant since the P-value is above 0.05. It isn't far from 0.05 so this shows that the data follows a slight regression downwards, with smaller total amounts of aggregate pieces in recent years.

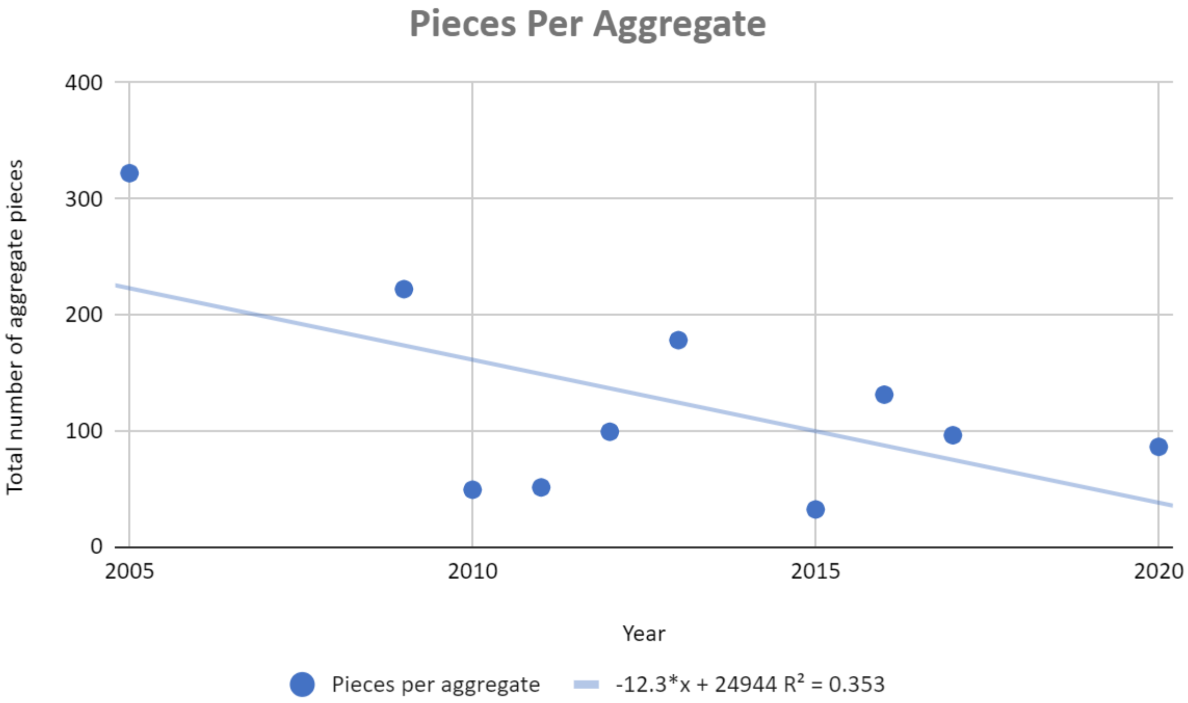


Figure 8. Comparison of current year total of 86 large woody debris aggregate pieces to past years data with a regression line and P-value of 0.070282.

Length and diameter of the aggregate pieces were compared to past years data (Figures 9 and 10). Figure 9 shows that the smallest size class for length was not observed until 2016. There are also fewer pieces in the length class 8-16 meters in more recent years. The distribution of aggregate piece diameters seem to be more uniform than the distribution of length, which was more variable over time. Almost all of the size classes are present throughout the history of the monitoring as well.

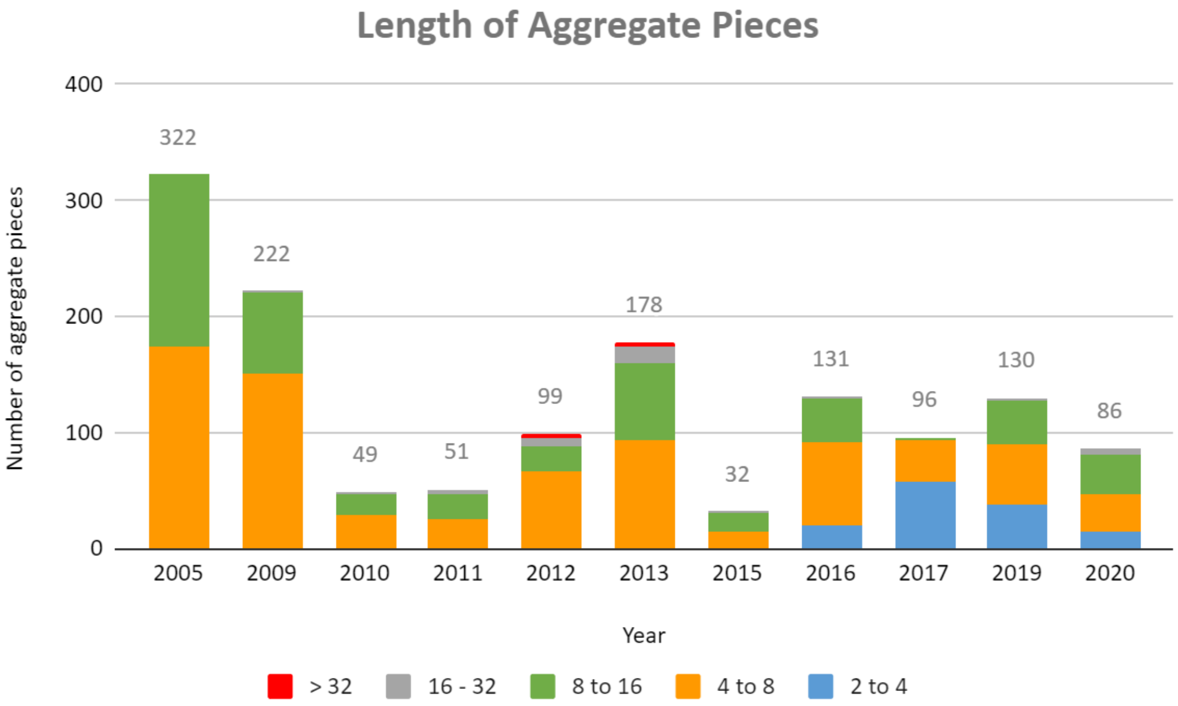


Figure 9: Total number and length of aggregate pieces in 2005-2020 for the study reach showing 86 pieces in current year.

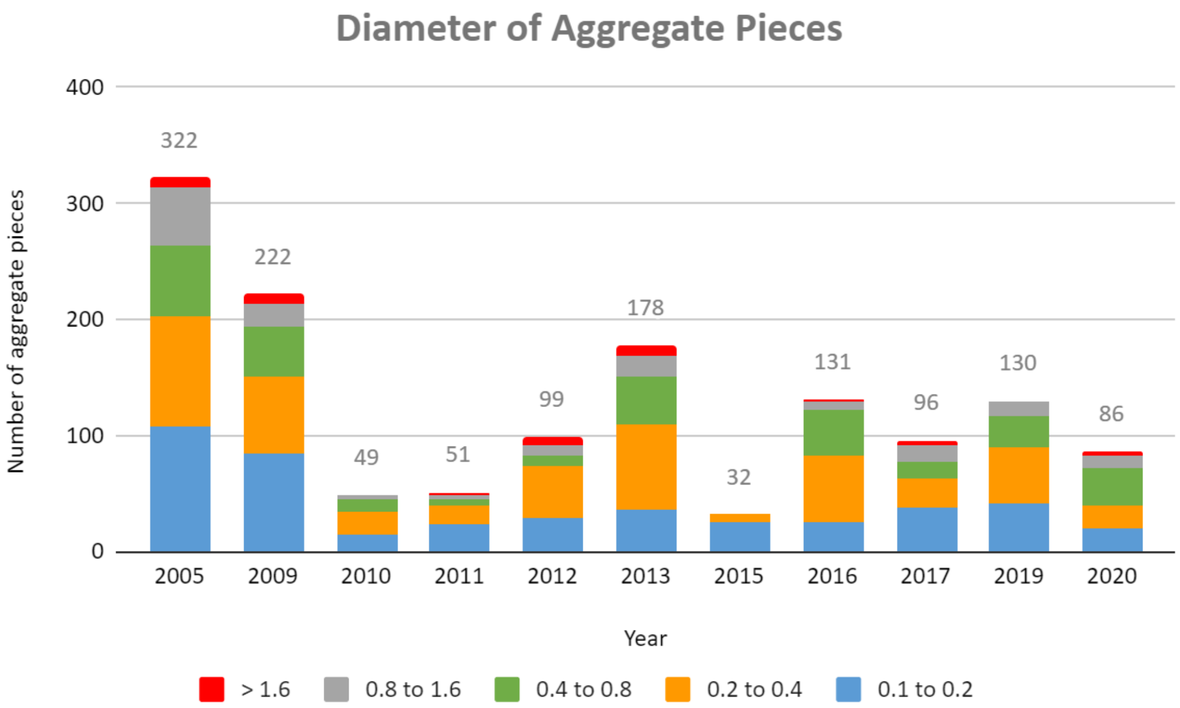


Figure 10: Total number and diameter of aggregate pieces in 2005-2020 for the South fork Elk River.

Sixty-three single pieces were counted in the study reach. The length and diameter of these pieces were compared to past years data separately. Figure 11 portrays the comparison between the length of pieces. It shows that pieces with shorter length became more abundant in recent years while longer pieces became less abundant. There were no pieces in the longest size class (in red) since 2013. Figure 12 compares the diameter of single pieces throughout the study years. Again, pieces with a larger diameter were more present in past years and greatly decreased after 2013.

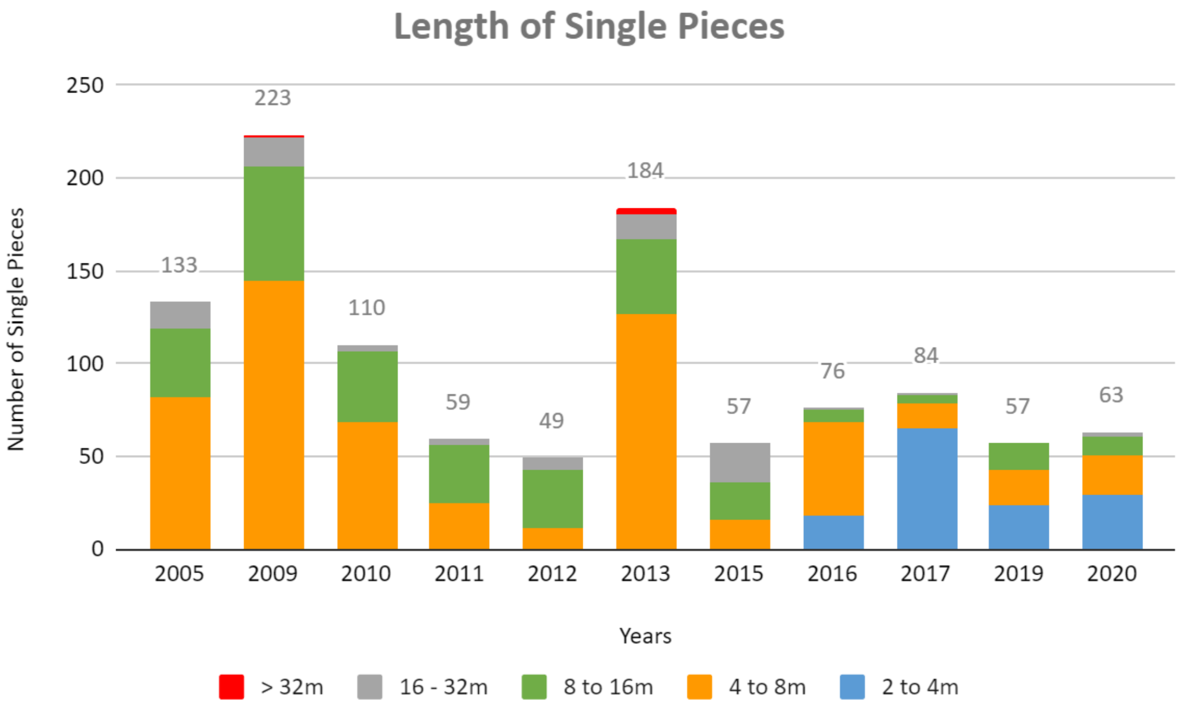


Figure 11: Total number and length of single pieces in the South Fork Elk River from 2005-2020.

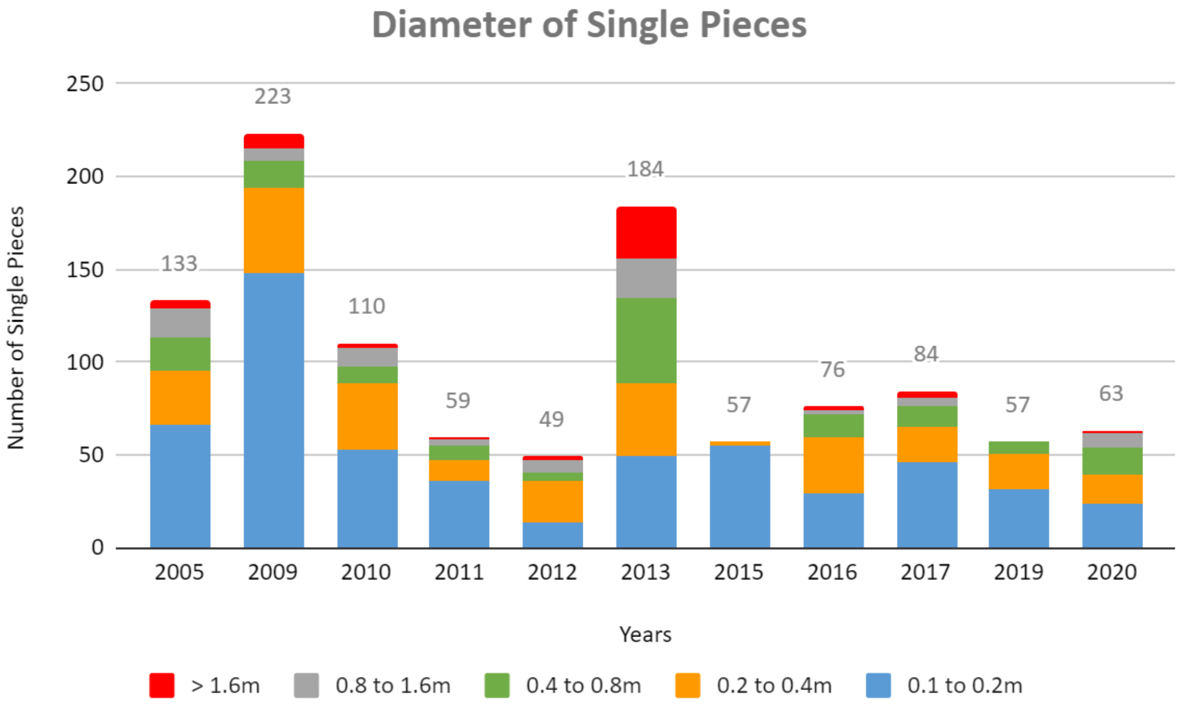


Figure 12: Total number and diameter of single pieces in 2005-2020 for the South Fork Elk River.

Sediment Size Characterization

Sediment size characterization is the percentage of fines, cobbles, and gravels that were identified during this study (Figure 13). In 2020, the gravels substrate class made up 98% of the total particles measured. After gravels, the next highest substrate class was cobbles which made up 2% of all particles measured. There were no fine sediment particles, boulders or bedrock particles identified in the 2020 study.

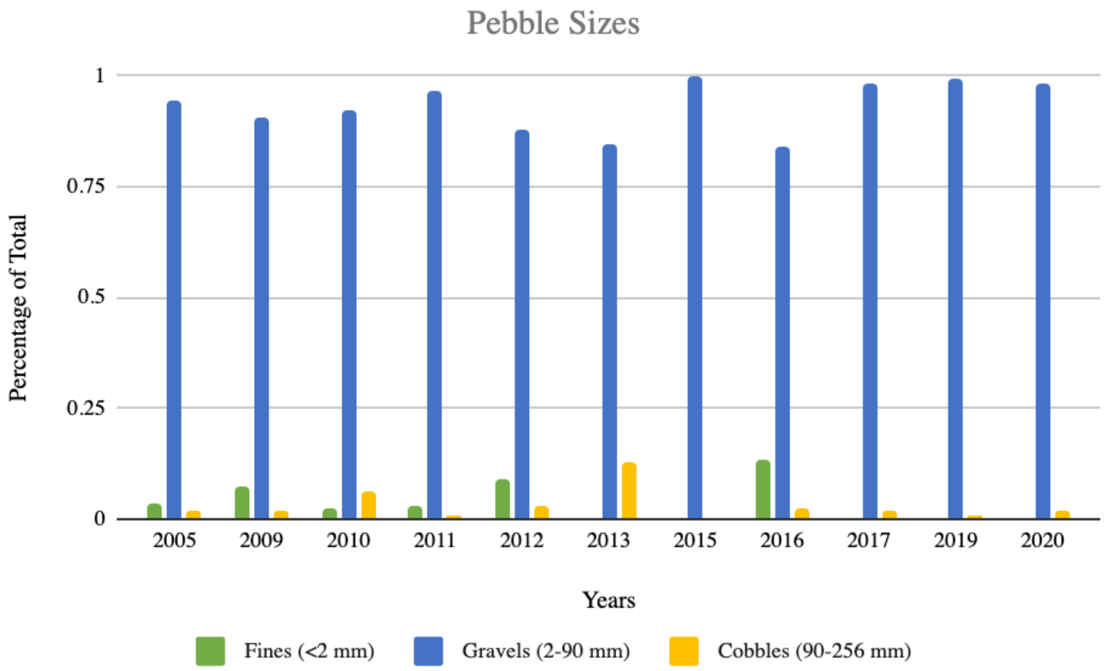


Figure 13: Sediment size distribution in a 1km study reach of the South Fork Elk River 2005-2020.

An ANOVA test was used to compare the percentage of sediment size distribution from 2005 to 2020. This test resulted in a P-value of 0.999 which indicated that there was no significant difference from 2005-2020 in the sediment size distribution. The findings of fine particles (<2mm) present in the bed substrate from 2005-2020 has consistently been relatively low. There have been no fine sediments measured in riffles in this reach since 2016.

Discussion

Average pool length and width has stayed relatively consistent over the timeline of the study between 2005 - 2020 (Figure 4). Outliers appeared in 2006 and 2016, with the average pool length and width being far smaller than other years' measurements. While not entirely clear, this is likely due to the measurements being rendered in metric rather than imperial units, and unfortunately the prior years of data do not indicate the units of measurement used. This inconsistency also translated over to the average volume, with precipitous drops in value shown around 2006 and 2016 (Figure 7). 2011 also appears to be a notable year, as the residual depth and volume of pools was considerably higher compared to other years in this study (Figure 4 and Figure 6). 2008 - 2009, 2013 - 2015, and 2020 have all been low precipitation years (Table 1), and so it can be speculated that increased rainfall was responsible for the higher values. Average pool length was also highest in 2011 at 157.5 feet, with the 2020 average measurement of 134.7 feet being the second highest (Figure 3). This could be due to inaccuracy in carrying out of measurements, as neither 2011 or 2020 were particularly wet years (Table 1). Bankfull width of the study area was defined as 20 feet. Minimum residual pool depth for optimal salmonid habitat at this bankfull width is 0.8 feet (Chadd et al., pg. 7). The average residual depth of each study year exceeds this minimum, indicating that the depths of the pools in the study reach are adequate for salmonid rearing, with the current year featuring a residual depth of 1.4 feet (Figure 3).

All figures and data indicate that the total amount of large woody debris has decreased along the study reach since 2005. Areas with a history of logging often have more woody debris during logging and right after logging is stopped (Hendry et al., 1992). This could be why there are less pieces as monitoring has continued. Hendry et al. (1992) also suggest that large woody debris numbers decrease when the width of the channel increases. This could explain why there seems to be lower amounts of large woody debris in recent years. Further research or modification of the monitoring could be conducted to study this relationship in depth. An event could have caused a lot of smaller pieces of wood to be distributed into the stream, explaining why the shortest length class of wood for both single and aggregate pieces were not observed until 2016. They also move easier within the stream system, so they would have already moved through the channel when the monitoring occurred in earlier years (Lienkaemper et al., 1987). According to Hendry et al. (1992), one reason for the large spikes in total number of wood pieces in 2005 and 2009 could be landslides or channel failure. These are especially common in areas with a history of logging and clearcutting (Hendry et al., 1992).

Less large woody debris in the study reach over time has negative implications for salmonid habitat. According to a study done by Roni and Quinn (2001), streams with a higher number of large woody debris pieces are correlated with a larger density of Coho salmon. Large woody debris has also been found to create secondary channels and pools, which increase the biomass and numbers of salmon in the stream (House & Boehne, 1986). Since the number of large wood pieces in the study reach are diminishing over time, this may impact the density of salmonids present in the stream in the future. Large woody debris may need to be artificially placed in order to regain deep pools and habitat for salmonid species within this reach.

The results from the sediment size analysis showed that gravels ranging from 2-90mm made up 98% of the bed substrate. The data from 2019 also resulted in a finding that 98% of the bed substrate was gravel. This result indicated that the riverbed is well-suited for salmonid spawning because salmonids prefer gravel that ranges from 6-78 mm (Kondolf & Wolman, 1993). If the particle sizes making up the bed substrate are too small, salmonids have a hard time being able to move the sediment in order to lay their eggs (Kondolf, n.d.). Bed substrates that are composed of mostly fine sediments also do not allow water to flow through the gravel, therefore limiting the amount of dissolved oxygen available to the salmonid eggs (Kondolf, n.d.). The findings of fine particles (<2mm) present in the bed substrate from 2005-2020 has consistently been relatively low. The mean value of fine particles present over the 15-year study has been a total of 3.47%. This indicated that the Bureau of Land Management's road decommissioning efforts have had a positive effect on the stream's bed substrate composition.

Study Limitations and Recommendations for Future Monitoring

There were a few limitations and shortcomings to our study worth noting. For example, pool dimension data could have been gathered more carefully in 2020. Slack was allowed on the meter tape used to measure in the interest of time efficiency, and this could have caused the length and width measurements to be overestimated. The average depth also could have been estimated more systematically. While depth measurements were taken throughout each pool, their averaging together was not done by writing down each depth taken and doing the arithmetic, but by mentally calculating a ballpark of what the range of measurements taken would be, as seemed to be indicated by the data collection protocol. A suggested improvement to the methods for this sort of data collection would be to have a fixed number of depth measurements taken based on the width and length dimensions of the pool, and have each of these individual depth measurements written down and average to increase accuracy. While the average depth was certainly towards the median of each pool, it could have been over- or under-estimated.

Another limitation of this study was that only trees that were non-living were counted as large woody debris, which ended up skipping some of the important instream habitat provided by living trees within the reach. One suggestion would be to count all trees, living and dead, as large woody debris. The living ones are still in the bankfull width and create pools of water around them.

This is similar to why dead wood is counted. Instream living trees function the same as dead wood except that live trees have leaves and live branches. Counting living debris would also make it easier to count the number of aggregate pieces. Sometimes, there were living pieces within an aggregate of wood and it was difficult to decipher whether the piece that was being counted was dead or not since all the wood is tangled together.

The data collected over the years are important in order to determine if the Headwaters Forest Reserve is on the right track to being restored. Pool dimension characteristics indicate that the pools are within the range of suitable habitats for salmonid rearing. The results on the sediment size characterization in this study show that the Bureau of Land Management's road decommissioning efforts have had a positive effect on the stream's bed substrate composition. Results from the large woody debris counts have indicated a reduction in the size and amount of large woody debris and therefore less salmonid habitat. Further monitoring needs to take place to determine if the number of salmonid populations has decreased as a result of the reduction in large woody debris. Monitoring for streambed characteristics should continue to be conducted to document any changes in the recovery trajectory of the reach.

Citations

Bisson, P. A., Dunham, J. B., and Reeves, G. H. (2009). Freshwater Ecosystems and Resilience of Pacific Salmon: Habitat Management Based on Natural Variability. *Ecology and Society*, *14*(1). JSTOR. http://www.jstor.org/stable/26268060

Blom, B. Z. (n.d.). *Headwaters Forest Restoration Resource Management Plan Amendment*. 98.*Elk River | California Northcoast Regional Water Quality Control Board*. (n.d.). Retrieved September 30, 2020, from https://www.waterboards.ca.gov/northcoast/water_issues/programs/watershed_info/eureka_plain/elk/

Brown, L. R., Moyle, P. B., and Yoshiyama, R. M. (1994). Historical Decline and Current Status of Coho Salmon in California. *North American Journal of Fisheries Management*, *14*(2), 237–261. https://doi.org/10.1577/1548-8675(1994)014<0237:HDACSO>2.3.CO;2

Chadd, E. A., Clancy, E. M., and Mowe, J. H. (n.d.). A Physical Habitat Index Focusing on Salmonids in the Pacific Northwest. 20. http://www.clallam.net/streamkeepers/assets/applets/NWQMC_4-8-03.pdf

Clark, R. N. and D. R. Gibbons. (1991). Recreation. Pages 459-479 in W. R. Meehan, ed., Influences of Forest and Rangeland Management on Salmonid Fishes and Their Habitats. American Fisheries Society Special Publication 19; Bethesda, MD.

Elk River Restoration Gets Boost. (2016). Retrieved November 06, 2020, Retrieved from https://caltrout.org/uncategorized/elk-river-restoration

Fausch, K., Northcote, N. (1992). Large Woody Debris and Salmonid Habitat in a Small Coastal British Columbia Stream. *Canadian Journal of Fisheries and Aquatic Sciences,* 49(4). Retrieved from https://cdnsciencepub.com/doi/abs/10.1139/f92-077

Flanagan, S., Fuller, D., Job, L., Morrison, S. (2012). Erosion at Decommissioned Road-Stream

Crossings: Case Studies From Three Northern California Watersheds. *Proceedings of coast redwood forests in a changing California: A symposium for scientists and managers,* Retrieved from https://www.fs.fed.us/psw/publications/documents/psw_gtr238/psw_gtr238_053.pdf

Hendry, A. Peterson, N.P. , Quinn, T.P. (1992) Assessment of Cumulative Effects on Salmonid Habitat: Some Suggested Parameters and Target Conditions. *Washington Department of Natural Resources.* Retrieved from https://geo.nwifc.org/CMER/PublicDocs/TFWDocs/TFW_F3_92_001%20Assessment%20of%20Cumulative%20Effects%20on%20Salmoid%20Habitat%20Some %20Suggested%20Parameters.pdf

House, R. A., Boehne, P. L. (1986). Effects of Instream Structures on Salmonid Habitat and Populations in Tobe Creek, Oregon. *North American Journal of Fisheries Management*, 6(1). https://afspubs.onlinelibrary.wiley.com/doi/abs/10.1577/1548-8659(1986)6%3C38:EOISOS%3E2.0.CO;2

Humboldt Threatened and Endangered Species—Humboldt Bay—U.S. Fish and Wildlife Service. (n.d.). Retrieved October 28, 2020, from https://www.fws.gov/refuge/Humboldt_Bay/wildlife_and_habitat/HumboldtThreatenedandEndangered.html

Kondolf, G. M. (n.d.). *Transactions of the American Fisheries Society 129:262–281, 2000 q Copyright by the American Fisheries Society 2000 Assessing Salmonid Spawning Gravel Quality.*

Kondolf, George Mathias, & Wolman, M. (1993). The Sizes of Salmonid Spawning Gravels. *Water Resources Research - WATER RESOUR RES*, *29*, 2275–2286. https://doi.org/10.1029/93WR00402

Lienkaemper, G. W., & Swanson, F. J. (1987). Dynamics of large woody debris in streams in old-growth Douglas-fir forests. *Canadian Journal of Forest Research*, 17(2). https://andrewsforest.oregonstate.edu/sites/default/files/lter/pubs/pdf/pub703.pdf

Reeves, G. H., J. D. Hall, T. D. Roelofs, T. L. Hickman, and C. O. Baker. (1991). Rehabilitating and modifying stream habitats. Pages 519-557 in W. R. Meehan, ed., Influences of Forest and Rangeland Management on Salmonid Fishes and Their Habitats. American Fisheries Society Special Publication 19; Bethesda, MD.

Roni, P., Quinn, T. P. (2001). Density and size of juvenile salmonids in response to placement of large woody debris in western Oregon and Washington streams. *Canadian Journal of Fisheries and Aquatic Sciences*, 58(2). https://www.researchgate.net/publication/251479085_Density_and_size_of_juvenile_salmonid_in_response_to_placement_of_large_woody_debris_in_western_Oregon_and_Washington

Scholz, J. G. and D. B. Booth, 1999. Stream habitat assessment protocols: An evaluation of urbanizing watersheds in the Puget Sound lowlands. The Washington Water Resource, 10(1): 1-9.

Washington Forest Practices Board. (1997). Standard Methodology for Conducting Watershed Analysis Manual, version 4.0. Olympia, WA. http://www.dnr.wa.gov/forestpractices/watershedanalysis/manual.