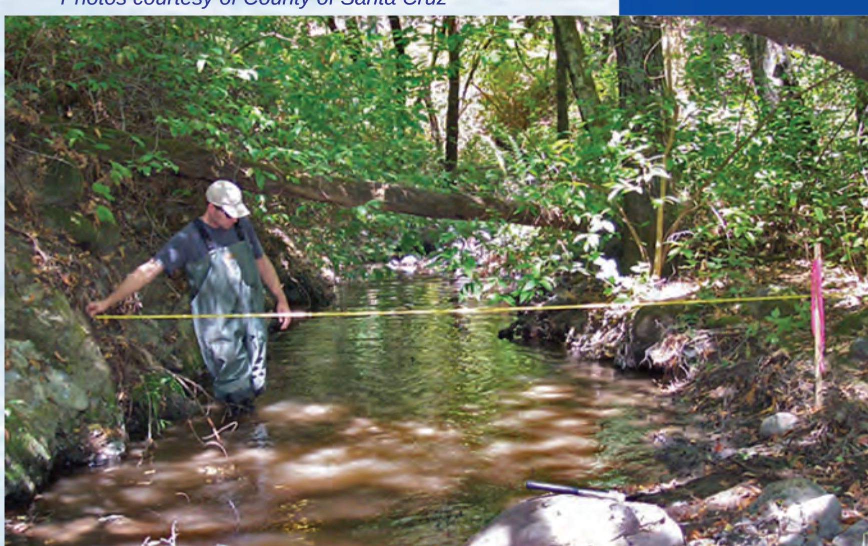
Analysis of the Juvenile Steelhead and Stream Habitat Database, Santa Cruz County, California

Web Products and Recommendations

Photos courtesy of County of Santa Cruz



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SCCWRP Technical Report #1082

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Overview

The Juvenile Steelhead and Stream Habitat (JSSH) Database includes monitoring data of steelhead (*Oncorhynchus mykiss*) density and stream habitat characteristics in four watersheds in Santa Cruz County, California. Data have been collected every fall since 1994, with one survey available in 1981. Data include steelhead density in two size classes and presence/absence of coho salmon. Additional presence/absence data are available for other species of fish, amphibians, and reptiles that are observed or captured during sampling. Stream morphometry, riparian, and bed characteristics are measured at each sampling location in pools, runs, and riffles.

In partnership with the County of Santa Cruz, the Central Coast Wetlands Group, and USEPA Region 9, research staff at the Southern California Coastal Water Research Project were contracted to provide an independent and comprehensive assessment of the JSSH Database. Analysis of the JSSH Database was driven by the following questions:

1. What is the status and trends of the steelhead and coho populations in these four watersheds?
2. Where do fish and wildlife species occur in these four watersheds?
3. What are stream habitat conditions in these four watersheds?
4. How can information about the steelhead and coho salmon populations and stream habitat conditions inform conservation and restoration efforts?

This technical memorandum will address the analysis questions above using information in the current database and to provide recommendations for future monitoring efforts. To assist in the analysis, a website (https://sccwrp.shinyapps.io/jssh_web/) was created that provides interactive tools to explore and evaluate the data. This website is provided as a deliverable under the contract. The remainder of this memo will describe 1) structure of the website, 2) general conclusions derived from website content (including status and trends of steelhead populations, community analysis, habitat analysis), and 3) recommendations for additional monitoring.

Structure of the Website

JSSH data describing both habitat and biological surveys were synthesized and evaluated on a customized web-based platform. This website was created using RMarkdown (Allaire et al. 2018) rendered in an R Shiny (Chang et al. 2018) runtime environment that merges HTML content with interactive elements. All data processing and analyses were completed using the free and open source R statistical programming language (RDCT 2019). The website and source content can be accessed using the following URLs:

Website: https://sccwrp.shinyapps.io/jssh_web/

Source content: https://github.com/fawda123/jssh_web

Fig 1. The landing page for the JSSH website. The analysis tabs are listed on the top toolbar.

The website (Fig. 1) was created to provide an interactive platform to comprehensively evaluate over 15,000 records of fish density and habitat measurements across four watersheds in Santa Cruz County. The data included information on over 40 aquatic species and 9 habitat variables covering up to twenty years at 81 individual monitoring sites. The website was structured around the main questions described above with separate tabs for each type of analysis. Full descriptions of these analyses are provided on the website; they are briefly summarized as follows.

- Steelhead status and trends: Status and annual trends in steelhead density by size class, watersheds, and individual sites
- Factors associated with trends: Habitat factors associated with steelhead density trends
- Community analysis: Multivariate community analysis of each watershed using species presence/absence, changes over time
- Community and habitat analysis: Multivariate analysis of association between habitat measurements and community composition, changes over time, using habitat data collected at fish sampling sites
- Habitat:
    - Site: Analysis of habitat differences between riffle, runs, and pools, and changes over time, using habitat data collected at fish sampling sites
    - Reach: Analysis of habitat changes at approximate 1/2 mile reach segments

- [San Lorenzo flow](): Analysis of modelled flow changes in the San Lorenzo watershed, comparisons with changes in steelhead density
- [Soquel flow](): Analysis of modelled flow changes in the Soquel watershed, comparisons with changes in steelhead density
- [Pajaro flow](): Analysis of modelled flow changes in the Pajaro watershed, comparisons with changes in steelhead density

For each analysis tab, interactive drop-down menus are provided to toggle different options that are appropriate for the analysis. Toggling these options will affect the display of information in the plots and tabular data depending on the selections. This format was used to provide a range of options for viewing the results, particularly for those that required evaluation of thousands of records. As an example, the map below (Fig. 2) shows one of the analysis products that are provided by the website. The map shows changes over time in fish density at each site; large green circles mean increasing density, large red circles mean decreasing density. The different size classes and date ranges shown on the map can be toggled. Most of the analyses on the web site follow this interactive approach.

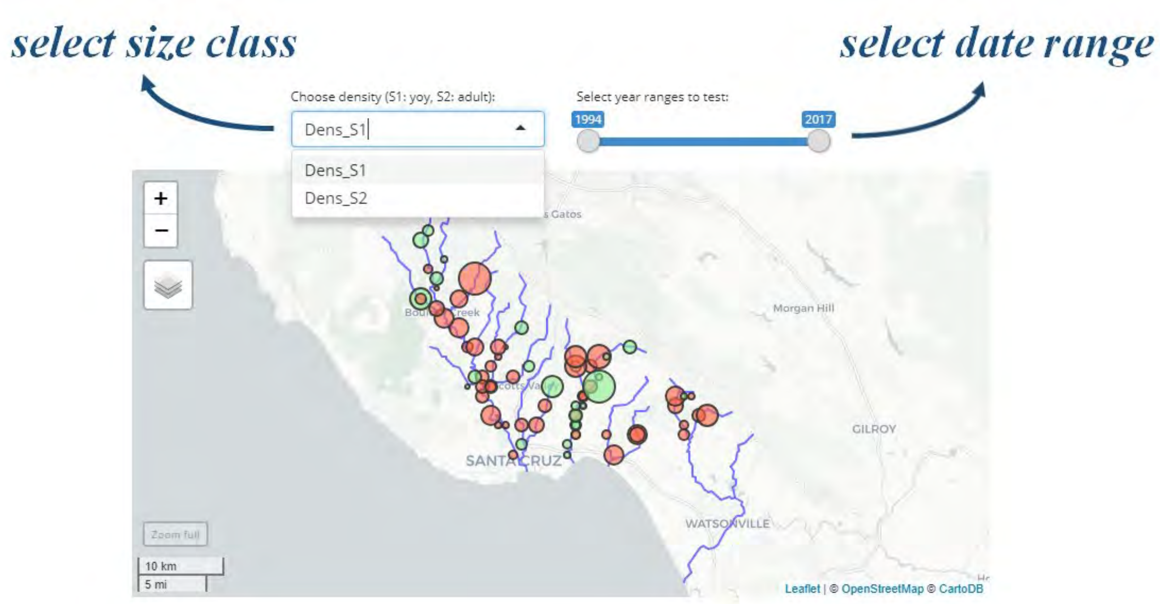

Fig 2. Example of interactive selection of fish and date ranges to map for trend assessment.

STATUS AND TRENDS OF STEELHEAD POPULATIONS

The objective of these analyses was to evaluate the status and trends of steelhead in the four watersheds (note that San Lorenzo is divided into mainstem and tributaries):

- SLR-main: San Lorenzo, mainstem
- SLR-trib: San Lorenzo, tributaries

- SOQ: Soquel
- APT: Aptos
- PAJ: Pajaro

All results can be viewed on the Steelhead status and trends tab. Maps and summary plots on the website showed the changes in density (# fish/100 ft) over time of the different size classes (Dens_S1 or Dens_S2). Trend statistics of the different size classes for aggregated watershed data and by site were also provided. The trend analyses only evaluate an increase or decrease (monotonic change) between selected years.

At any sampling site, the juvenile steelhead are composed of different sizes and ages. For this analysis, the focus is on two size classes, which provides information on both total density and life history characteristics. Size Class 1 (S1) are fish less than 75 mm standard length and are predominantly young-of-the-year fish (hatched in the previous winter or spring). Size Class 2 (S2) are fish that are greater than 75 mm and less than 150 mm standard length and are either fast growing young-of-the-year or yearlings (more than 1 year old). Size Class 3 are greater than 150 mm standard length and can be older juveniles or resident rainbow trout. Since Size Class 3 are less common, they are included with the Size Class 2 densities in the data.

The size classes provide information about the juvenile population that is not captured in total density. Size Class 1 densities indicate areas of successful spawning and spring through summer rearing of young-of-the-year. However, many of the S1 fish will die or are consumed as prey prior to reaching a size sufficient for migration out of the watershed. Size Class 2 reflects the productivity of the stream and where juveniles survive as yearlings. These larger and/or older fish are more likely to successfully migrate out of the watershed and contribute to the adult population.

The plot below (Fig. 3) shows long-term averages of S1 and S2 density across watersheds and time. In general, densities were highest in the San Lorenzo River watershed. S1 individuals had higher densities in the tributaries of the San Lorenzo river. Between watersheds, S2 densities were generally lower than S1.

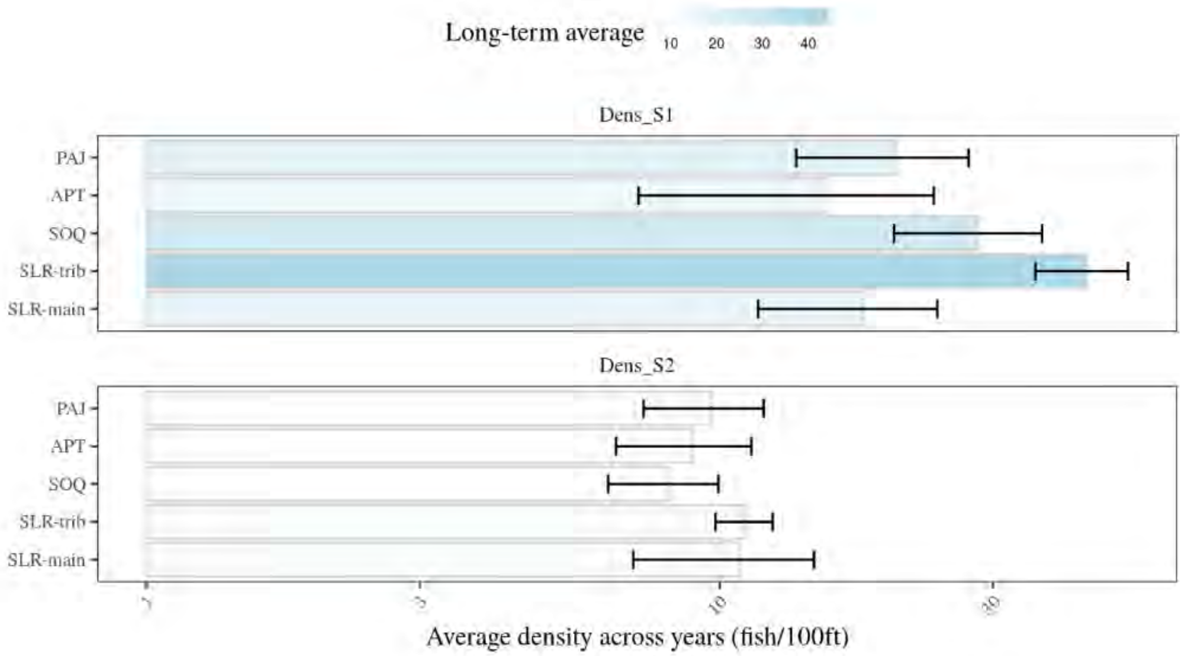

Fig 3. Aggregated steelhead densities by size class (S1 < 75 mm, S2 > 75 mm) across watersheds.

The plot below (Fig. 4) shows long-term averages in each tributary; darker green meaning higher than the average and darker red meaning lower than the average (the actual densities from which the averages were derived can be viewed on the website). Over time, densities across the sampled sites in each watershed and both size classes have been declining since 1994. These results are supported by regression and Kendall tests of the trend anomalies.

Fig 4. Steelhead density changes from long-term averages by size class and watershed.

An evaluation of habitat variables collected at each monitoring site provided some information about how changes in habitat may have contributed to the observed trends (second tab on the website: [Factor associated with trends](#)). However, as noted below under the recommendations, the sampling design for steelhead and habitat variables presented challenges for identifying drivers of change. Regardless, results suggested the following and additional analyses could help discriminate between habitat measures that have contributed to density changes.

1) Station depth measures were the most commonly associated variables with changes in steelhead density (i.e., average depth, maximum depth). These changes may relate to annual changes in flow, as compared to natural variation in depth among sample sites. The direction of density changes with depth was not consistent between locations, habitat types, and size classes, such that both negative and positive associations were observed.

2) Canopy cover was an important habitat variable in the SLR mainstem but not the tributaries for the S1 individuals. This association was observed for riffles and runs, but not pools. However, this association could be alternatively explained by the observed density changes during the period of record independent of canopy cover. Specifically, models that included both the canopy cover variable and year as predictors no longer showed a significant association of density with canopy cover (i.e., long-term trends could have masked the association of density with habitat). Escape cover was also positively associated with S1 densities in the SLR tributaries for some of the models.

3) Percent fines and embeddedness were somewhat important variables for S1 and S2 classes that were negatively associated with densities in the SOQ watershed. Percent fines were positively associated with S1 individuals in the PAJ watershed, but this may have been confounded with annual density changes.

The conclusions above were determined through standard model selection procedures for linear regression to evaluate significant associations between density estimates and habitat variables. The analyses were structured to evaluate only simple bivariate associations (e.g., S1 density vs. canopy cover). For these models, a global model containing year and the selected variable was fit and then further evaluated using stepwise selection to identify the most parsimonious model for the selected variable combination. An interpretation of the regression tables for each model is provided on the website (http://fawda123.github.io/jssh_web/images/model_table_explanations.pdf).

COMMUNITY ANALYSIS

In addition to steelhead densities, data on presence/absence of 40 other aquatic species were also collected at the monitoring sites. These species were identified as follows:

A_goby: arrow goby, **BayPF**: bay pipefish, **Bl_Fg**: bull frog, **Bl_Gill**: bluegill, **Brwn_Tr**: brown turtle, **Ca_Nwt**: California newt, **Ca_Rch**: California roach, **Coho**: coho Salmon, **Cst_Sculp**:

coastrange sculpin, **Dace**: dace, **Gi_Sal**: giant salamander, **Gld_Fish**: goldfish, **Gld_Shin**: golden shiner, **Grn_SF**: green sunfish, **HCH**: hitch, **Lamp**: lamprey, **LM_Bass**: large mouth bass, **MQF**: mosquitofish, **NWT**: newt, **Pac_herr**: Pacific herring, **Pike_Minw**: pike minnow, **Prk_Sculp**: prickly sculpin, **Rd_Fg**: redlegged frog, **Rgh_Nwt**: roughlegged newt, **Rif_Sculp**: riffle sculpin, **Sa_Suck**: Sacramento sucker, **Shin_SP**: shiner species, **Sln_Sal**: slender salamander, **Stag_Scul**: staghorn sculpin, **Sthd**: steelhead, **SthdRT**: rainbow trout, **Stick**: stickleback, **Stp_Mull**: striped mullet, **Str_Flo**: starry flounder, **T_goby**: tidewater goby, **Tp_Smlt**: topsmelt, **Ws_Turt**: western turtle, **YF_goby**: yellowfin goby, **Ywl_Fg**: yellowlegged frog

Analyses of these data provided an assessment of how community structure has changed across time and locations (presented on the Community analysis tab). First, trends for individual species were assessed with plots showing aggregate changes over time by watershed (i.e., percent sites) and with maps showing presence/absence for a selected year or frequency occurrence at a site across selected years. Second, a multivariate analysis was conducted to evaluate combined species data. These analyses used non-metric multidimensional scaling for ordination and hierarchical clustering (Oksanen et al. 2019) to identify groups of species that may have varied through space and time (Figs. 5, 6, 7).

The following conclusions were made:

1) Spatially, community structure varied as a function of longitudinal variation from headwaters to downstream coastal areas of each watershed.

2) Some species were observed only in specific watersheds, e.g., riffle sculpin in the PAJ watershed.

3) Some species were observed only in coastal habitats, e.g., bay pipefish and tidewater goby.

4) Amphibian species were more common in headwaters, e.g., giant salamander, roughlegged newt.

5) Overall, community structure was generally characterized by two to four natural groupings defined by cluster analyses, although results varied between years. These groups were generally not segregated by watershed, although some species were more common in specific watersheds.

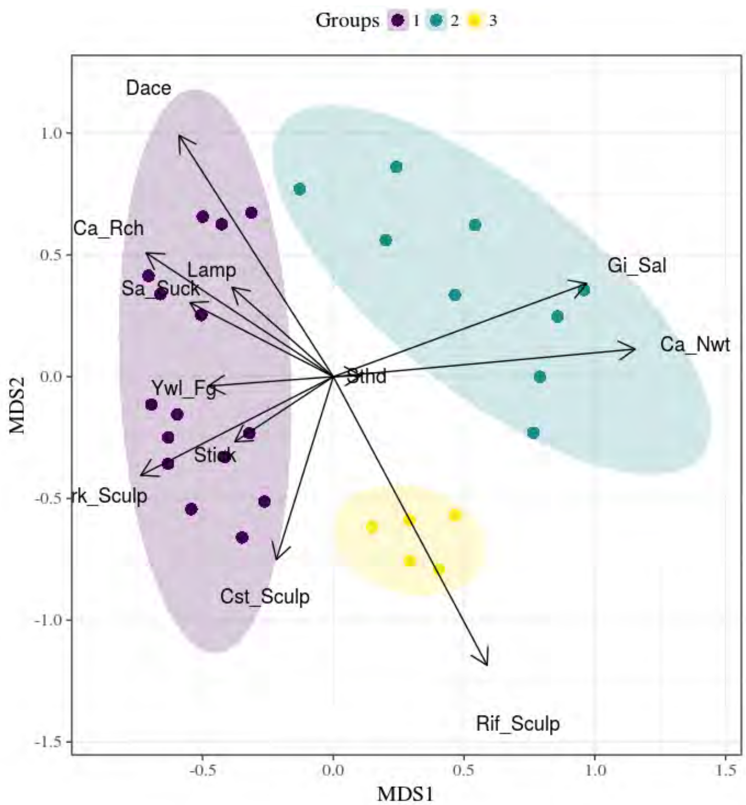

Fig 5. Example of ordination analyses of community presence/absence data for 2011. The groups indicate those identified through cluster analysis.

Fig 6. Example of cluster analyses of community presence/absence data for 2011. The groups indicate those identified through cluster analysis (purple group 1, green group 2, yellow group 3).

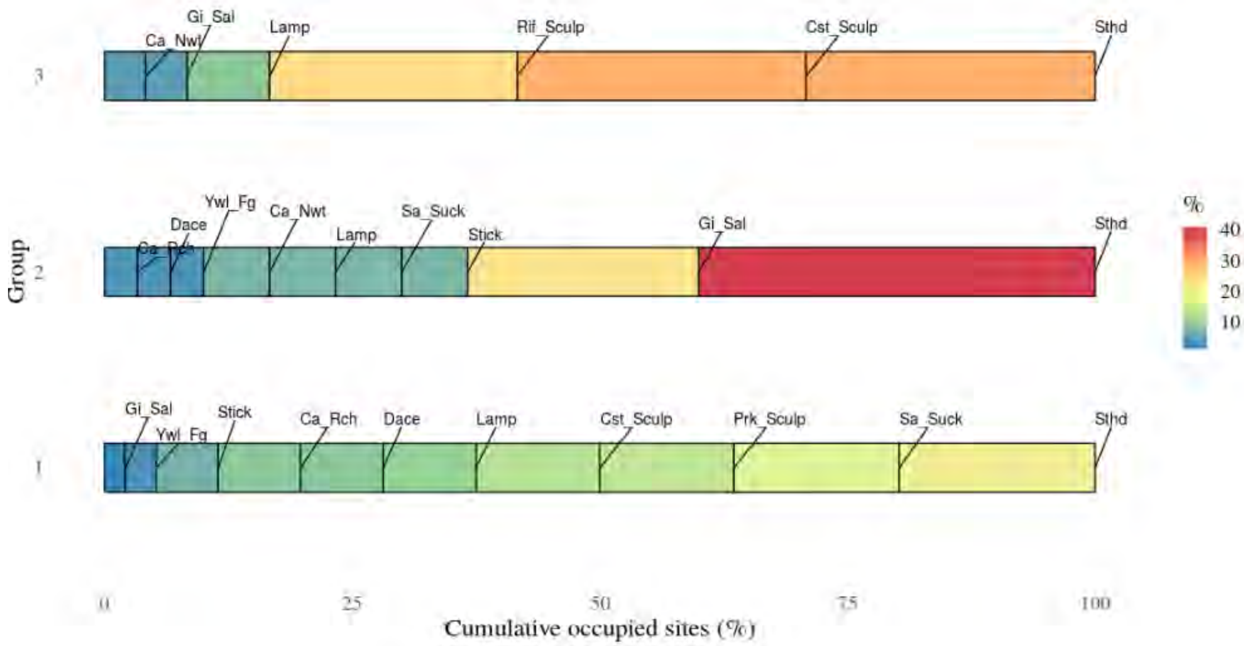

Fig 7. The proportion of sites in a group where a species was observed for 2011 data. This provides a measure of relative abundance based solely on presence/absence data.

The examples above (Figs. 5, 6, 7) show an ordination for 2011 with three groups separated by tributary or headwater species (group 2), coastal or otherwise non-headwater species (group 1), and a group dominated by one species (riffle sculpin, PAJ watershed). The map shows the locations of the 2011 groups. A final tab is provided to view the proportion of sites in each group where the species were observed. This example was selected to demonstrate the general patterns described in the conclusions.

HABITAT ANALYSIS

The habitat analyses were grouped across five sub-tabs on the website:

- Site: Habitat data collected at the same sites where fish were sampled
- Reach: Habitat data collected at approximate 1/2 mile reach segments for all streams
- San Lorenzo flow: Modelled flow data for the San Lorenzo watershed
- Soquel flow: Modelled flow data for the Soquel watershed
- Pajaro flow: Modelled flow data for Pajaro watershed

Site

Habitat information was collected at each site where fish were sampled:

***Can**: Canopy cover (%), **Decid**: Deciduous canopy cover (%), **DpthAvg**: Average depth (ft), **DpthMax**: Maximum depth (ft), **Embed**: Embeddedness (%), **EsCov**: Escape cover (ratio), **Fines**: Fines (%), **Lgth**: Station length (ft), **Wdth**: Station width (ft)*

Each habitat variable was also collected separately in different habitat types defined as **run**, **riffle**, or **pool**. The analyses were structured to evaluate each of the habitat variables separately for each habitat type. Trends were evaluated based on site aggregations within each watershed and at individual sites.

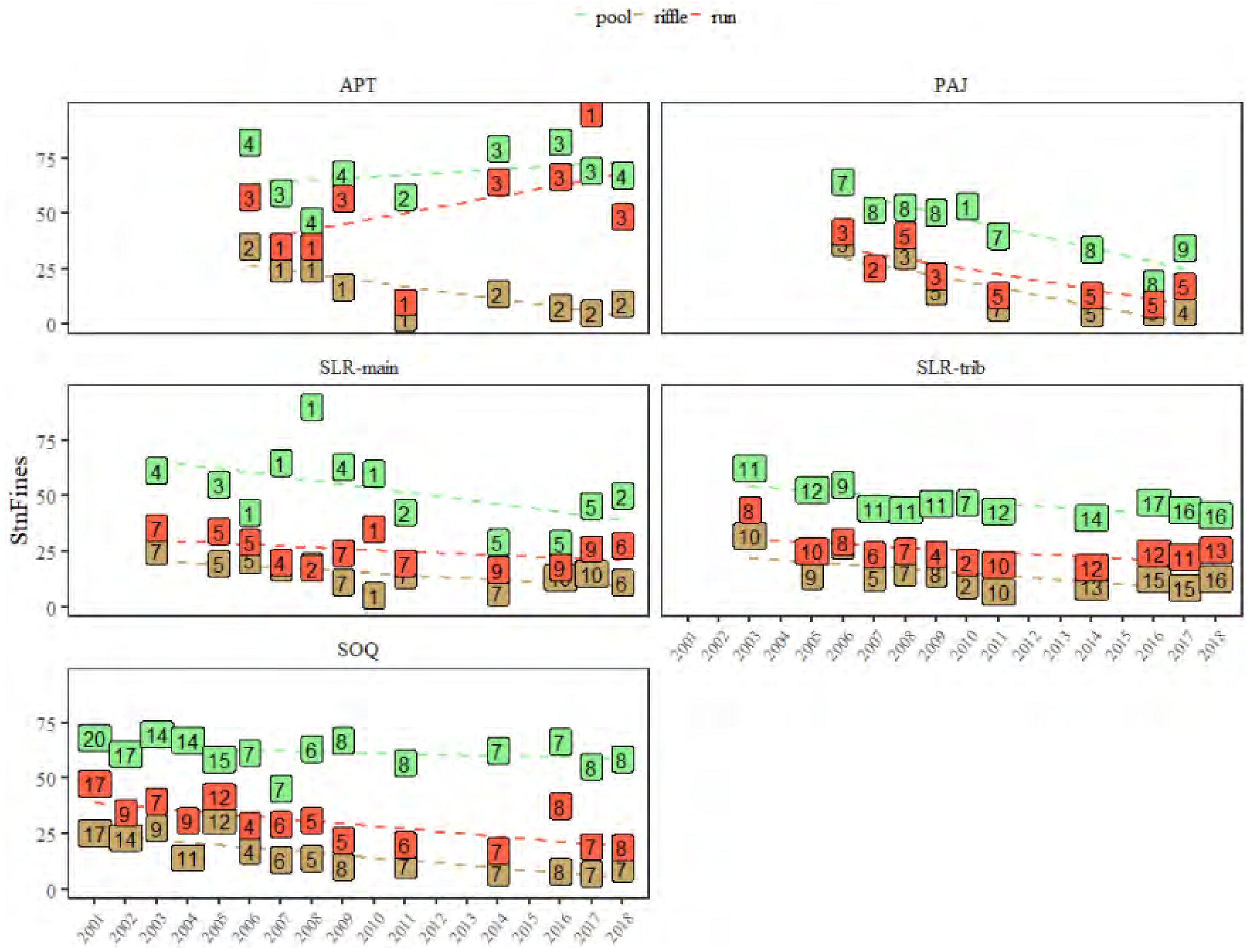

Fig 8. Average % fines across years, by watershed (labels are numbers of averaged sites). Trends are shown separately for different habitat types as pool (green), riffle (brown), or runs (red).

The above plot shows changes of percent fines for aggregated sites within each watershed, separated for different habitat types. The numbers in each point show the number of sites that were averaged for the combined estimate. Some patterns are as expected, e.g., pools have more fines, but variation in effort between years makes comparisons difficult. However, some patterns are shown, such as the overall decrease in fines in the PAJ watershed. These results were partially supported by formal trend tests.

An assessment of trends in habitat variables at individual sites was also difficult. Maps of estimated changes for habitat variables measured in a particular habitat type suggested that changes were observed, but a majority of the estimated effects were insignificant. This result is likely from low sample size at the site-level rather than absence of actual changes, such that trends at an individual site were based on only a few observations (e.g., five years with one observation per year). Figure 9 shows changes in average station depth for pools across the sampling period. Most of these changes were insignificant due to low power of the trend tests.

Fig 9. Relative changes in average station depth for pools from 2001 to 2018. Size of the point shows magnitude of the change with green as increasing and red as decreasing.

As a site-specific example, Figure 10 shows estimated changes in pool, riffle, and run habitats for average station depth at a selected station. Although a negative trend is suggested, the ability to detect the trend was limited by sample size (denoted by "trend ns" in the plot labels). Also note the overall shallow depths in riffles, as expected.

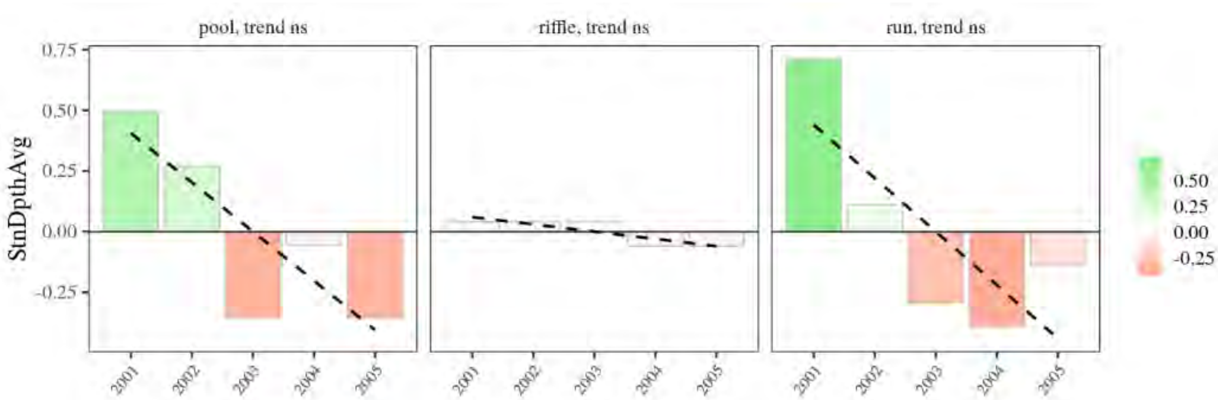

Fig 10. Estimated changes for average station depth for a selected site by habitat type. Bars show changes from the overall mean across years in the same habitat type. Dotted lines are regressions fit through the mean deviations.

Reach

An additional habitat dataset was available that provided information at approximate 1/2 mile intervals along reach segments for each watershed. These data were collected at fixed distances along reaches and are not identified by sites where fish sampling occurred. As such, the data are useful to identify changes at a high spatial resolution along reaches independent of the fisheries data collected at individual sites. Habitat changes over time can also be evaluated for an individual reach. However, comparing results between years was challenging because explicit sample locations were not collected. Data for each reach were identified only by the overall reach designation and the station length.

The reach sub-tab is organized for the evaluation of individual reaches. It is currently not possible to compare habitat results between reaches. The analysis begins by first selecting the watershed, and then selecting the reach to evaluate within the watershed (Fig. 11).

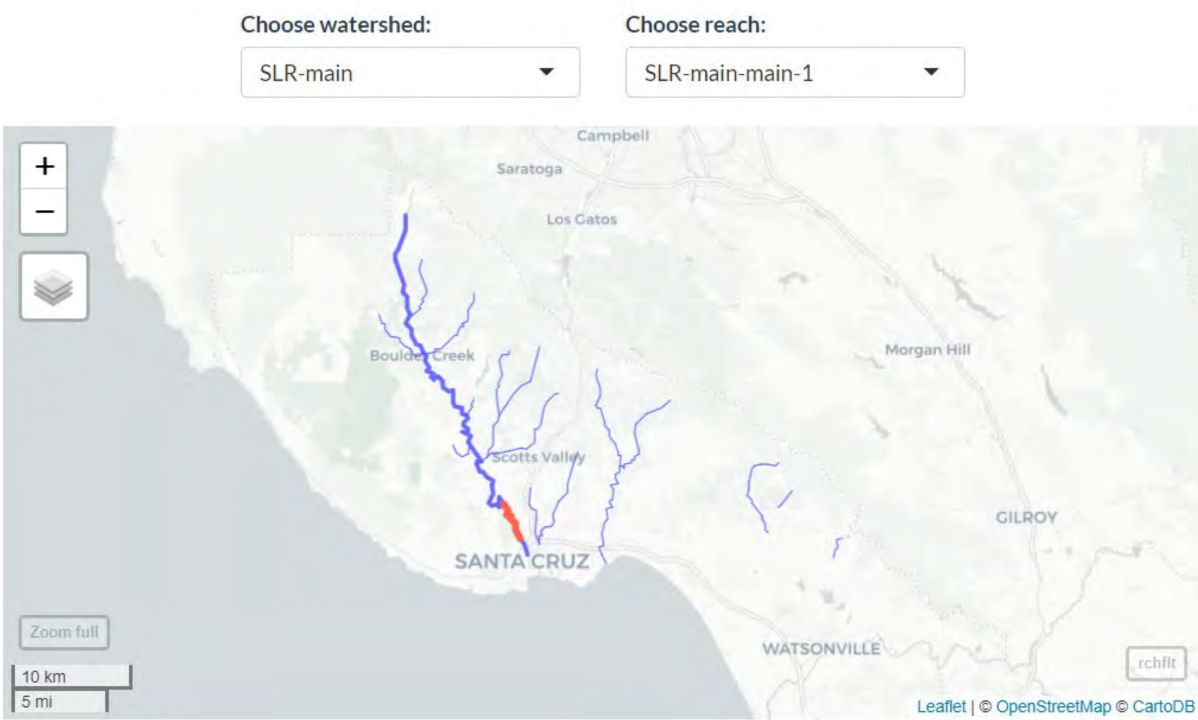

Fig 11. Watershed and reach selection for evaluating reach-level habitat data.

Once the reach is selected, the habitat data can be evaluated. Habitat data sampled at each reach were similar to those collected for the site data, with some additions:

Mean length, Mean width, Mean depth, Max depth, Avg. embedd., Escape cover, % fines, % shade, % deciduous, cover/length, cover/perimeter, wood.

As for the site data, habitat variables were also sampled within habitat types. The habitat types within each reach were organized as nested categories with different specificity. The type 3 classification scheme included **glide**, **pool**, **riffle**, and **run** types, and the type 4 classification scheme included **glide**, **lateral (l.) scour pool - bedrock formed**, **l. scour pool - boulder**

formed, **l. scour pool - root wad enhanced**, **low gradient riffle**, and **run**. The selected habitat variable can be filtered by the chosen habitat types at the relevant scheme.

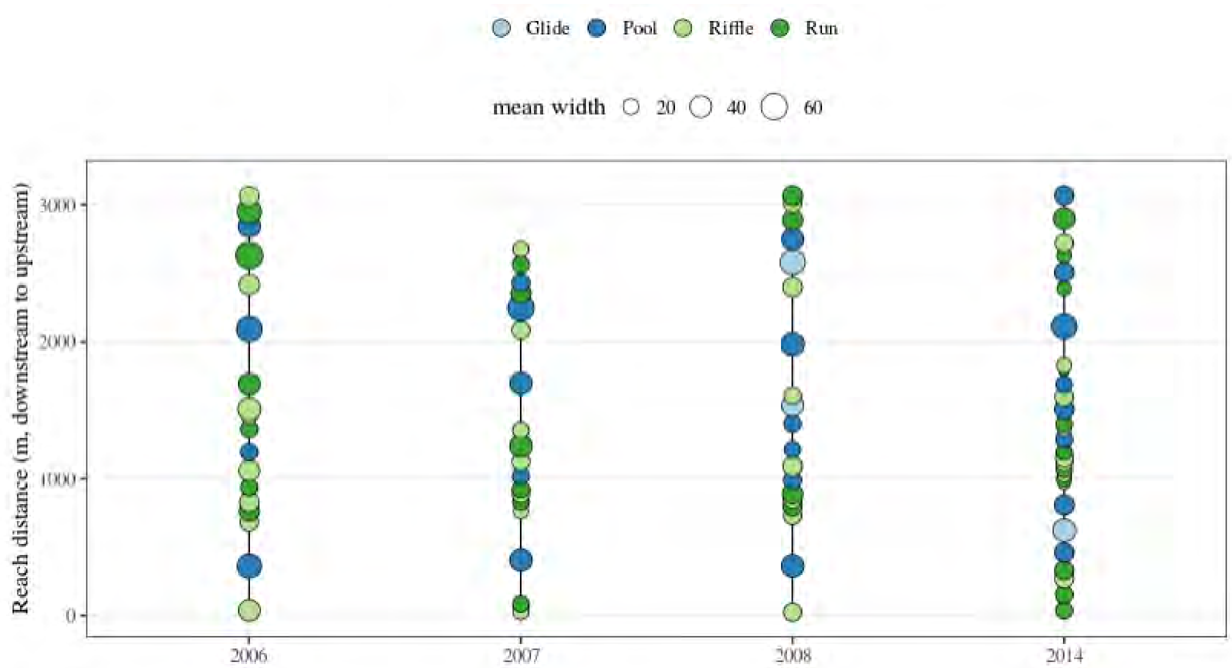

Fig 12. Measured values for percent fines at the beginning (plot bottom) of the reach segment to over 3 km from the beginning (plot top). Points show relative values across segments and between years, with colors showing the habitat types. Location of each point on the vertical lines indicates the approximate center location of the sampled habitat unit. For example, observations with more space between them cover habitat units with greater length along the stream reach than points closer in space.

Figure 12 shows the output for the habitat results given the 1) reach selection (SLR-main-1), 2) habitat type (type 3, glide, pool, riffle, and run), and 3) the habitat variable as % fines (size of points). The plot provides a visual comparison of how % fines changed along the length of the reach (start is bottom of y-axis, end is top of y-axis), as well as how the values may have changed between the years for which sampling occurred.

A second analysis provided a formal hypothesis test to determine if the selected habitat variable differed 1) between habitat types within the same year, or 2) between years within the same habitat type. A selection menu is provided to toggle between the two tests. Figure 13 shows results for the hypothesis that % fines was significantly different between habitat selections (Glide, Pool, Riffle, Run) for the same year (2006, 2007, 2008, 2014) at reach SLR-main-1.

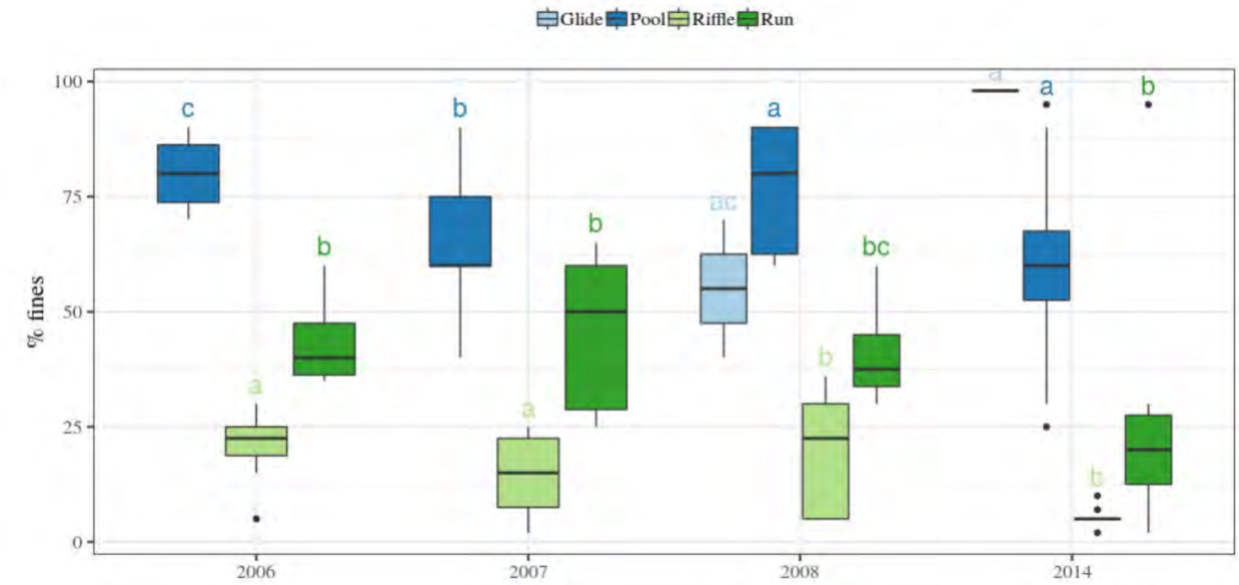

Fig 13. Comparison of % fines between habitat types for the same year.

Boxplots that share the same letter are not statistically different (at alpha = 0.05, p-values corrected for multiple comparisons). The comparison of letters is only relevant for the selected summary statistics from the drop down menu. That is, letters can be only be compared within the same year if “between groups, within years” is selected, or letters can only be compared between years for the same group (habitat type) if “between years, within groups” is selected. Comparisons for boxplots without letters are not shown if the test could not be completed due to sample size.

Because the number of possible comparisons of habitat variables within a reach and across reaches was excessive, identifying overall trends across the watersheds was difficult. As such, the organization of the reach sub-tab was meant to facilitate exploratory analysis for specific locations and variables. It is not possible to provide a synthesis summary across locations with the current format.

Flow analyses

Flow estimates were modelled for select locations in the San Lorenzo, Soquel, and Pajaro watersheds. These included June and September flow estimates from 1997 to 2018. These data provided valuable information to evaluate 1) long-term changes in flow, and 2) if flow was related to changes in steelhead density. Three identical sub-tabs are provided on the website to individually evaluate results for each watershed. Flow changes are evaluated on a site basis in each watershed, whereas comparisons of flow with changes in steelhead density are evaluated by different spatial groupings within each watershed (e.g., mainstem or tributaries, described below).

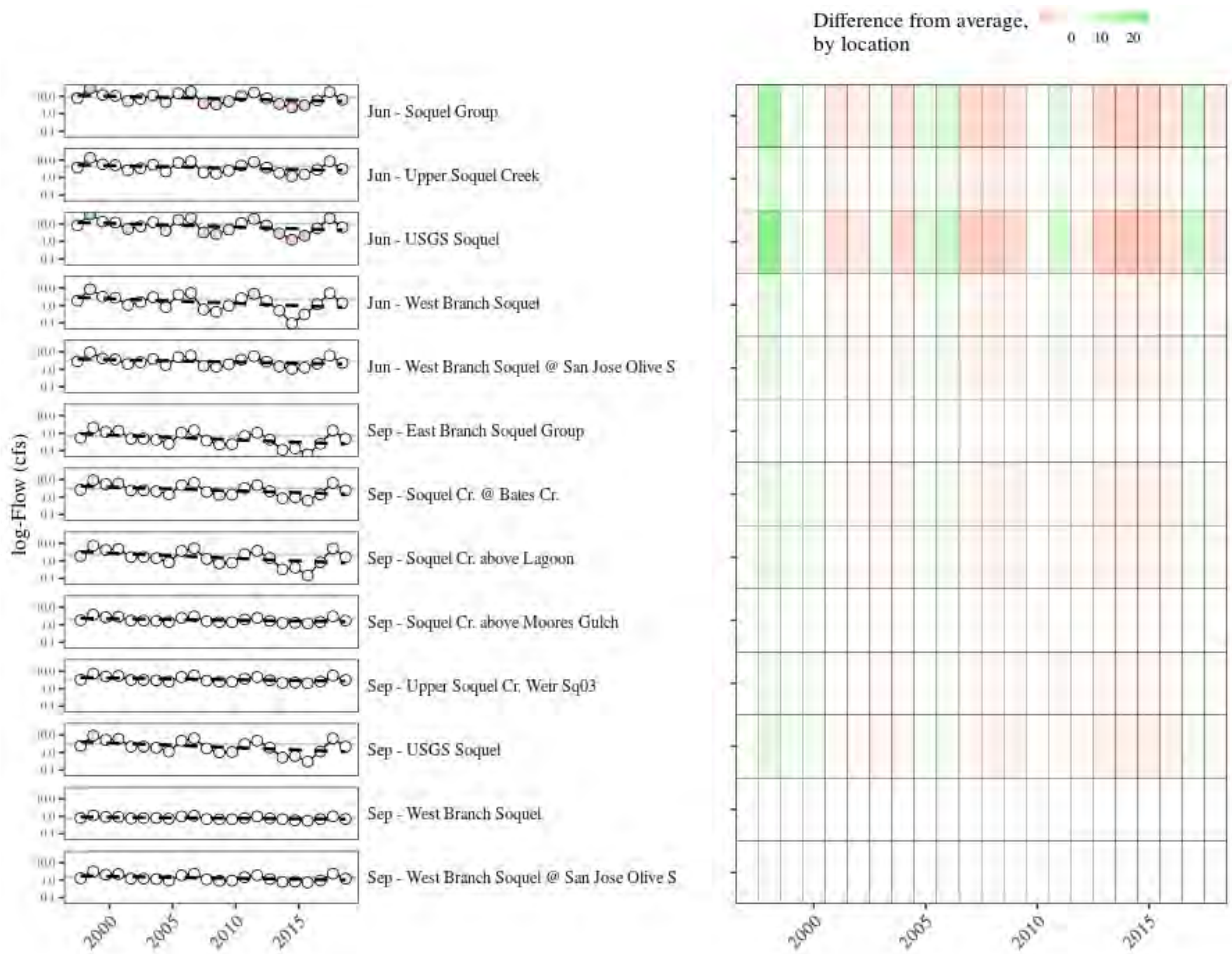

Fig 14. Trends from estimated June and September flow values at selection locations in the Soquel watershed.

Figure 14 shows aggregated flow results for the Soquel watershed. The left plots show individual site trends separated into June and September estimates. The horizontal gray lines in the plots are the individual site averages and the points are the estimates colored by differences from the averages. The dotted lines are regressions for flow over time. The right plot shows the same information as the left plots, but only the deviation of the individual flow estimates from the site-specific averages is shown. In general, flow varies considerably between years, but appears to be decreasing in the Soquel watershed.

Changes in flow at each site, month combination (June or September) were also evaluated with formal trend tests and are summarized in an additional plot (Fig. 15). These results show that eight flow records out of thirteen had significant trends from 1997 to 2018, eight decreasing and zero increasing.

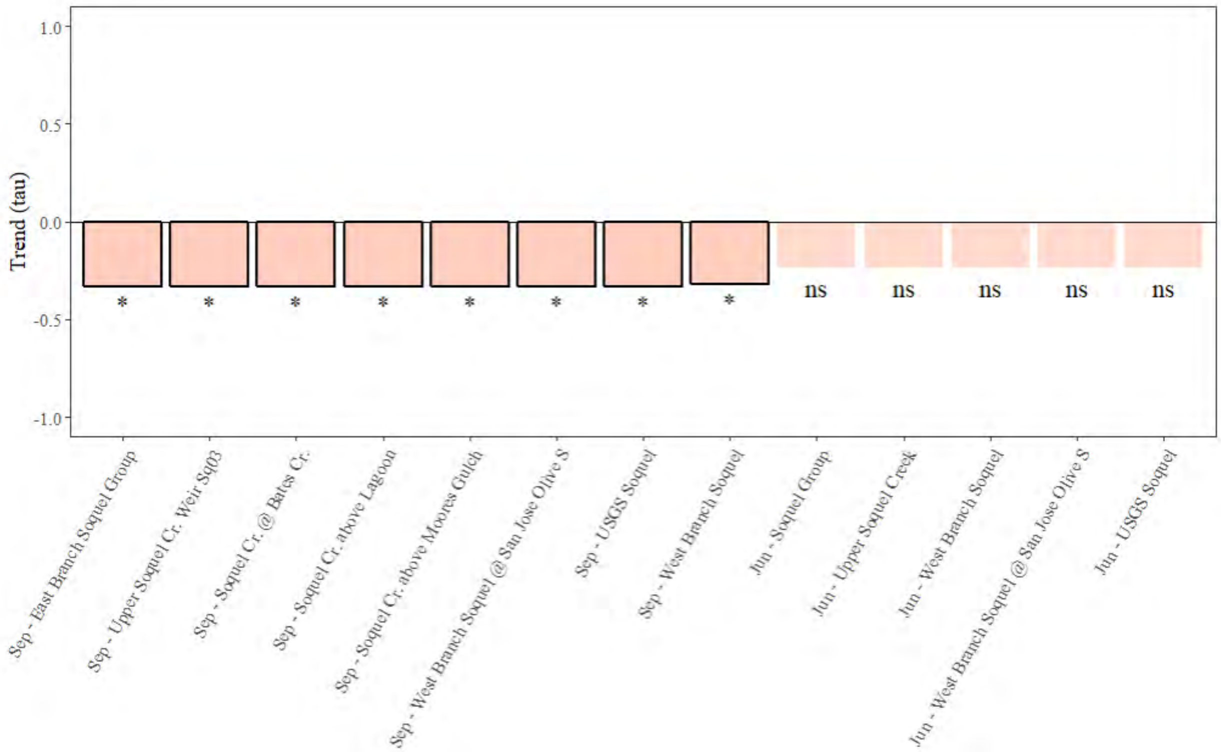

Fig 15. Significance of estimated flow trends across the period of record at sites in the Soquel watershed.

Flow changes were compared with steelhead densities using simple regression analyses to identify associations between the two (Figure 16). Fish sites were spatially matched to locations where flow was estimated and comparisons were made on broad spatial groupings within each watershed. For the San Lorenzo watershed, spatial groupings included mainstem and tributary sites. For the Soquel watershed, spatial groupings included mainstem, East Branch, and West Branch sites. For the Pajaro watershed, only the Corralito sites were considered. For each grouping, results can be evaluated for any combination of groups from one to all together.

In general, flow was significantly associated with steelhead density estimates across the watersheds and by the different size classes. The S1 size class was typically negatively associated with flow, such that densities decreased with an increase in flow. Conversely, the S2 size class was typically positively associated with flow, such that densities increased with an increase in flow. These results were observed in the mainstem of the San Lorenzo and Soquel watersheds and the West Branch of the Soquel watershed (significant associations for all, $p < 0.05$ for linear models between log-density of steelhead and log-flow). Only the S2 size class was significantly associated with flow in the tributary sites of San Lorenzo and East Branch Soquel. Results for Pajaro were inconclusive due to small sample size.

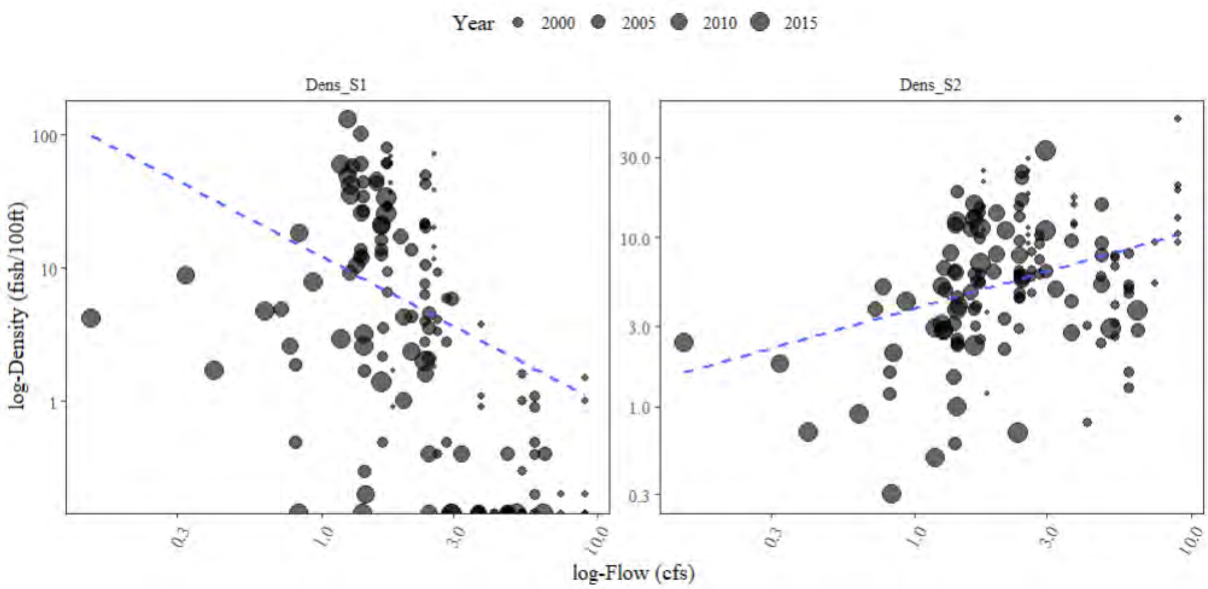

Fig 16. Comparison of steelhead density by size class against flow estimates in the Soquel main branch for September across years. Points are sized by year.

The following conclusions were made:

1) Flow is generally decreasing across the watersheds.
2) The density of S1 individuals has increased with a reduction of flow, whereas S2 individuals have decreased.

RECOMMENDATIONS FOR MONITORING AND ANALYSIS

The following recommendations are made based on information obtained from the website, both from the process of creating the content and evaluation of the website in its current form. These recommendations are provided as general guidance for future monitoring efforts and are not meant to displace methods for the existing monitoring programs. As such, these recommendations should be viewed as general guidance to support the current monitoring program; they are meant to support and serve as a foundation for future work.

1) A probabilistic survey design is needed to allow extrapolation of status and trends data to unsampled locations. The current survey design allows only an evaluation at locations that have been sampled. However, continuity of the existing dataset should be considered such that modifications or additions in monitoring should maintain integrity of the data that are currently available.
2) Habitat factors collected at fish sample sites are difficult to associate with steelhead trends. Steelhead densities are aggregated across habitat types (pool, riffle, runs), whereas habitat measures are retained by habitat types. This confounds the ability to identify which habitat measures in which habitat type are associated with changes in steelhead density because it is not known how densities vary separately within the habitat types.

Retaining density estimates by the habitat type would allow direct comparison to habitat measures.

3) Reach-level data collected at approximate 1/2 mile intervals are a highly valuable description of habitat characteristics, both in space and time. However, comparison between specific locations (e.g., one location across years) was not possible because sample sites were not consistently identified and only relative distances between locations were recorded. Moving forward, site or explicit “river-mile” identifiers should be used to allow comparison of locations between years. A consistent naming convention for the habitat types, especially level 4 classifications, would be helpful.

4) The June and September flow estimates obtained through regression modelling were critical to understanding annual flow variation at different locations in the major watersheds. A primary analysis question was understanding how flow variation was associated with changes in steelhead density. However, flow estimates were based on locations that differed from the fish sample sites and considerable time was spent matching the two for analysis. Moving forward, flow estimates should be modelled at locations that more closely match the fish sample sites.

5) The importance of flow to steelhead densities was clearly demonstrated and should be further evaluated. For the site-level habitat analyses, habitat associations with steelhead trends consistently showed that station depth measurements (max, average) were most strongly associated with density changes relative to other habitat measurements. Similarly, decreasing flow across most sites was consistently associated with changes in steelhead densities. Key differences between size-classes were also observed. S1 densities increased with flow reductions, whereas S2 densities decreased. Higher resolution flow models should be explored to provide finer spatial and temporal coverage of flow estimates at ungauged locations.

The lessons learned from the creation of this website have many important implications for future monitoring efforts of steelhead in the region. Continued collection of data is critical for building a comprehensive evaluation of status and trends, in addition to efforts for compiling and cleaning the data in an appropriate format for inclusion in the website. Future surveys can be included in the website analyses only if the methods used to create the original geodatabase are reproducible and consistent between years. Finally, website maintenance will be a necessary task that ensures the content continues to have relevance for management of this important fishery. Routine updates or additions to the website will be needed to address issues in the underlying analysis code and revisions to the database as corrected, revised, or new data become available.

References

Allaire, J.J., Y. Xie, J. McPherson, J. Luraschi, K. Ushey, A. Atkins, H. Wickham, J. Cheng, and W. Chang. 2018. *Rmarkdown: Dynamic Documents for R*. https://CRAN.R-project.org/package=rmarkdown.

Chang, W., J.Cheng, J.J. Allaire, Y. Xie, and J. McPherson. 2018. *Shiny: Web Application Framework for R*. https://CRAN.R-project.org/package=shiny.

Oksanen, J., F.G. Blanchet, M. Friendly, R. Kindt, P. Legendre, D. McGlinn, P.R. Minchin, R.B. O'Hara, G.L. Simpson, P. Solymos, M.H.H. Stevens, E. Szoecs, H. Wagner, and J. Oksanen. 2019. *Vegan: Community Ecology Package*. https://CRAN.R-project.org/package=vegan.

RDCT (R Development Core Team). 2019. "R: A language and environment for statistical computing, v3.6.0. R Foundation for Statistical Computing, Vienna, Austria."