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Benthic Invertebrate and Deposited Sediment TMDL Guidance for the Pajaro River Watershed

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Uvas Creek in Uvas Canyon County Park

Contents

Executive Summary

The Pajaro River and its tributaries are exposed to sediments from a variety of sources. To establish limits for regulating this pollutant, it is necessary to understand how and where deposition of sediments impact biological health. Benthic, or bottom-dwelling, invertebrates offer a direct way to assess the impacts of deposited sediment on the integrity of stream ecosystems. The channel bed is where sediments accumulate and persist, so benthic macroinvertebrates that live in this habitat provide a responsive indicator of the effect of these sediments. Previous criteria for bedded sediment fines in spawning gravels have been established for salmonids, but these may not be appropriate to all stream segments, are not typically measured in stream assessments, and are confounded by other factors limiting steelhead vitality. Instead, the effects of sediment cover can be evaluated using benthic macroinvertebrates (BMIs) as indicators of stream condition to assess any stream segment and can be related to the bioassessment and stream habitat surveys of the Surface Water Ambient Monitoring Program (SWAMP). The approach taken in this study was to select 25 sites throughout the perennial Pajaro watershed and in the adjacent upper Coyote Creek watershed that represented a cross-section of land uses, above and below reservoirs (unregulated/regulated flows), and in varied geographic settings that would permit examining source area influences on sediment deposition.

Rather than define conventional TMDL estimates for daily loads of sediment, a more relevant survey of the cover of deposited fine and sand (FS) sediments on the stream bed was used here to find the level at which BMIs lost integrity of species composition and diversity. BMI responses were examined at the reach scale (50-meter channel length) and at local patch scales (30x30 cm) of varied FS sediment cover. The data were used to define target levels at which sediment impairs stream bed habitat quality. Reaches of varied sediment cover were compared to conditions at relatively undisturbed reference streams of the Central Coast region to evaluate sediment impacts.

Significant loss of species diversity and altered community type occurred above a sediment cover range of 40% FS at both reach and local-patch scales. In a range of 20-40% FS, BMI diversity declined, showing incipient losses of biological integrity. Richness of mayfly, stonefly and caddisfly taxa richness (EPT) was used as an indicator of biological effects of sediment, and reduced diversity associated with sediment increase corresponded to declines below the criterion 10^{th} percentile of reference site EPT found in other central coast streams. Because of multiple stressors, some streams may not achieve these sediment or EPT targets just by improving the local sediment condition. For example, streams that are regulated (below reservoirs) or in arid regions may be influenced by temperature, dissolved minerals and/or elevated pH, in addition to sediment.

Rankings of streams surveyed were based either on sediment cover within the wetted stream width or the entire bankfull channel profile, accounting for both current habitat conditions and recent environmental exposure. Although the design of this study examined sediment deposition at different spatial scales and used a variety of sediment measures, the results are compatible with habitat and bioassessment surveys using standard SWAMP protocols. Only three to five of the 25 streams surveyed in the Pajaro region showed sediment and diversity levels indicating likely sediment deposition impacts. Results from this study can be used to identify streams where sediment degradation to biological integrity is likely (at >40% FS), and those in a warning range (20-40% FS) that should be flagged for further assessment.

Background and Introduction

The purpose of this project was to examine sediment deposition in streams of the watershed of the Pajaro River and its tributaries and how this affects biological health using benthic macroinvertebrates (BMIs) as indicators. Existing regulatory targets for sediment in the Pajaro River have been suggested based on salmonid habitat requirements (reviewed by Kondolf 2000). The Central Coast Regional Water Quality Control Board adopted a sediment TMDL for the Pajaro and tributaries in 2005 because sediments were identified as impairing cold water, migration and spawning beneficial uses. An objective of this study was to connect ultimate sources of sediment with the amount of deposited sediment in channels as the proximate driver of habitat quality supporting aquatic invertebrate community health (coldwater beneficial use). Sediment sources in the Pajaro have been identified as agriculture, urban and rural development, roads, landslides, hydromodification, channelization, and loss of riparian and natural vegetation cover (CCRWQCB 2005).

Multiple stressors (e.g., pesticides) may confound the influence of sediments, potentially making it difficult to separate this influence in the complex environment of the main stem Pajaro River. However, in independent studies done on the Salinas River, metrics of BMI community integrity showed degraded condition was related more to the physical extent of sedimentation than to the chemical effect of pesticides (Hall et al. 2013). Overall, multiple regression models found that sediment had a more significant effect on community composition and BMI metrics than pesticides. Multiple stressors nonetheless play an important role in impacts to BMI communities and in urban and agricultural settings of the present study we recognize that it is difficult to isolate the effect of sediment alone.

Studies done in the nearby San Lorenzo River and throughout the Central Coast region were conducted in 2007-2009 and serve as a basis for contrasting conditions in the Pajaro to streams identified as least-disturbed reference condition (Herbst et al. 2011). In those studies, encompassing surveys of streams on both the Pacific and interior drainages of the coast range, reference condition was defined for 39 of 84 surveys as ≤10 percent combined human land use, and <3 km/km^2 riparian road density. Conditions of sediment and biological metrics are used here as a frame of reference for impairment in Pajaro streams.

Environmental Setting

Geology of the region is dominated by sedimentary rock and Franciscan sandstone, with some serpentine formations in southern areas. The western portions of the watershed receive more precipitation and have more forest cover (Figure 1), while the eastern and southern areas are drier and have predominately intermittent flows (Figure 2). Stream sampling in the studies reported here surveyed only perennial reaches, although there are areas where flows may be discontinuous in some seasons and years. Sampling in May 2013 occurred during the second year of a drought in the region but in the season when flows are most dependable.

The natural higher erosion rates of the Franciscan sandstone geology of the region often result in braided channels in the lower reaches of streams such as Uvas and Llagas Creeks, but the upper reaches provide habitat for spawning steelhead. Reconstruction work was done in lower reaches of Uvas Creek in 1995 to engineer a sinuous meandering C4 channel type according to the Rosgen system of “natural channel design” but this washed out in high flows of

1996 (Kondolf et al. 2001). Failure of this project suggests that the natural flow and geomorphic setting of this reach were not re-created and thus was not a stable feature of what historically would have been an irregular braided sand-gravel channel. Many of the lower valley segments of the Pajaro watershed streams have been channelized through urban areas, excavated and levees constructed, have increased drainage networks from interception of stormwater runoff over impervious surfaces and sewers, and no longer have a natural flow regime because of impoundments, irregular releases and withdrawals for municipal and irrigation uses. Historical ecology studies of the San Francisco Estuary Institute (www.sfei.org/HE) show that the natural condition of the watersheds of Uvas, Llagas and Coyote Creeks have been modified such that dams and reservoirs change the hydrograph from the classic Mediterranean-type winter-wet, summer-dry pattern to reduced flows in the winter (storage) and higher flows in the summer (release). The lower valley portions of these streams, as well as the San Benito and Pajaro Rivers, had extensive intermittent stretches where flows sank into the alluvium of the valley floor or formed wetland areas where flood flow could spread out and sediments fall out. Irrigation around the turn of the century drained much of the lowland area for agriculture and so removed the source of recharge resulting in lowering of groundwater levels. High winter flows on upstream perennial reaches would have had a scouring influence and transport sediments out of the channels but these flows are attenuated now in regulated streams. Pulsed flow releases from reservoirs could improve habitat quality in many regulated stream reaches as flushing flows would re-suspend and transport sediment, beneficial to aquatic invertebrates, steelhead habitat and riparian growth. The stream segments below the reservoir dams are thus highly modified by agriculture, urbanization, fragmented connectivity to upper watersheds and altered hydrograph, so these form a separate class of stream types in this study, substantiated by biological distinctions (refer to results section, especially Figure 8).

Natural episodes of sediment inputs to streams from storm events have been identified as important sources of sediment impairing stream habitat in the Corralitos Creek drainage (Hecht and Woyshner 1991). Landslides and debris flows on erodible terrain during intense rainfall and flooding can deliver large quantities of sediment. Pool habitats were found to be more prone to sediment filling and retention following a 1982 winter flood, but repeated flooding flushed these sediments. Rider Creek continued to deliver sediment to Corralitos from roads and from construction sites that employed little erosion control. Restoration practices should thus include consideration of flow regime and flood histories, the landscape vulnerability to erosion, and developments such as urbanization, roads and culverts that promote erosion and gullies linked to stream courses. Without curtailed sediment delivery and sufficient flushing flows there may be limited potential for reducing the sediment deposition that impairs benthic stream habitats.

Objectives:

1. Analyze relationships between sources of sediment (owing to disturbance from land uses) and deposited sediment as a factor affecting biological community metrics.
2. Improve on the reach-scale comparison of sediments to BMIs by localizing sampling of sediments and BMIs within the same discrete patches of benthic habitat and develop sediment targets associated with these relationships.

3. Evaluate existing numeric targets and indicate if these targets are exceeded and under what conditions.
4. Evaluate if conditions meeting targets would support healthy salmonid habitat and compare to the alternative sediment targets developed in (2) above.
5. Identify where opportunity for recovery may be limited (such as in regulated stream segments, and where biogeography differs) and may require use of site-specific guidance for control and evaluation of sediment impairment.
6. Provide guidance for using data collected following the SWAMP Standard Operating Procedure for collecting BMI samples and associated physical habitat data to determine if there is a negative effect on the BMI community from fine and sand sediments.
7. Deliver data including lab and field quality control (field sheets and bench sheets) to CEDEN (California Environmental Data Exchange Network).

Methods of Data Collection and Analysis

The approach taken was to select 25 sites throughout the perennial Pajaro watershed and in the adjacent upper Coyote Creek watershed that represented a cross-section of land uses, above and below reservoirs (unregulated/regulated flows), and in varied geographic settings that would permit examining source area influences on sediment deposition. Surveys at each site included BMIs collected from across each reach (reachwide sample method) and from 4 local quadrat-grids (patches of 30 x 30 cm^2 area) of varied sediment cover of fines and sand (FS). Sediment cover is defined here as the percent of the surface area of the active stream bed within the regular high water mark covered by FS (particles smaller than 2 mm). Associated measures of stream bed substrate particle distributions, sediment deposition, and rocks embedded by sediment were also recorded from each study reach. Variations in the level of FS deposition at reach- and patch-scales within the 25 sites in the watershed (and adjacent drainages) produced a data set to identify numeric targets for levels at which sediment impairs stream bed habitat quality. How these FS levels relate to altered benthic macroinvertebrate metrics (diversity, tolerance) was the basis for determining impairment of biological integrity.

The existing Pajaro River TMDL targets include both suspended sediment and streambed characteristics, with the streambed targets based on measures of residual pool volume V* (habitat available to fish, not filled by sediment), median particle size D50 ≥69 mm in spawning gravels, or fines ≤21% if ≤0.85 mm (roughly equal to the F size class) or ≤30% if ≤6 mm (roughly the FS class) in spawning gravels. Reach-scale data from SWAMP stream surveys do not assess any of these attributes (no V* or spawning gravel data are collected), so these targets cannot be derived from standard SWAMP physical habitat surveys. The cover of sediments on the streambed across the survey reach can be determined using SWAMP data, so in this study, this estimate was compared to the TMDL spawning gravel targets as an approximation of habitat quality across the reach. The patch-scale, where clusters of similar substrate size classes (facies) sort and accumulate, was measured using both quadrat grids and maps in this study and so can be compared to the spawning gravel targets as more localized measures of habitat suitability. Spawning gravel targets apply only to streams designated for the "Spawning" beneficial use.

Data collection procedures were the same as those used in similar bioassessment studies of sediment done in the nearby San Lorenzo River watershed so that results were comparable and so that San Lorenzo data could be used for reference targets. The protocols were also similar to SWAMP protocols for stream surveys, as detailed below, but scaled to a reach length of 50 instead of 150 meters.

Sediment and Physical Habitat

Surveys of the physical habitat of the 50-meter reach length of study sites emphasized measures of sediment deposition taken concurrent with benthic invertebrate samples in order to link both habitat and biological response variables to the land use and sediment sources. To evaluate sediment deposition at varied scales we documented sedimentation in the following ways (illustrated in Figure 3):

1. The substrate particle size distribution (intermediate of sieve-axis diameter) within the section was measured in a set of ten transects taken at 5-meter intervals in the 50-m reach. Along each transect were 10 equally-spaced intercept points. This is equivalent to SWAMP except that the entire bankfull channel was used to define transect width and was done at 10-points on ten transects instead of 5 points over eleven transects. At each point we measured depth and substrate size (defined in the SWAMP protocol as having an intermediate axis of particle unless placed in fine <0.06 mm or sand 0.06-2 mm category). As with the SWAMP method, this method permits the calculation of (a) deposited percent fines (F) and sand (S) on the stream bed, and (b) D-50 particle size and cumulative particle distributions. From this we derived cover estimates of substrate composition, an important predictor of impaired condition of benthic invertebrate communities in streams. These measures were expressed both in terms of the entire bankfull channel and just that portion of the channel that contained water (the wetted width, as used in SWAMP protocols) which was generally 60-80 percent of the bankfull width, the other points being dry at the time of sampling. Bankfull was defined according to slope-break features, strand lines of vegetation and water staining and other bank structure features that showed where the most regular high flow conditions occurred within each channel reach. In addition to mineral substrate particle size recorded at each point, we also noted macroalgae, wood, leaf, detritus, roots, moss or aquatic vegetation when present. None of these were used to measure particle sizes of the bed.

2. Grid-frame quadrat counts were taken at 20 locations, alternating combinations of right-center-left positions within the wetted width (1 at top and bottom reach boundaries and 2 at 9 transects inside the reach). Visual counts of the presence/absence of fine or sand particles were made at 25 intersecting grid line points of a 30x30 cm quadrat frame for a total of 500 point-counts per reach (20 frame locations x 25 points/frame). Eleven of these grids corresponded to the macroinvertebrate sample locales, and the other 9 filled the offset sampling array (Figure 3). Grid counts were used to generate high-resolution data on fine particle distribution within the reach segment.

3. Cobble substrate embeddedness (n=25 samples per reach) was estimated as the percent volume of rocks of cobble size (64-250 mm) that were buried by fines and/or sand. This provides a direct measure of the extent to which interstitial microhabitat spaces are occluded by deposited fine and sand material. If cobbles were not available, pebbles (same as coarse gravels, 16-64 mm) were substituted.

4. Stream bed facies maps showing patch distributions over riffles and pools for the 50 m reach. Sediment patches and pool areas covered by fines can be mapped where there are clusters of adjacent particles of similar size class using the point-transect data. Stream bed patches, or facies, were grouped as fine-sand, gravel-pebble, and cobble-boulder (or bedrock). The gravel-pebble facies provide an indicator of potential area available for salmonid spawning (redds). Along with site photos, these facies maps are documented in **Appendix 1**.

In addition to these sediment deposition measures, we also measured the depth profiles across all transects, channel slope at 0-25 and 25-50 meter segments, bankfull channel width at each transect, and temperature, conductivity and pH (Oakton PC10 meter). Photos were taken from the channel center at 0 m upstream, 50 m up and down, and 100 m downstream. Geographic Position System (GPS) coordinates were recorded to provide a georeference point for each study reach. The field data forms used in all surveys can be found in **Appendix 2**.

At each reach transect we measured width across the bankfull profile. The height from the measuring tape to streambed (dry or within the wetted stream) defined the bankfull level (these were leveled to water height at both sides, within 2 cm). Ten measures across each transect were taken at equally spaced points across each transect. For the in-stream locations, the bankfull depth was simply the water depth plus the height at each stream margin. For the dry locations, we simply measured height to tape and also recorded substrate particle size as with stream locations. We used all dry and wet particles to calculate the substrate distribution under bankfull flow conditions. Stream power was calculated as the product of average percent slope of the reach and average bankfull cross section area, and is an estimate of capacity of flow to transport sediment at maximum discharge channel configuration.

Study reaches were not bedrock dominated, but there were cases of bedrock measurements along our substrate transects. In these cases, the substrate measurement was marked as bedrock, and during data analysis it was given the value of the bankfull width divided by 10 (transect point-space interval).

Benthic Invertebrate Sampling

The biological surveys involved collection of 11 collections of benthic macroinvertebrate taken from fixed locations and combined into a single sample, using the SWAMP-standard reach-wide benthos (RWB) protocol over varied habitats within each 50-meter study reach. Quadrat grid-counts (25-point) of substrate size classes (up to cobble size) were also taken at each sampling location prior to the sampling of invertebrates so that total FS associated with the combined sample could be determined. In addition, patch-scale grid-frame samples were taken from stream bed areas selected to represent a mixed range of FS cover (from 0 to 25 quadrat points) using the 30x30 cm grid-frames. After carefully placing the frames and counting F+S, the frame was removed and sample area swept into a D-frame net placed downstream of the grid. Four grid collections were taken at each of the 25 streams, for a total of 100 of these patch-scale samples to enable finer spatial resolution of the effects of sediment deposition.

Geographical Information Systems Analysis

Site Selection

Potential survey sites were identified based on varied levels of land use disturbance that could contribute to sedimentation. The identified sites were ground-truthed for perennial flow, access, and relation to study objectives (relating sediment levels to BMI communities). Prior to sampling in the Pajaro River basin for this study, a Geographical Information Systems (GIS) analysis was performed to pre-screen potential sample sites. The project involved selection of 25 stream sampling sites, covering most all perennial tributaries and portions of the main stem river above the Soap Lake plain. The main Pajaro River below this point is extensively altered by agriculture, channelization and runoff containing nutrients and pesticides. Besides these sections not being wadeable, these were also not sampled because the influence of widespread sedimentation in the main stem cannot easily be isolated from other stressors. The sites selected for surveys were located to encompass a range of land use disturbance conditions that could be linked to potential sediment sources, above and below flow modifications (dams, reservoirs), across the geography of the watershed that held streams with primarily perennial flows, and also in adjacent Coyote Creek watershed and some existing monitoring sites of the Central Coast

Regional Water Quality Control Board (Figure 4a, b and c, showing the project sites and area). Sites discovered to be dry were dropped from consideration, as were sites determined to be unwadeable because they were too deep and unsafe to sample. Additionally, sites that did not have sufficient stream flow were removed from the list of potential sites.

Analysis Scales

A second GIS analysis was conducted after sampling was completed, and focused on a hierarchy of three different nested spatial scales. This was done to determine the relationship between the spatial proximity of landscape disturbance to the condition of the sampled creek or river within the watershed. The usefulness of analyzing hierarchical nesting of watershed spatial scales is reviewed in Allan (2004). The three nested spatial scales used for this study were:

<u>Catchment Scale:</u> Measured as the entire contributing watershed area upstream from the beginning of the sample reach, derived from Digital Elevation Model (DEM) catchment delineations provided within the NHD (National Hydrography Dataset, high resolution 1:24,000 version). NHD is used for mapping and measuring stream networks (metadata: http://nhd.usgs.gov/wbd_metadata.html).

<u>Riparian Buffer Scale:</u> A 100-meter buffer zone on both sides of all contributing upstream stream segments. Stream network data was based on NHD.

<u>Local Contributing One Kilometer Buffer Scale:</u> Measured as the upstream contributing watershed area within a one-kilometer radius of the beginning of the sample reach.

Analysis of Land Use, Land Cover, and Environmental Features

GIS analyses of land use, land cover, and environmental features were performed for each of the twenty-five sample locations in the study. The following data layers were used to represent the landscape disturbance and environmental factors impacting each study site:

Road Density and Crossings

Road density was calculated with data from the 2013 Topologically Integrated Geographic Encoding and Referencing (TIGER) dataset produced by the U.S. Census Bureau. This layer provided a comprehensive and uniform dataset that could be used between counties and across varying land designations. The roads layer was clipped at all three spatial scales, and the total road length at each scale was divided by the area. Road density was calculated as kilometers of road per square kilometer of land. It should be noted that differences in road surface type (e.g., paved versus unpaved) and road size were not included in this analysis. Metadata for the TIGER dataset can be found at http://www.census.gov/geo/maps-data/data/tiger-line.html

The number of road crossings was calculated by the number of intersections between the TIGER road data and the NHD perennial stream layer at each spatial scale. The number of intersections between the two layers was divided by the calculated upstream channel length, and expressed as a density measurement of road crossings per stream kilometer. The crossings were also verified with road maps.

Land Cover

The National Land Cover Dataset (NLCD) 2006, developed by the Multi-Resolution Land Characteristics Consortium, was used to analyze levels of human land use (urbanization as NLCD classes 21, 22, 23, 24; and agriculture as NLCD classes 81, 82), and natural vegetation (forested as NLCD classes 41, 42, 43) within each spatial scale. The dataset was additionally reclassified into broad categories to look at percentages of land use within each catchment. The land cover areas were expressed as a percentage of the total area for each scale. Metadata for the NLCD can be found at http://www.mrlc.gov/nlcd2006.php.

Imperviousness

Imperviousness is a measure of the inability of a landscape to absorb water. Imperviousness is calculated from the same source imagery as the NLCD, but uses a different algorithm and method for assigning pixels to a class of imperviousness. Output data is the percentage of an area that is deemed impervious. Metadata for this layer is found at http://www.mrlc.gov/nlcd2006.php.

Upstream Reservoirs

An index of upstream reservoirs was calculated based on the artificial connectors that bridge stream line segments across lakes and artificial bodies of water in the NHD. The length of the connectors was summed for all artificial reservoirs in the contributing watershed above each sample site. This output was in stream kilometers, calculated only at the catchment scale.

Modified Channel

The NHD dataset distinguishes if a stream channel line segment has been artificially modified. For this calculation, we defined all stream segments designated as an artificial path, canal or ditch, connector, pipeline, underground conduit, or reservoir as a modified channel, and the results were summed for each catchment and expressed as a percentage of the upstream perennial channel length. We validated these designations, where possible, with information from land use maps. This layer was only analyzed at the catchment spatial scale.

Catchment Terrain and Streamflow Statistics

The physical terrain setting and stream flow statistics for each catchment were analyzed with the U.S. Geological Survey (USGS) online StreamStats application. The StreamStats application allows users to obtain state-specific, regression-based stream flow statistics and drainage basin characteristics. The stream flow statistics are estimates of peak flows for the outlet of a catchment, based on a regression of nearby USGS gaged streams. Note that these estimated peak flows do not account for the influence of reservoirs or other human impacts on peak flows. The drainage basin characteristics of the catchment are a series of elevation, slope, and distance metrics calculated from the USGS StreamStats DEM. Metadata for the California state StreamStats application can be found at http://water.usgs.gov/osw/streamstats/california.html

Climate and Soils

Climate data for each catchment was derived from the Parameter-elevation Regression on Independent Slopes Model (PRISM), created by the PRISM Climate Group at Oregon State

University. This was used to estimate annual precipitation and average temperatures for each of the catchments. Metadata for the PRISM data can be found at http://www.prism.oregonstate.edu

Various soil characteristic for each spatial scale were calculated from the Soil Survey Geographic Database (SSURGO), produced by the Natural Resources Conservation Service (NRCS). Measures of soil detachability, rainfall erodibility, and topographic factors were spatially averaged over each spatial scale. Metadata for SSURGO can be found at http://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm

Relation of Sediment Deposition to Land Use

The relationship of developed land uses (as GIS layers of percent area) to sediment cover was initially explored as correlations among differing land uses at 3 spatial scales (catchment, riparian and local as defined above), and the amount of sedimentation. We then used NonMetric Multidimensional Scaling (NMS) ordinations to explore how multiple land use practices were related to sediment deposition expressed as combined measures from surveys at each stream (%FS in bankfull reach, mean %FS on submerged quadrat grids, D50 particle size of bankfull point counts, and % embeddedness of submerged cobbles). NMS is an analytical tool used to visualize the similarities among discrete units of a data set and what factors are related to patterns of unit grouping. All ordinations were conducted using PC ORD 6 (McCune and Mefford 2011; http://www.pcord.com/). Plots show data points (streams) and display groupings according to the amount of sediment deposition and relation to differing land uses and the degree to which these may contribute as potential sources of the sedimentation observed.

Analysis of Macroinvertebrate Metrics and Community Relationship to Sediments

BMI Community Metrics

Measures of community structure used in analysis of RWB and quadrat samples included measures of diversity such as total richness, **EPT** richness (**E**phemeroptera mayflies, **P**lecoptera stoneflies, and **T**richoptera caddisflies are regarded as most sensitive to impaired habitat or water quality), midge family Chironomidae richness, and Shannon index diversity; measures of tolerance such as biotic index (the sum product of taxon tolerance values to pollution and habitat degradation); sensitive species richness (the number of taxa with tolerance values of 0-2), and percent tolerant taxa (those with tolerance values of 7-10); and measures of food web structure (types of food resources used by functional feeding groups). These were examined as responses to percent fines and sand within the bankfull bed and within just the wetted channel at the time of sampling, and as response to FS counts from grid quadrats.

In order to discern the break-point in sediment levels where loss of sensitive EPT taxa became significant, Gabriel comparison interval analysis was applied to EPT diversity from quadrat samples (where FS deposits covered a full range), using an excel calculator template (McDonald 2009). The Gabriel comparison interval allows pairwise comparisons of means (Gabriel 1978). Gabriel comparison intervals show significance where interval bars do not overlap (for alpha=0.05) when compared to the diversity found in quadrats with no FS present. EPT diversity was selected as the metric for evaluating this break-point because it is one of the most reliable indicators of stream health.

Cluster analysis of streams and species

Stream communities are often distinguishable as distinctive assemblages of species, and display of species held in common among different sites serves as a kind of fingerprint of streamgroups. Cluster analysis was performed on taxa from RWB and quadrat samples using PC ORD 6 with Euclidian distance and Ward's group linkage methods (as recommended by McCune and Grace 2002). This permitted grouping of sites by similarity of biological communities, to identify the environmental settings associated with the characteristic species present in these different stream types.

Community similarity ordinations in relation to sediment cover

The effect of FS sediment cover in changing BMI community structure was explored using community similarity ordinations. NMS ordination in PC ORD 6 was used to examine how similarity among quadrat BMI samples diverged relative to the extent of FS deposition. NMS analysis of community composition used the autopilot procedure at medium speed and a Sorensen (Bray-Curtis) distance measure. Rare taxa (occurrence ≤ 5% of sites) were removed from ordination analysis (McCune and Grace 2002). Multi-Response Permutation Procedure (MRPP) analysis was used to assess the significance of differences among the communities of sediment levels grouped in increasing bins of 20% FS cover. MRPP used the Sorenson distance measure and the recommended weighting of groups as n/sum(n). MRPP is used to compare differences among units in an ordination that are grouped by some category – in this case the quadrats with zero FS cover and within increasing 20% bin range intervals (>0-20, >20-40, >40-60, >60-80 and >80-100 percent FS cover).

Indicator species analysis for sediment tolerance

Species that serve as indicators of sediment deposition can be revealed from patterns of association with local quadrat FS cover or with reach-scale FS cover in RWB samples. Indicator species analyses were conducted using PC ORD 6. Analysis of quadrats excluded southern sites (n=20) because these were geographically isolated and influenced by warmer temperatures and high dissolved mineral content. The 80 remaining quadrats from the northern Pajaro region were divided into bins of 0, 0-20, 20-40, 40-60, 60-80, and 80-100% FS cover to search for associations with these levels (corresponding to the 25 grid intersects of 1-5, 6-10, 11-15, 16-20, and 21-25 FS counts). Analysis of RWB data included all streams (n=25), separated into sediment coverages of 0-20, 21-40, and 41-100% FS to partition the range of deposition found at the reach scale.

Results / Findings

Reach Differences and Relation of Land Use and Environment to Sediment Deposition

Increased sediment in stream reaches was related at both the riparian and catchment scales to land use disturbance including urbanization, agriculture, roads, and upstream modified channel, as shown in NMS plots (FS shown according to size of point in Figures 5 and 6). No correlations were found at the local 1 km scale. Urbanization and road density or crossings at both the catchment and riparian corridor scales showed the most correlation (r>0.72) with the amount of FS found at stream sites, along with agriculture, modified channel length, and grassland grazing (Figures 5 and 6). Sediments found within the entire bankfull profiles were used to examine the relation to land use and upstream disturbance, as this expresses all channel sediments derived upstream, transported and deposited, not just those found in the wetted channel at the time of sampling. More FS was found in the bankfull channel than in the wetted channel, showing that deposition occurs on the margins as flows recede. The margins were still habitats that most invertebrates sampled would have been exposed to during their life cycles, especially longer-lived, sensitive species (Figure 7). Reach-scale habitat features and land use attributes are summarized in Tables 1 and 2.

Grouping of Stream Types by BMI Community Composition

A total of 298 taxa were identified from the 25 streams sampled (256 taxa from RWB samples and 279 taxa from quadrats samples). The composition of invertebrate communities of the Pajaro watershed fell into distinct cluster groups according to whether streams had regulated flows below reservoirs and dams, were unregulated above reservoirs, or were located in the arid southern end of the watershed (Figure 8). Using the composition of taxa comprising the quadrat samples, groupings fell into "fingerprints" corresponding for the most part to these stream types. Some species are more common and widely distributed and did not distinguish between stream types. The channel habitat factor most associated with these community differences is the amount of fine sediment in regulated streams compared to unregulated streams (shown in Table 3). Southern area streams were distinguished by their higher temperatures, pH and conductivity, and contained species more tolerant of these arid conditions.

Cluster analysis of community composition from quadrat samples separated sites into these three groups with differing amounts of overlap between groups:

- 42 of 48 unregulated site quadrats separated into the same cluster
- 15 of 20 southern site quadrats separated from all regulated sites
- Each of the quadrats not clustered within the unregulated and southern groups were nested within the regulated group, and 25 of 32 regulated site quadrats came together into 2 sub-clusters

The separation of regulated, unregulated, and southern sites according to community composition does not appear to be associated with sediment alone, but by location and exposure to other stressors. This is better illustrated in the metric scatter plots where regulated sites show reduced richness relative to unregulated sites at the same sediment density.

Relation of Sediment Deposition to Benthic Macroinvertebrates

Across all streams, RWB metrics of benthic invertebrate community integrity declined with increased FS cover from either wetted or bankfull surveys (Figure 9). These graphs show diversity metrics decrease but tolerance increases as sensitive species are lost and tolerant species gained. These relationships were most evident within the unregulated streams, whereas low FS within the other stream groups showed only slightly greater levels of diversity or sensitivity in taxa present. The patch-scale quadrat samples also showed loss of integrity with higher FS cover, but again the quadrats from regulated and southern streams did not exhibit much increase in metric value when low levels of FS were present – for example, having fewer than 10 EPT taxa even at the lowest FS cover levels (Figure 10). Similar metric responses to FS occurred whether deposition was measured over the entire bankfull area or just the wetted area, and best metric condition was typically found in the 0-20% FS range, declining in the 20-40% FS mid-range, and weakest indicators of health above 40% FS.

EPT richness (a common indicator which often has lower metric variability and is comprised of the most sensitive species) was used to compare quadrats with no FS cover to quadrats grouped by increasing intervals of 20% FS cover. A significant decline in condition was shown at the >40-60% range and above (southern streams excluded), based on the Gabriel comparison interval (Figure 11).

Indicator species analysis results for quadrat samples identified only ten taxa as having statistically significant affinities for particular sediment categories (Table 4). In the 0% FS cover category were five EPT taxa, at >0-20% were two orthoclad midges, at 40-60% were two more tolerant Chironominae midges, and at 60-80% FS cover were only ostracods. Maximum densities of these ten taxa were associated with these sediment categories, respectively. RWB sample results identified ten taxa as having significant affinities for only the lowest sediment category of 0-20% FS, including five EPT taxa, two riffle beetle taxa, two midge taxa, and one water penny (Table 5).

The composition of functional feeding groups (or guilds) relative to sediment levels among quadrat samples (Figure 12) showed collectors (both gatherers and filterers) in greatest abundance at intermediate FS levels (40-80%), and declining again within the highest sediment bin (80-100%). This density increase of these feeding guilds at intermediate sediment levels was mostly comprised of midges (*Tanytarsus, Parakiefferiella, Micropsectra, Microtendipes, Corynoneura*).

Ordination bi-plots of NMS analysis for all RWB samples (n=25) showed a similar separation of streams to that of the cluster analysis (Figure 13). Most of the separation occurs along axis 1, with southern streams associated with vectors of higher temperatures and conductivity, and regulated streams associated with percent FS in the channel. Removing the isolated southern stream group, the ordination bi-plot of NMS analysis for RWB samples (n=20) showed a complete separation of regulated and unregulated streams along axis 1 (Figure 14a). Regulated streams were associated with lower stream power and higher bankfull fines and temperature. The association with greater levels of fines in regulated streams was seen whether measured in just the wetted channel or in the whole bankfull channel. When fines and sand were analyzed separately within the wetted channel, influence of fines dominated the regulated stream grouping, while unregulated streams had higher power and more sand content (Figure 14b and Table 3). These RWB samples surprisingly showed better correlations with the reach-scale measures of FS (100 point transects) than with the quadrat-based measures of FS taken at the RWB sample locales. For this reason, the ordinations used the reach FS measures.

Ordinations of quadrat samples also showed samples grouped by stream type (Figure 15). The species assemblages of regulated stream quadrats were related to fine sediments, those from unregulated streams related to stream power and riparian cover, southern samples to temperature.

Quadrats from both regulated and unregulated streams were separated along ordination axis 2 by combined FS cover (Figure 16). Even though quadrat samples clustered according to stream type, within and across quadrat samples there was significant separation related to the amount of FS sediment cover (Figure 17). When quadrats were grouped by increasing 20% FS interval levels, a shift was seen along ordination axis 2, and MRPP analysis of significant community divergence showed that the shift occurred between quadrats at 0-20% FS and all other quadrats with FS cover higher than that. Environmental vectors showed both FS and warmer temperature accounted for increased dissimilarity. This threshold represents a breakpoint or transition for altered species composition resulting from sediment deposition on local patch-scale habitats.

Habitats & Species of Special Interest or Concern

There were some sites that were notable for rare species or unusual assemblages of invertebrates. The upper site on Coyote Creek above the reservoir appears to have flow influenced by groundwater/spring sources and was inhabited by the California floater mussel (*Anodonta californiensis*), the isopod *Calasellus californicus*, an uncommon microcaddisfly (*Ithytrichia sp.)*, and the riffle beetle *Dubiraphia sp.* The upper sites on Uvas and Swanson Creeks also showed groundwater-associated amphipods of the genus *Stygobromus*. Below Coyote Reservoir there was an abundance of filter feeders, as often occurs below such water bodies, including net-spinning caddis (*Hydropsyche sp.*), black flies (*Simulium vittatum*), dense colonies of freshwater sponges (Spongillidae), and the introduced lesser asiatic clam *Corbicula fluminea*. Clear Creek and its confluence with the San Benito River was inhabited by desert stream invertebrate types including the predatory Belostomatids (*Abedus indentatus*), Naucorids (*Ambrysus californicus*), the damselfly *Argia pulla*, the Psychomyiid caddisfly *Tinodes sp.*, a variety of aquatic beetles, and an abundance of thermal tolerant *Gumaga sp.* caddisflies. Los Alamitos Creek below Almaden Reservoir held low densities of the invasive New Zealand mud snail *Potamopyrgus antipodarum*. The lowest site on Coyote Creek (end of Burnet Road) was also of interest in that it held species of freshwater amphipod (*Americorophium spinicorne*) and isopod (*Gnorimosphaeroma sp.*) that are often found in coastal rivers and streams and can occur in estuarine or marine environments.

Discussion, Conclusions and Recommendations

Compared to the quadrats without any FS cover (0%), the combined response among both regulated and unregulated streams showed that above 40% FS there was a significant loss of EPT taxa (Figure 11; Gabriel comparison intervals). Therefore, we recommend setting the sediment target for support of ecological integrity at <40% FS. This may be achievable only in unregulated stream types given the other stressors contributing to degradation in regulated streams. The ordination analysis of local-scale quadrats (Figure 17) showed that the FS deposition resulted in a separation of communities that grouped at the lowest levels (zero cover and 0-20% cover), and at all levels higher than this (>20-40, >40-60, >60-80, and >80-100%). This suggests that above 20% FS cover there is a break in community structure to an altered species composition, with loss of sensitive taxa and increase in tolerant taxa. Taken together, these results suggest that within the range of 20-40% there is an alteration of community composition that could be taken as cautionary level of impaired structure/function, and that above 40% results in significant loss of the most sensitive EPT taxa group and indicates impaired condition. In the intermediate range of 40-80% FS there is also a shift in trophic dominance of collectors, gathering and filtering fine particles, that is made up primarily of midges (Figure 12). This may be a food or habitat subsidy under conditions that are tolerable, but then midges decline again at the highest 80-100% FS range with further stress.

In regulated streams, the reachwide and local patch samples with low FS counts were not accompanied by increased biological diversity, suggesting little influence across the range of FS coverage in these settings (Figures 10 and 18). In the surroundings of these streams, higher levels of sediment cover combine with other stressors such as modified and diminished flows, urban and agricultural chemical pollutants and nutrients, and collectively suppress biological diversity. Under these conditions there is not much potential for improved biological integrity by reduction in sediment levels alone in local areas. The unregulated streams better represent the natural biological potential where lower FS levels allow for greater diversity. Apparently, other factors restrict recovery of habitat quality in regulated streams. Flushing of sediments with pulsed releases from reservoirs could improve the overall ambient conditions and also dilute chemical pollutants, so when available, discharge of high winter flows, rather than storage, could help reduce sediment levels in regulated streams. It may be most appropriate to simply manage for reduction of deposited sediment load (especially fines) in regulated streams and not set specific sediment targets. Fine sediment sources and deposition appear to be the primary sediment problem in the lower reach regulated streams where more erosion sources exist and less stream transport power is available. In contrast, unregulated streams had lower fine cover but more sand, and benefit from having greater power and less input of fine sediment erosion (lower sediment supply, more export capacity).

Geographic variability in biological composition of stream communities and multiple stressors in some situations make it difficult to compare streams and assign uniform standards for how sediments alone affect their health. The analysis of stream communities presented here showed that streams of the Pajaro River region partitioned into distinctive groups as regulated, unregulated, and southern area types. Setting allowable limits may not be useful for all stream types and regions where other factors can be limiting.

In the case of the southern stream group (Clear Creek and San Benito River), sediment levels in the reaches were higher (Tables 6 and 7) but temperature and conductivity were also higher in these arid streams and some reaches are within segments that become intermittent or discontinuous. The distinctive community assemblages of these streams have more affinity with desert streams and were generally comprised of fewer species. Reduced FS cover in quadrat patches showed slight increases in metrics in the southern streams (Figure 9), so even though there are other natural factors that restrict these discrete communities, control of sediment could still benefit habitat quality. One of the unusual land use features of the southern Clear Creek drainage, associated with serpentine soils, was asbestos mining. Fibrous asbestos substrata were found in many samples but appeared to have no relation to sediment deposition.

Evaluating Sediment TMDL Targets for the Pajaro River Watershed

Using the data gathered in this study, sediment deposition in Pajaro stream habitats can be summarized in relation to Central Coast reference streams, steelhead TMDL targets, and benthic macroinvertebrate indicators of degradation. Physical habitat data for these streams is summarized in Table 1. For context, reference streams of the San Lorenzo River watershed and a variety of other central coast streams (Herbst et al. 2011), defined as least disturbed (<3 km/km^2 riparian roads, and ≤10% combined human land use cover), can be used to set expectations at the 75th and 90th percentiles for total percent FS cover in these streams – 35.5% and 42% respectively. Using these reference streams as standards, streams found to exceed the 35.5% FS level might be considered a warning level for concern, and if >42% FS, there may be a need to consider sites for 303(d) listing (or designate as impaired biological conditions) and to re-visit and confirm degradation of both physical and biological conditions at the site(s). The 40% FS biological response threshold found in the Pajaro stream studies is close to the 42% FS among regional reference streams, lending further support to this criterion level. Surveys of the Pajaro watershed streams for percent FS within the wetted channel showed that two streams fell into this reference warning range and three streams exceeded the level for an impairment listing (Table 6). If percent FS within the bankfull channel are used, twice the number of streams would be classified this way, with four streams in the warning range and six streams exceeding the impaired level (Table 7). This underscores the importance of repeat surveys in different years and flow conditions, where percent FS cover varies over the cross-section profile of streams. It must be pointed out that standard SWAMP protocols include sampling at two of five transect points on the edge of the water-land interface (edge of water left and right), so this sampling approach also includes points that are not within the submerged stream environment. When the edge points are on the bank rather than channel bed, these are often scored as fines or sand soils, so percent FS on the bed may be overestimated in these instances. Sediment surveys should recognize these sources of variability and account for how deposition can vary in space and time so that assessments of habitat degradation are accurate and regulatory designations are dependable.

For biological metrics indicating healthy streams, coming again from the central coast and San Lorenzo reference streams, the 10th and 25th percentiles for EPT richness was found to be 11.6 and 16.5 taxa. If less than the lower of these two values (the 10th percentile of references), stream sites again might be considered for impaired listing because this indicates depleted diversity. Note again that this is consistent with the biological response threshold seen from quadrats showing <12 EPT when FS is >40% (Figure 10). Table 8 shows streams in the Pajaro and Coyote Creek watersheds where these biological indicators are not met and should be considered for listing (red), or are within the warning level range (yellow). This table also shows bankfull or wetted FS sediment cover according to warning (20-40%, yellow) and impaired (>40%, red) biological effect levels. This approach to assessing conditions shows that all eight regulated streams fall below the EPT metric targets, and that five of these also have wetted channel FS exceeding at least 20%. In contrast, five of 12 unregulated streams were in a warning range of 12-16 EPT, and three of these had wetted channel FS at or above 20%. All southern streams do not meet EPT diversity reference expectations. That said, it has been noted that regulated and southern streams have other limiting stressors and natural constraints on biological diversity, so improving conditions at these sites, where sediment degradation is also indicated (above the 20-40% FS levels), may require setting targets that include addressing other sources of pollution or disturbance impacts. To simplify and minimize redundant data only the EPT diversity measure was used here as a screening tool. To evaluate sediment effects, this metric is considered adequate because it is typically among the most consistent indicators of stream biological integrity (Karr and Chu 1999). Interpreting RWB data from SWAMP sampling in the Pajaro region, and consistent with results from nearby watershed (San Lorenzo, others), samples would be expected to have EPT diversity of more than 16 and with FS less than 20% to be considered supporting of biological and physical integrity (Table 10). Streams that are below reservoirs or constrained by other natural factors (the southern streams) may not reach these levels, so guidance here may simply seek to reduce FS and enhance diversity with more modest expectations for improvements.

At the unregulated streams where biodiversity targets are not met, linkage to sediment effects must take into account the state of deposition in these habitats. At Bodfish Creek (both sites), EPT richness was in the warning range and sediments were 29 and 41% FS. At Pescadero (North), Llagas (below Oak Glen) and Corralitos Creek (above Browns Valley Road), where again EPT diversity was in the warning range, none had wetted channel FS greater than 20% cover. For all three of these sites, however, the bankfull sediments were in the warning range, at 29-36% FS. Only where FS is observed to be above impact levels can this be identified as a likely source of degraded biological integrity, but this may include exposure to sediments under higher stream levels as suggested by the greater amount of FS in the bankfull profile, leaving a legacy effect on benthic invertebrates. Where both EPT are reduced below 12 and FS cover is above 40%, conditions can be used as a determinant of where habitat improvements are needed most. Needed habitat improvements, whether they be control of sediment sources or removal of deposition, can be informed by where sediment occurs in the channel and the degree of degradation. Flushing sediments under high flows may remove previous accumulated deposits, but control of sources may be more effective where streams have low power or have high levels of deposition across all flow profiles. Examining deposition across the bankfull profile can be informative for relating land use effects to sediment levels because the sediment present in the bankfull channel represents the net influence of sources of sediment and the amount deposited in a reach that is not exported by the power of flow at bankfull.

Sediment TMDL targets for the Pajaro River for steelhead habitat have previously been set at ≤21% F (fines) and ≤30% FS (fines and sand) cover and median particle diameter (D50) ≥69 mm in spawning gravels. We found that for reach-scale measures of bankfull sediment F, the target was exceeded in nine streams, for measures of FS the target was exceeded in 12 streams, and for D50<69 mm, the target was exceeded at all sites except Little Arthur Creek (Table 7). For the wetted channel, F was exceeded in just three cases and FS in six cases (Table 6). Steelhead targets are difficult to use because they apply just to spawning gravels (not assessed by the SWAMP physical habitat protocol), may not be relevant if fish cannot access areas above dams (migration-limited), and do not address the actual availability of spawning gravels. The facies maps constructed for these bankfull surveys do, however, show the areas of gravel-pebble clusters that could serve as suitable spawning habitat (Appendix 1, and Table 7).

Even where spawning gravels are abundant, there may be other factors limiting steelhead recruitment and survival. Indeed, the southern streams of the region are not even designated as supporting cold water or spawning beneficial uses.

Above 40% FS cover over the entire reach, benthic macroinvertebrate metrics from reachwide benthos samples showed pronounced limitations for total taxa richness, EPT, sensitive taxa richness and percent EPT, and rising percent tolerant taxa (Figure 9). Along with this indication of sediment effects across the reach-scale, the local patch-scale quadrats were used to evaluate the full range of sediment from zero to 100% cover. Contrasting the quadrats with no FS cover to quadrats of increased ranges of sediment cover, there was a significant loss of EPT richness above 40% FS cover (at the Gabriel comparison interval boundary, Figure 11). EPT richness was used to evaluate this effect level for the sake of simplicity and because it is regarded as a reliable indicator of degraded biological integrity. This 40% FS level is consistent with that observed in extensive studies of sediment in patch-scale samples on Central Coast and Sierra Nevada streams (Herbst et al. 2011; summary report Figure 13). Quadrat data was also evaluated for the level of sediment where overall community structure began to change: this occurred above 20% FS (Figure 17). Quadrats with cover above 40% FS were in most cases outside the 95% CI of zero FS cover quadrats (Figure 17). Using these 20/40% limits as warning and impairment levels, the distribution of Pajaro region streams according to reference targets for EPT richness and FS cover effect levels can be shown (Figure 18). Applying the "impaired" EPT richness of 11.6 (rounded to 12) from reference streams (10^{th} percentile of regional references) to unregulated streams, only 22% of quadrats with <20% FS had less than 12 EPT, 55% of quadrats with 20-40% FS had <12 EPT, and 73% of quadrats above 40% FS had <12 EPT (Figure 10). This graded loss of diversity supports these sediment levels as guidance for setting targets that support reference-level aquatic life use (Figure 19, Table 10).

To compile and interpret existing or new data from SWAMP habitat and bioassessment surveys, the following procedure can be used:

- From the SWAMP physical habitat data calculate the percent fines and sand (sum of percent sand (0.06 mm-2mm) and percent fines (<0.06mm)).
- From the SWAMP 500 count taxa list, calculate EPT richness (number of EPT taxa).
- Compare percent FS to the EPT richness and use Table 10 to assign a determination of whether impaired condition from sediment is likely.

Using the EPT richness and sediment percent fines and sands as outlined above is simpler to apply (uses fewer criteria) and supersedes the larger table created for earlier studies of San Lorenzo River and Central Coast region streams (in Herbst et al 2011).

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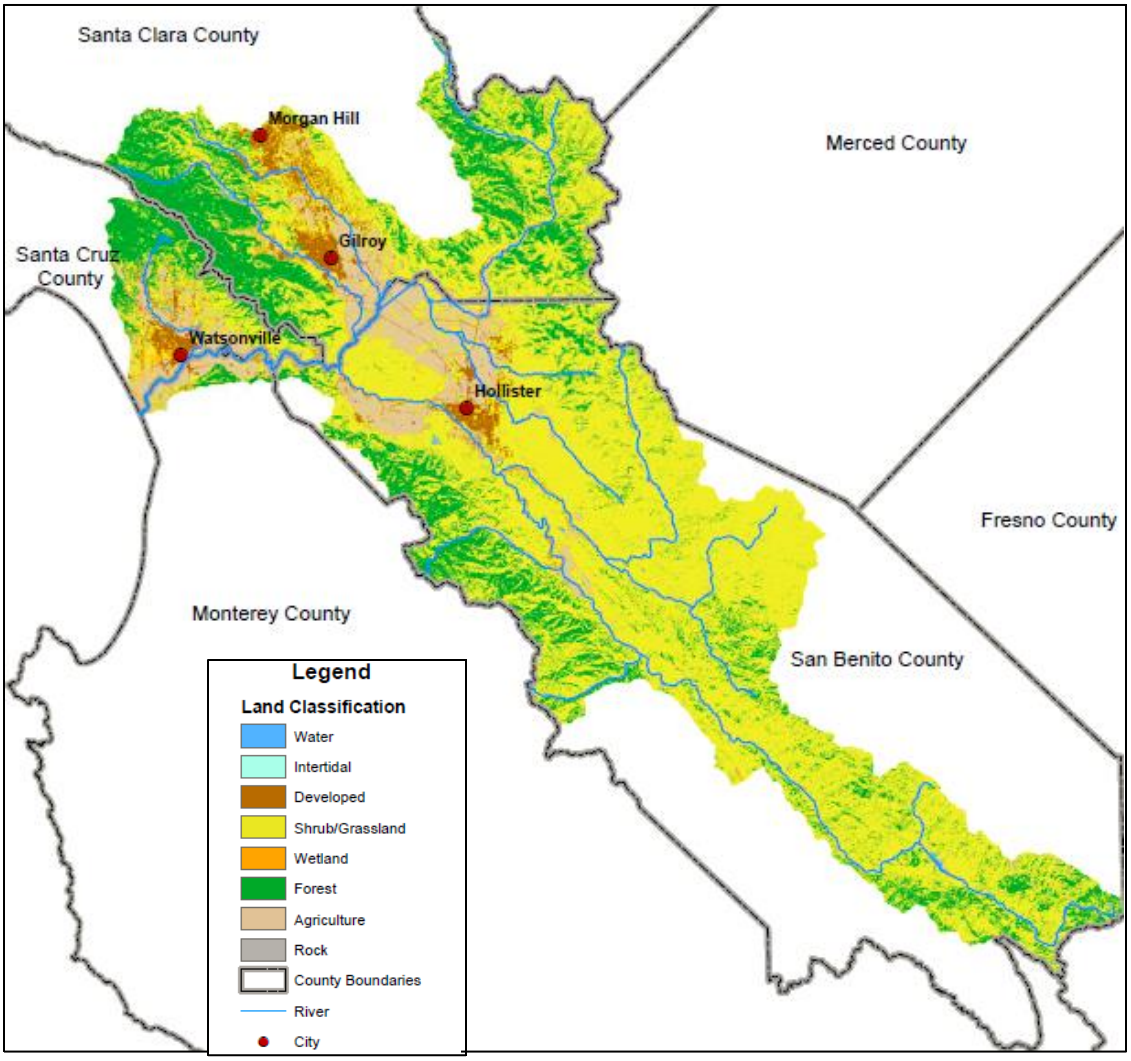


Figure 1. Landscape classification of the Pajaro watershed (from RMC Water & Environment, Pajaro River Watershed Integrated Regional Water Management Plan 2007)

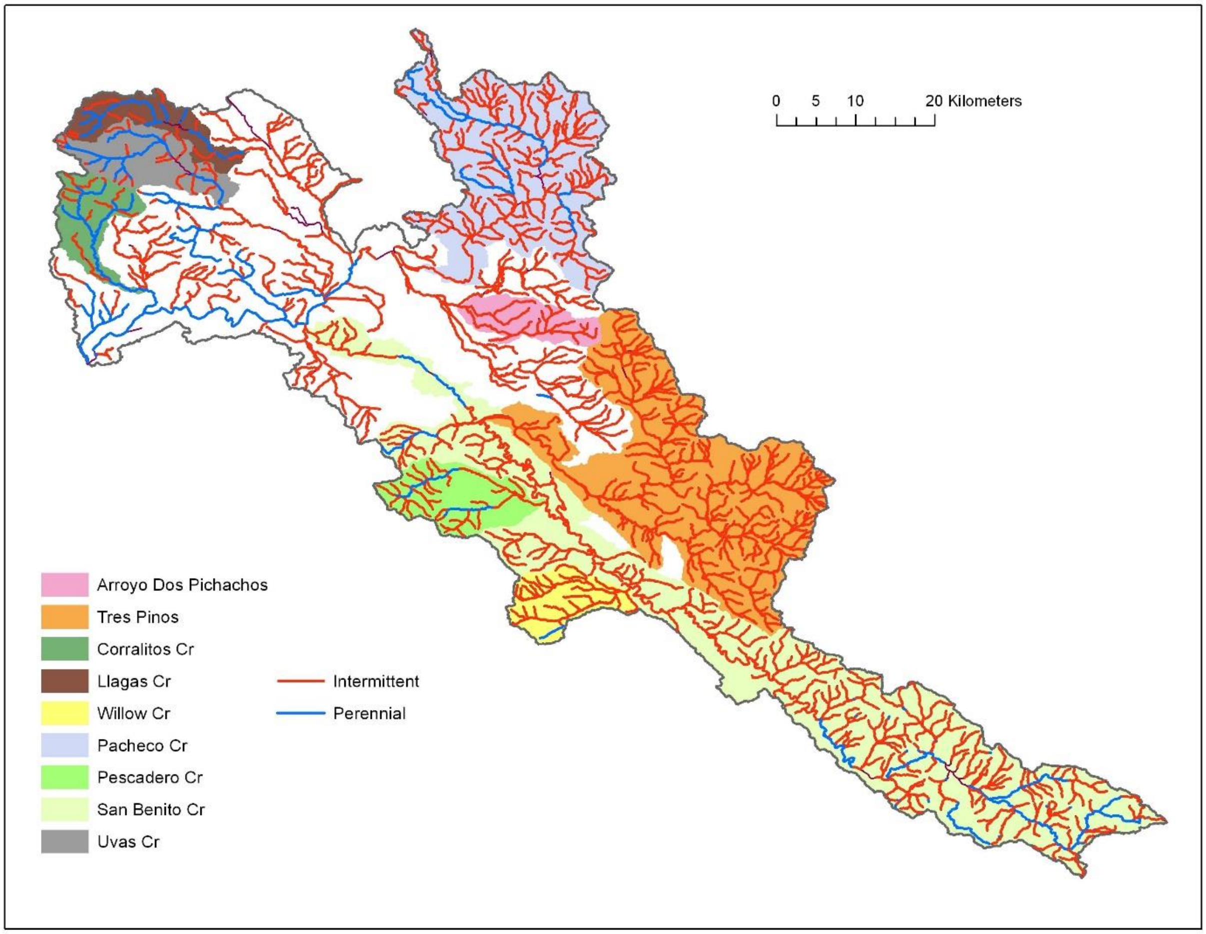


Figure 2. Pajaro River subwatersheds showing drainages and intermittent/perennial flows.

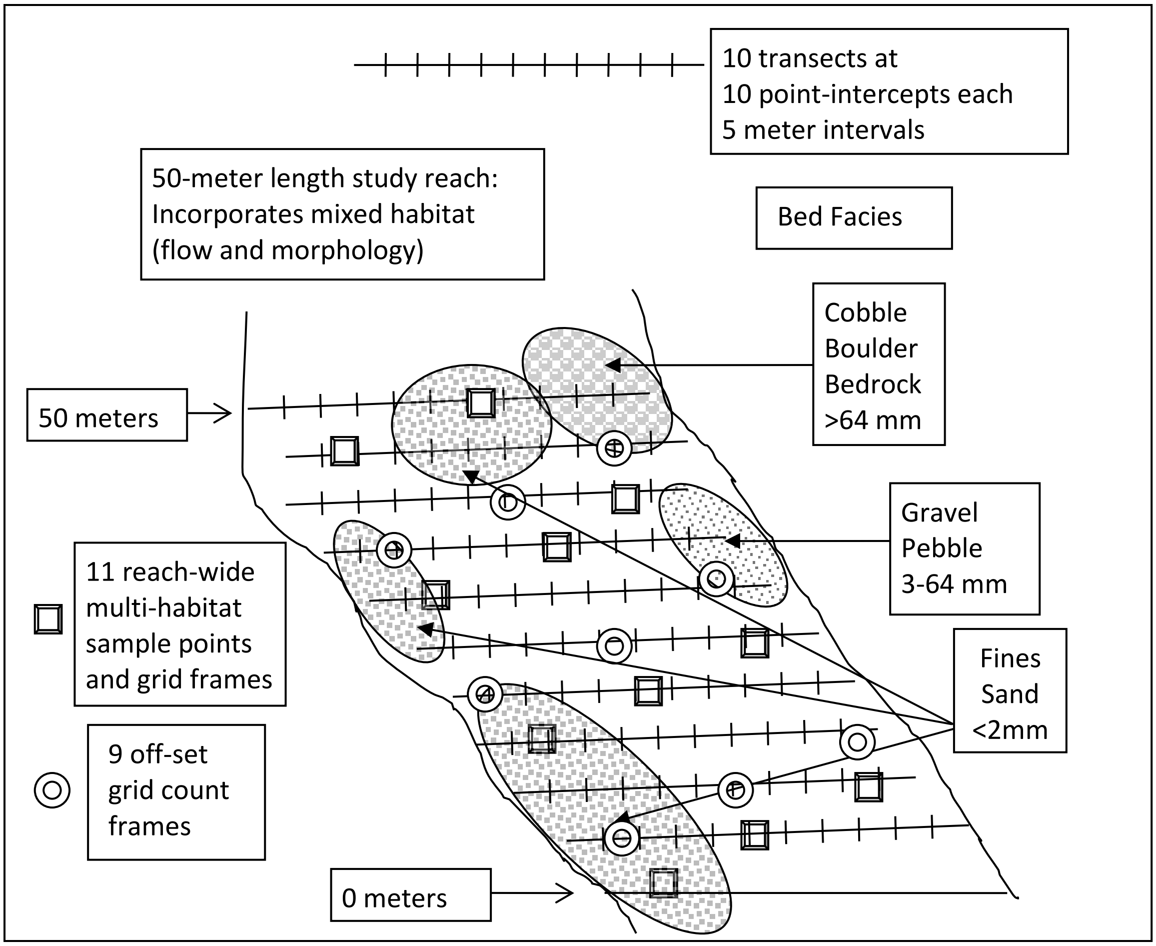
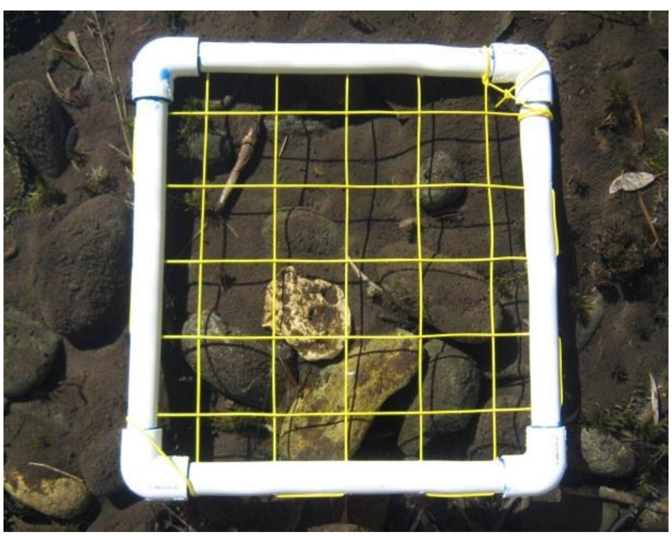


Figure 3. Layout of the stream sampling reaches and data collected showing locations of transects, grid-quadrats, RWB benthic invertebrate sampling locations, and facies maps. Inset below of the grid-frame sampling quadrat (30x30 cm).



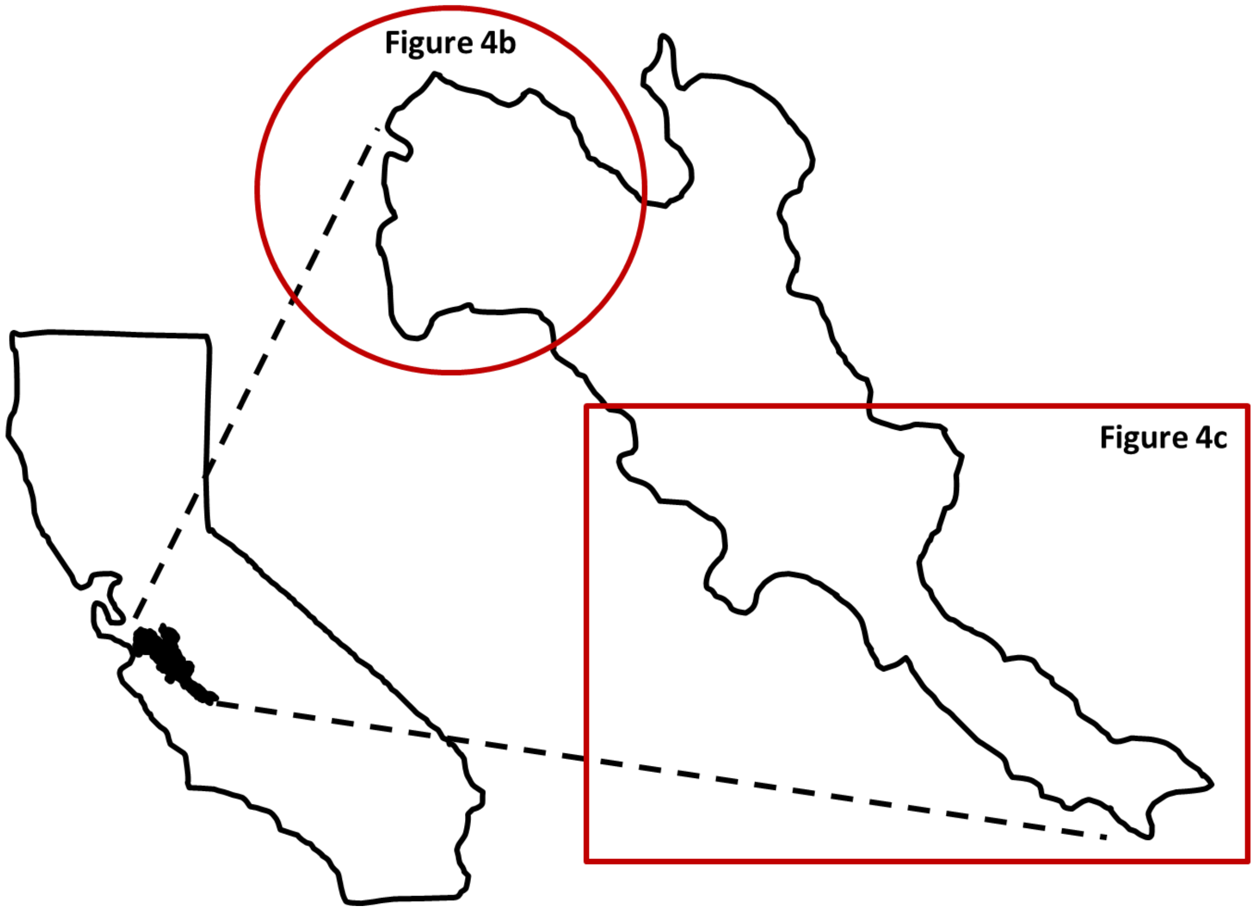


Figure 4a. Location of Pajaro River and Coyote Creek watersheds in California. Red circle and square indicate area of finer detail in figures 4b and 4c.

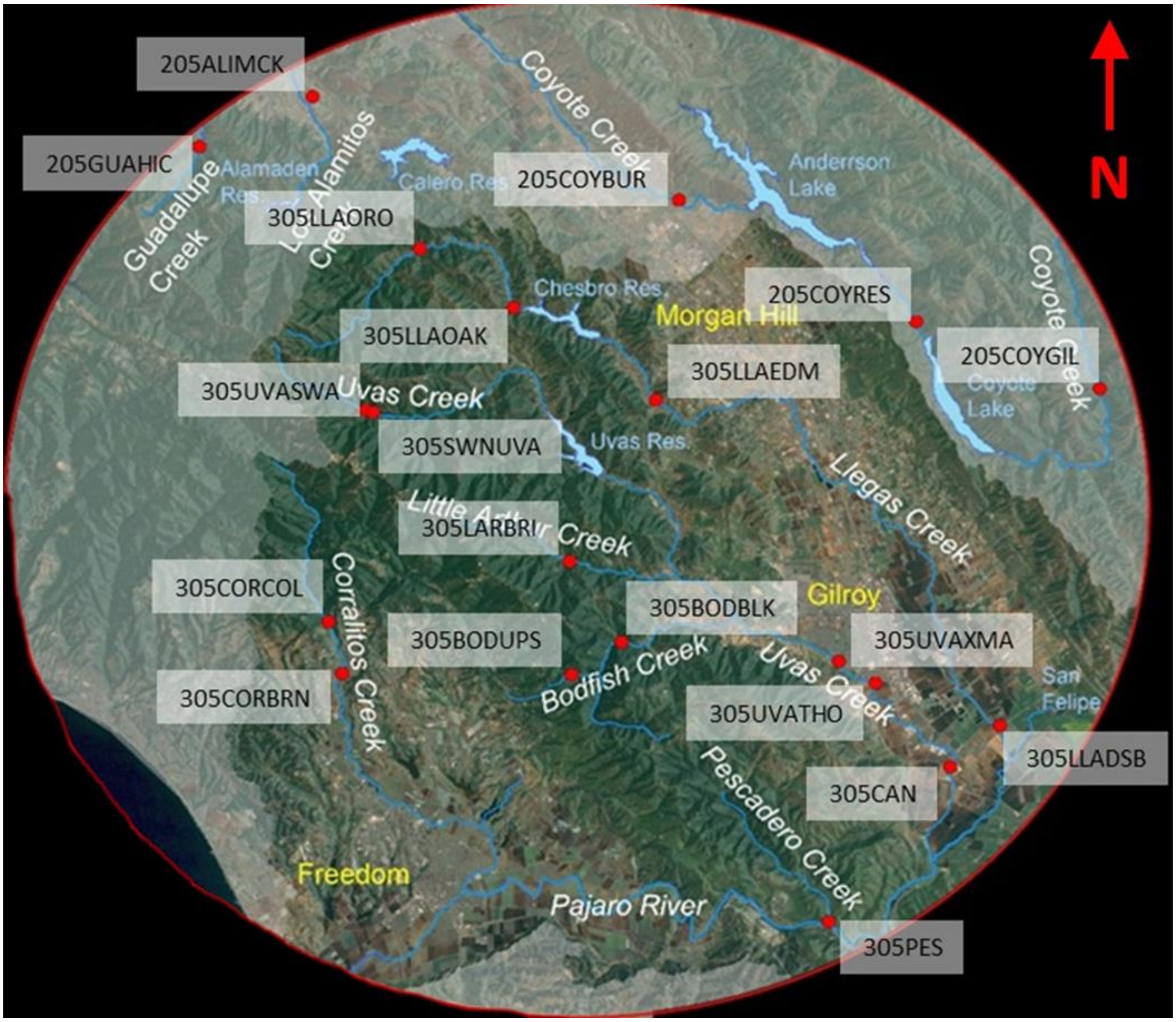


Figure 4b. Site locations (n=20) in the northern area of the Pajaro River and Coyote Creek watersheds.

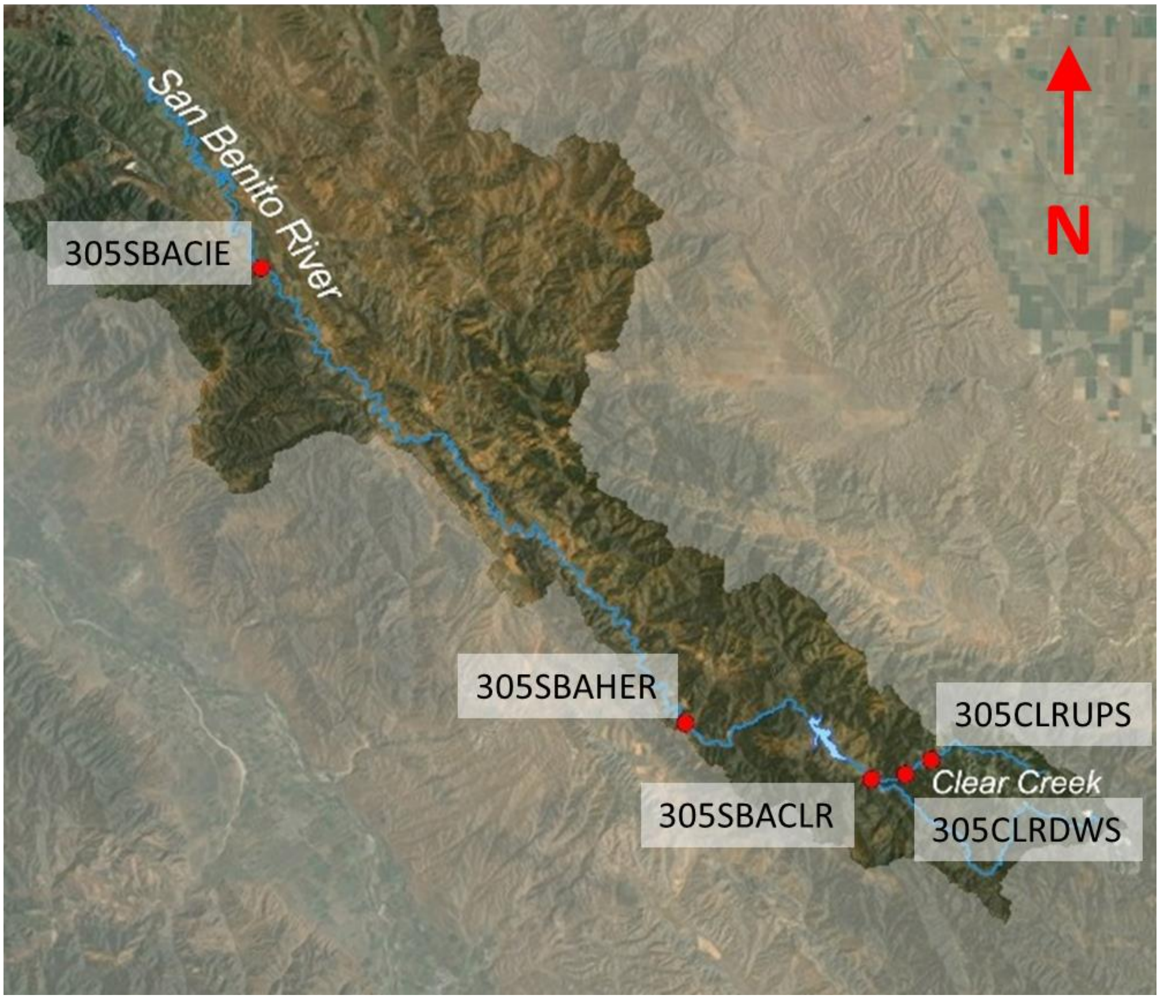


Figure 4c. Site locations (n=5) in the southern area of the Pajaro River watershed.

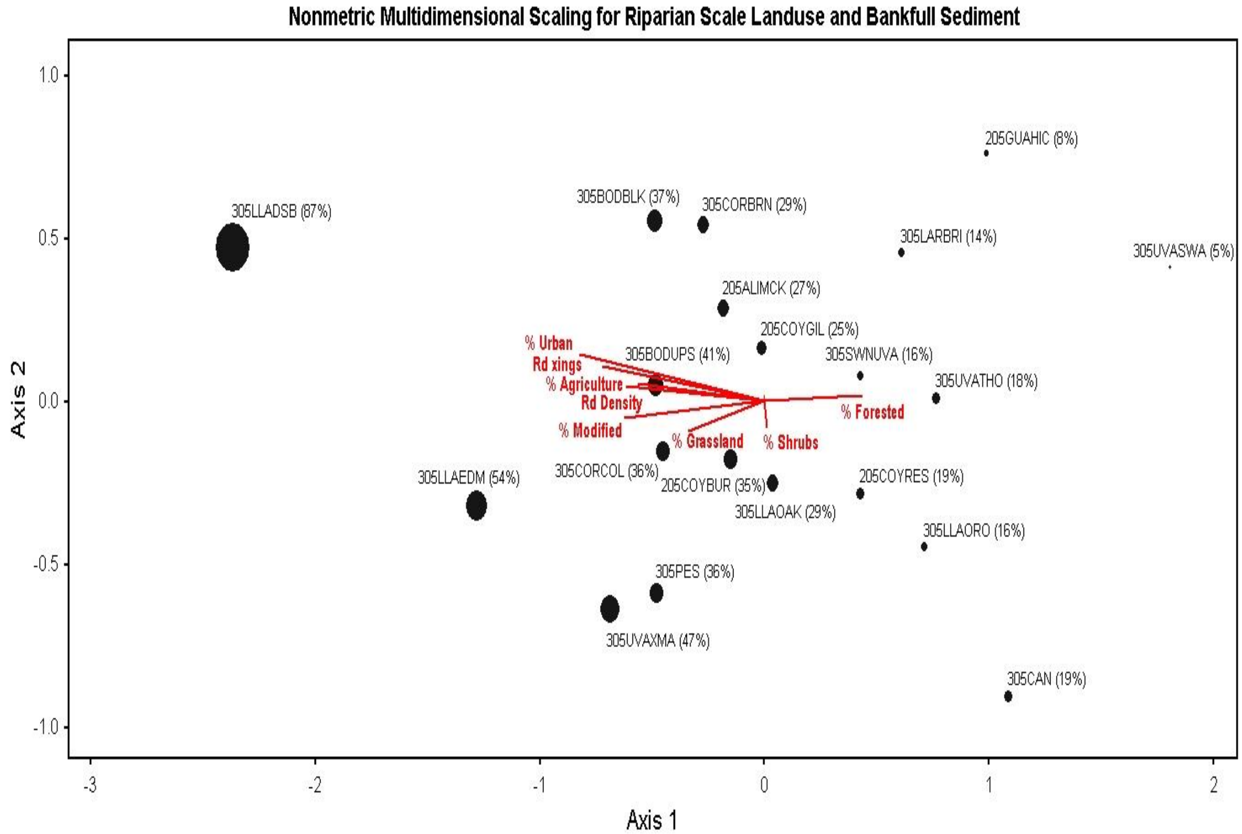


Figure 5. Ordination bi-plot of Nonmetric Multidimensional Scaling analysis for **Reach Scale Bankfull Width sediment deposits** (similarity among four measures of deposition: %FS bankfull, %FS from quadrat grids, D50 particle size and cobble embeddedness), and **Riparian Scale** environmental vectors excluding southern sites (n=20). Environmental vectors include percent areas in natural forest, grassland, and shrubs, developed agriculture and urban area, and road density (Rd. Density) and crossings (Rd. xings), and percent modified stream channel length upstream. Symbol size represents %FS cover (in parentheses). Final stress=7.22 for a two dimensional solution, 52 iterations to evaluate instability. NMS analysis of sediment deposition in relation to land use variables was run using the auto method. Sedimentation is related mainly to urbanization, agriculture and roads, with low levels found where forested area is more extensive. Axes are non-dimensional and vectors are centered on zero. Variance explained: axis 1= 87%, axis 2= 9%. Axis 1 highest r correlation vector = %Urban, -0.574.

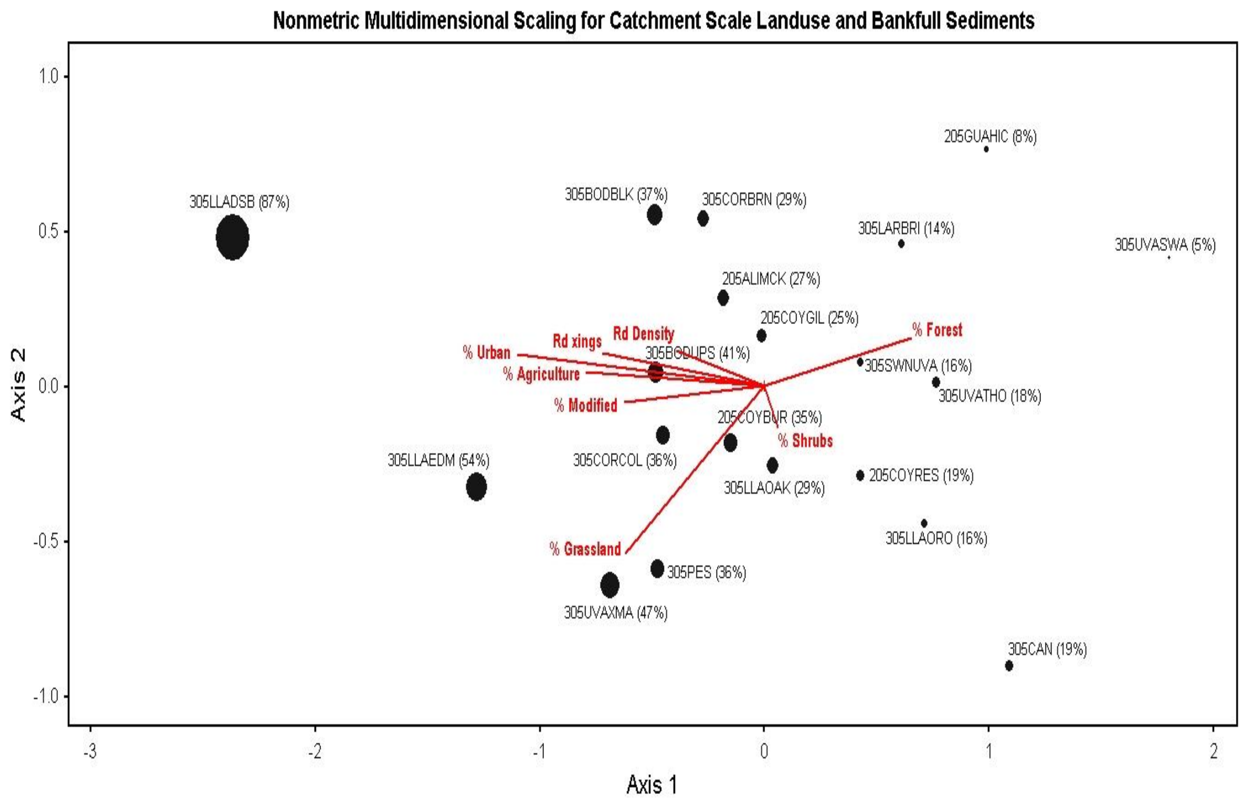


Figure 6. Ordination bi-plot of Nonmetric Multidimensional Scaling analysis for **Reach Scale Bankfull Width sediment deposits** (similarity among four measures of deposition: %FS bankfull, %FS from quadrat grids, D50 particle size and cobble embeddedness), and **Catchment Scale** environmental vectors excluding southern sites (n=20). Environmental vectors include percent areas in natural forest, grassland, and shrubs, developed agriculture and urban area, and road density (Rd. Density) and crossings (Rd. xings), and percent modified stream channel length upstream (all are centered at zero). Symbol size represents %FS cover (listed in parentheses). Final stress=7.22 for a two dimensional solution, 52 iterations to evaluate instability. NMS analysis of sediment deposition in relation to land use variables was run using the auto method. Percent bankfull FS correlated with the areas of urbanization and agriculture (r= -0.66 for urban, -0.57 for Ag), and road density, and low deposition correlated with forested area. The magnitude of these correlations are similar at the catchment scale as at the riparian scale (previous graph). Note that axes are non-dimensional but have correlations with the vectors shown (Axis 1 explains 87% of variance and Axis 2 9%).

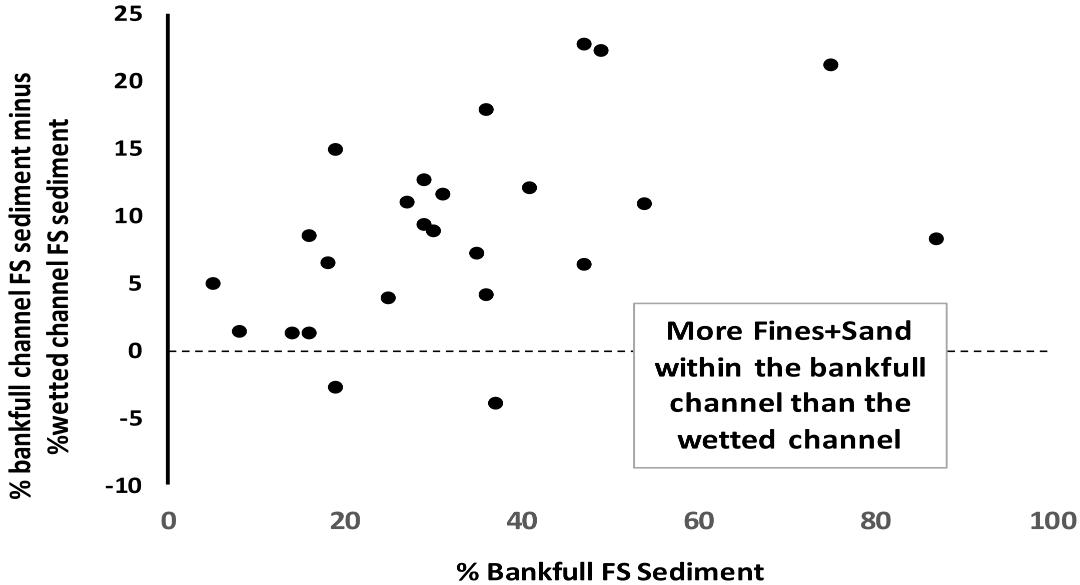


Figure 7. Relationship of percent fines+sand sediment cover within the wetted channel to that in the bankfull profile. Horizontal zero line would be 1:1 relation wetted to bankfull FS.

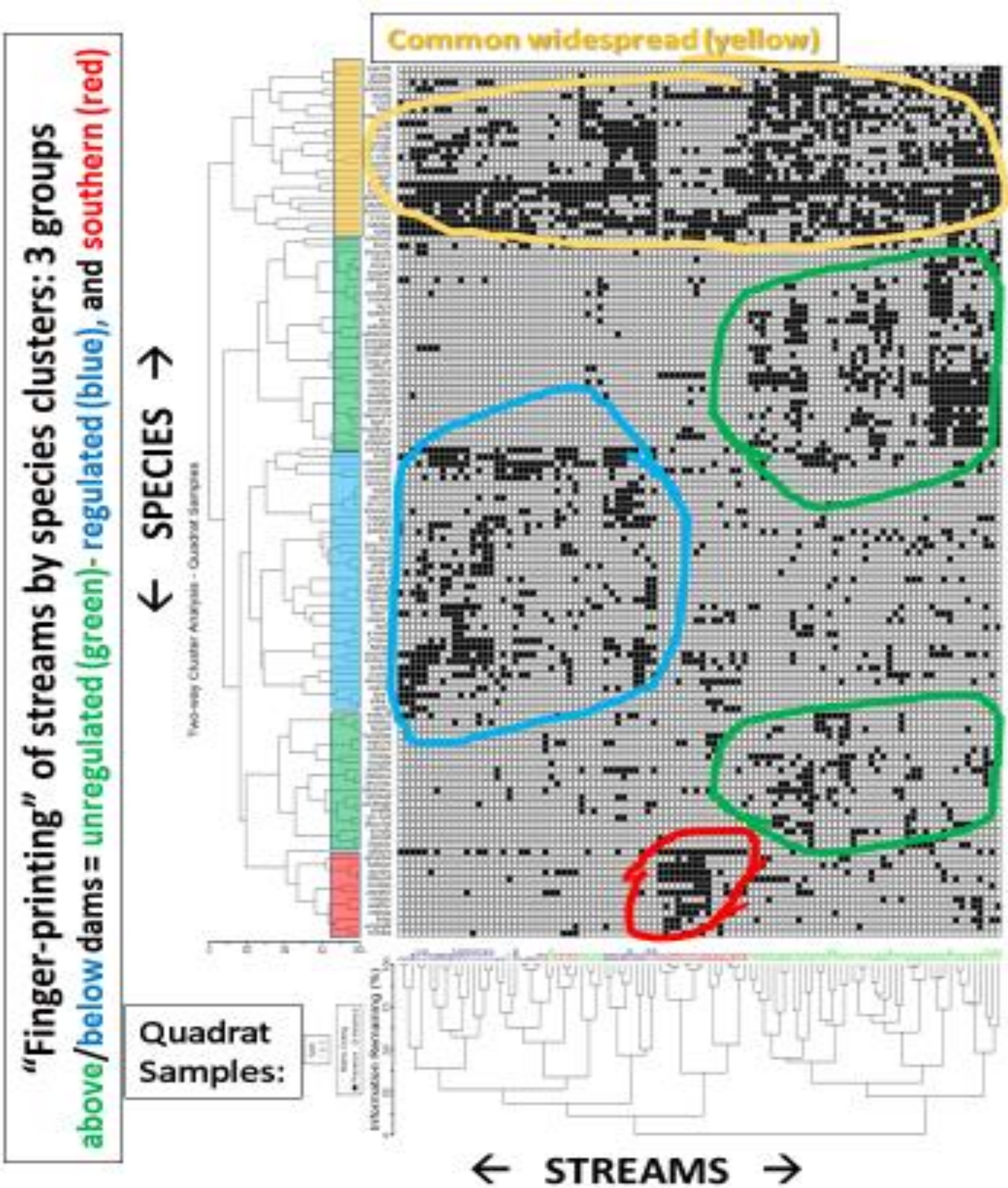


Figure 8. Cluster analysis “fingerprint” of invertebrate community composition by site for quadrat samples (n=100). Samples from unregulated streams are coded green, regulated streams blue, and southern streams red. Quadrats cluster similar to stream groupings.

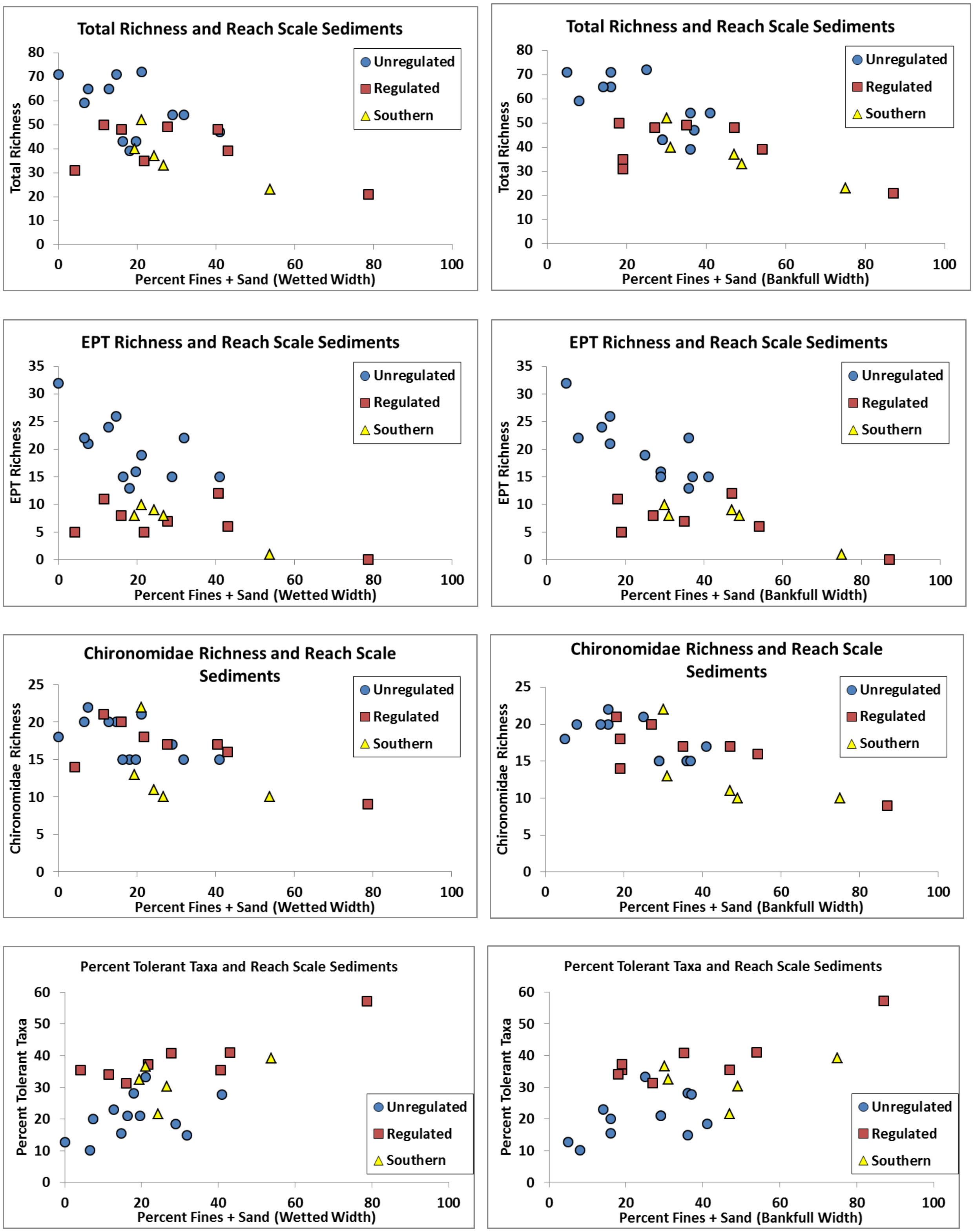


Figure 9. Various biological metrics and % fines+sand for reach-wide benthos samples in unregulated (n=12), regulated (n=8), and southern (n=5) streams (FS for wetted channel on left, and bankfull channel on right).

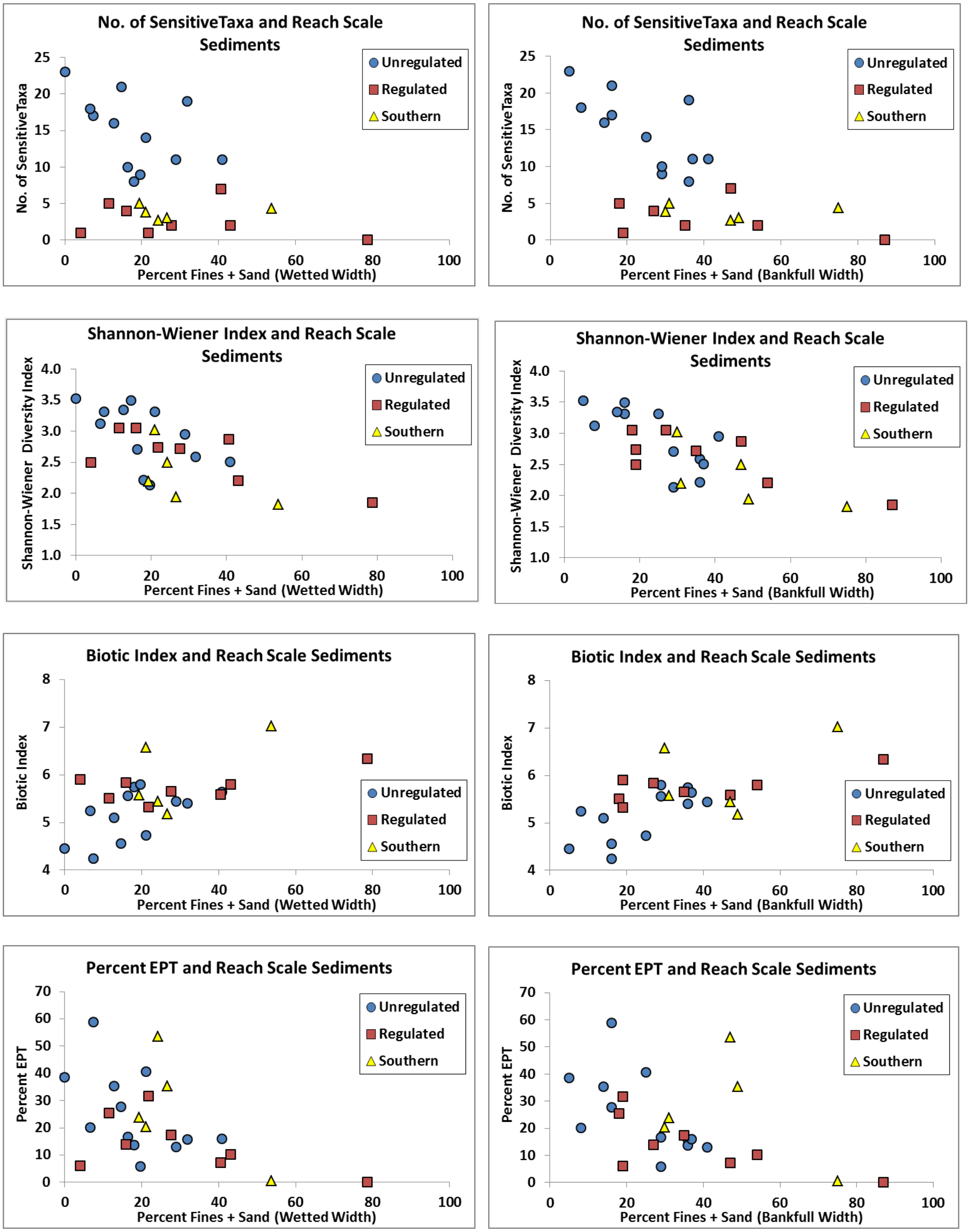
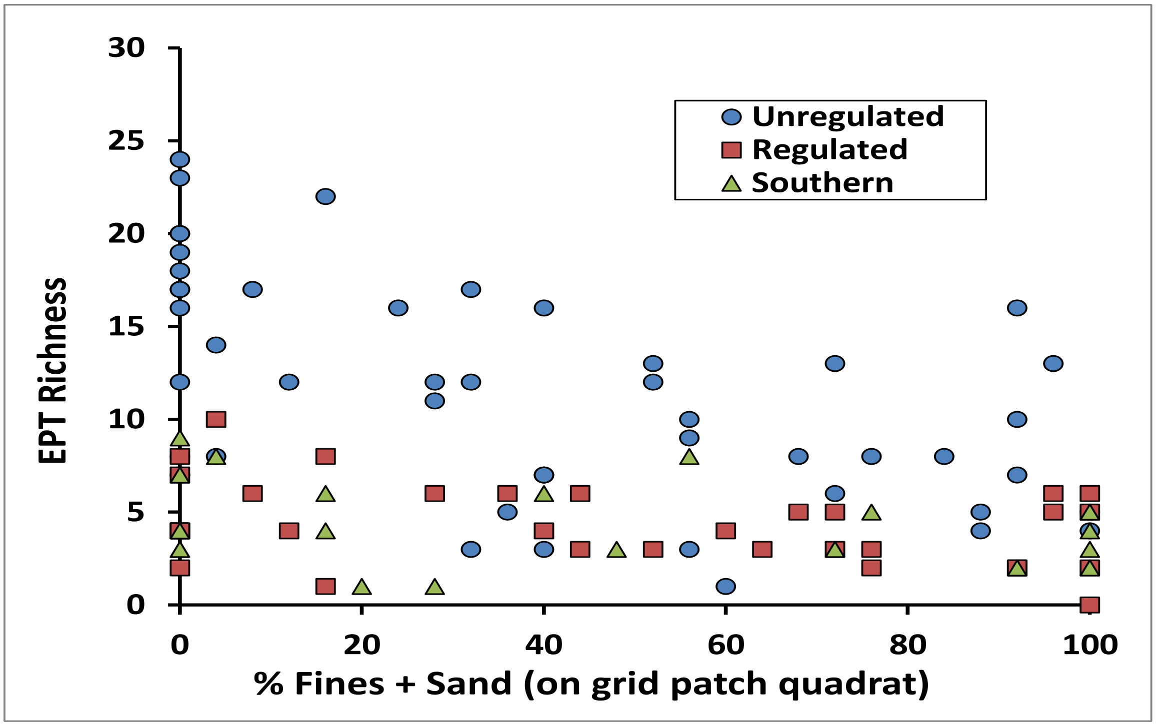


Figure 9 (continued). Various biological metrics and % fines+sand for reach-wide benthos samples in unregulated (n=12), regulated (n=8), and southern (n=5) streams (FS for wetted channel on left, and bankfull channel on right).



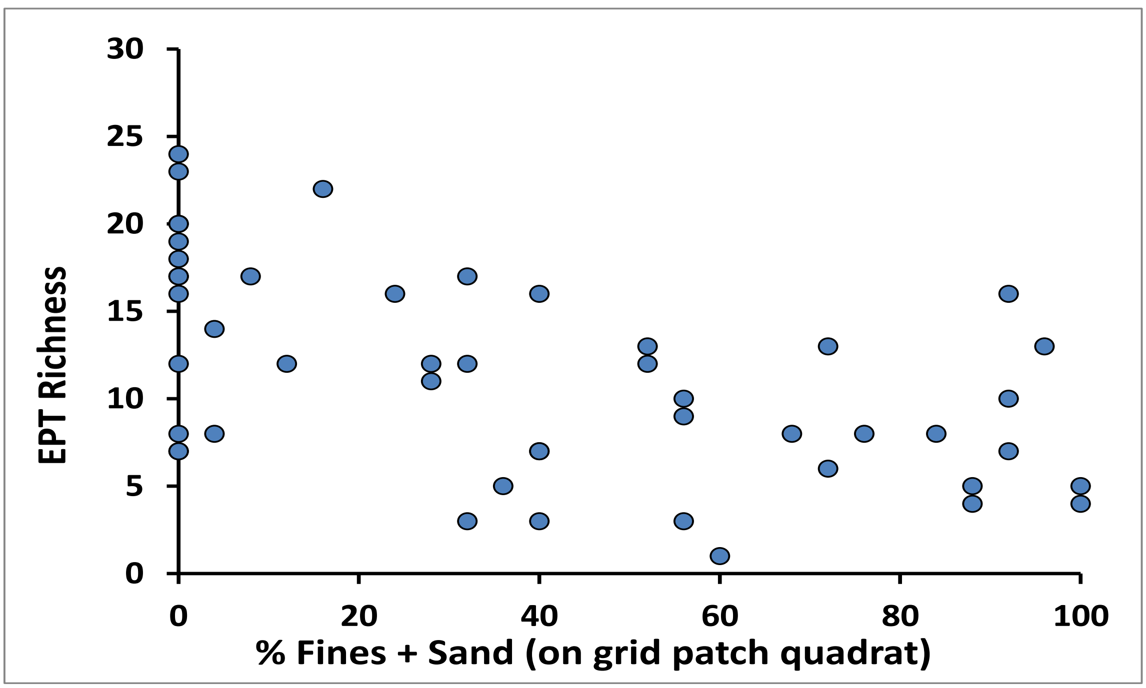
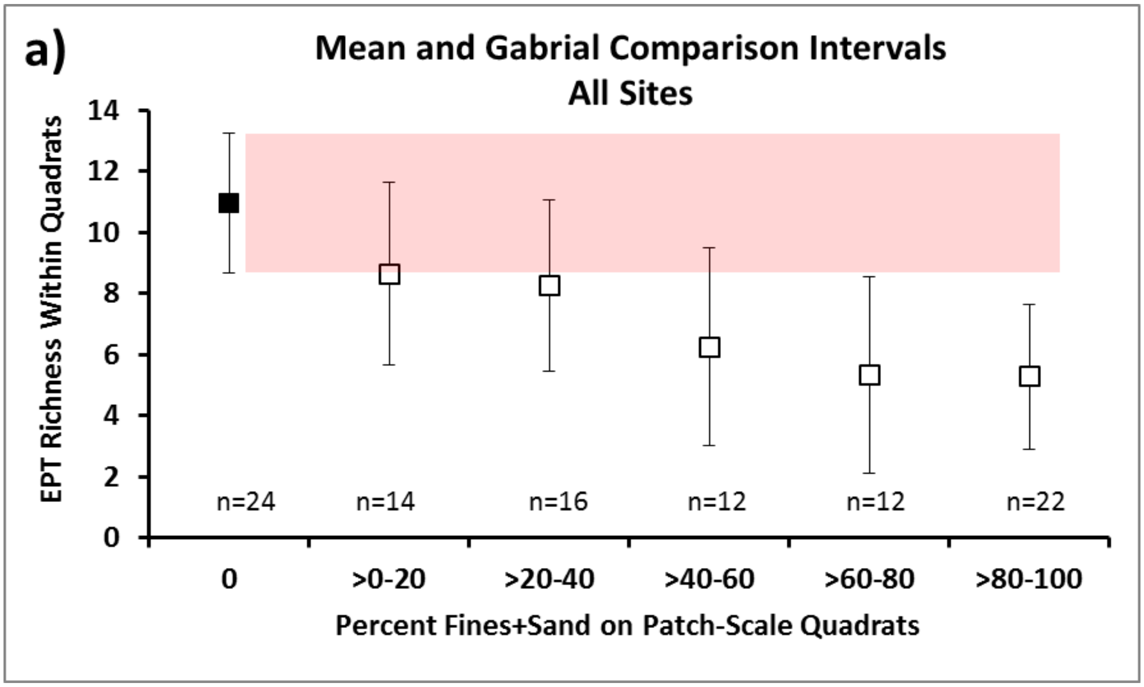


Figure 10. The richness diversity of EPT (mayflies, stoneflies, caddisflies) from quadrat grid frames (local patch-scale samples) in relation to FS counts at 25 grid-intersect points (each point equaled 4 percent of total cover). While quadrats from unregulated streams showed decrease in diversity with higher FS (especially above 40%), diversity in the regulated and southern stream types was only slightly enhanced at low levels of FS cover (but none with more than 10 taxa whereas unregulated streams were usually in the range of 12-25 taxa at FS levels <40%). The unregulated stream quadrats only (below) show mostly EPT <12 above 40% FS.



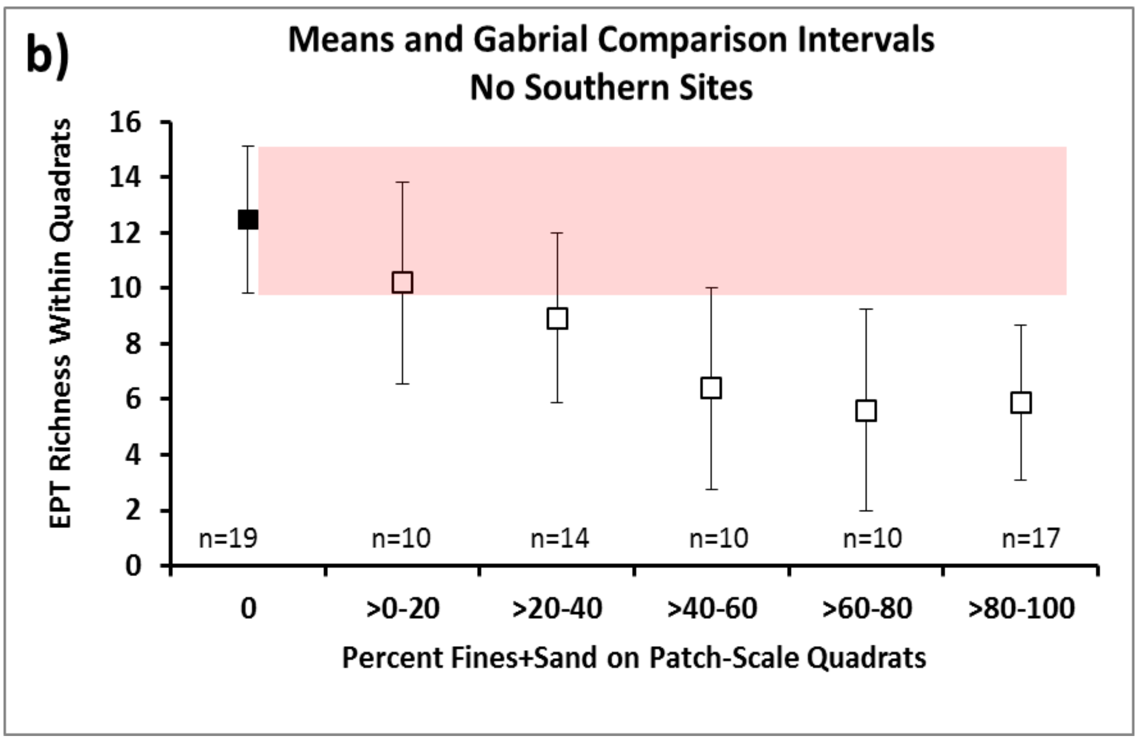


Figure 11. Means and Gabriel comparison intervals (alpha = 0.05) for quadrat EPT richness including a), and excluding b) southern sites. Mean EPT richness values where the interval does not overlap that of the first bin=0 (highlighted in red) are significantly different from mean EPT richness at 0% fines+sand. The >40-60% FS range bin is regarded here as the threshold for significantly lower EPT richness, compared to bins with lower FS cover, based on an alpha value that is only slightly greater than p=0.05 level of significance.

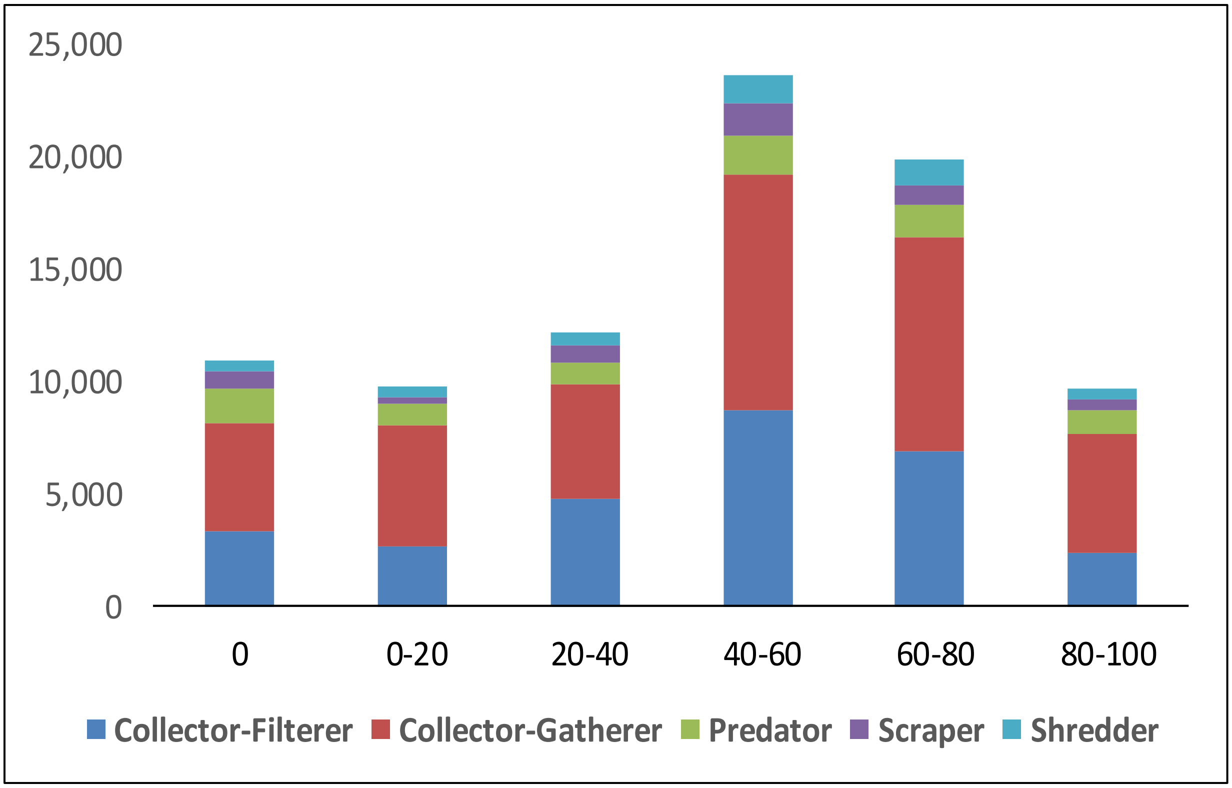


Figure 12. Average densities (#/m^2) of functional feeding groups within each of six sediment bin ranges (0, >0-20, >20-40, >40-60, >60-80, and >80-100% FS cover) for 100 quadrat samples.

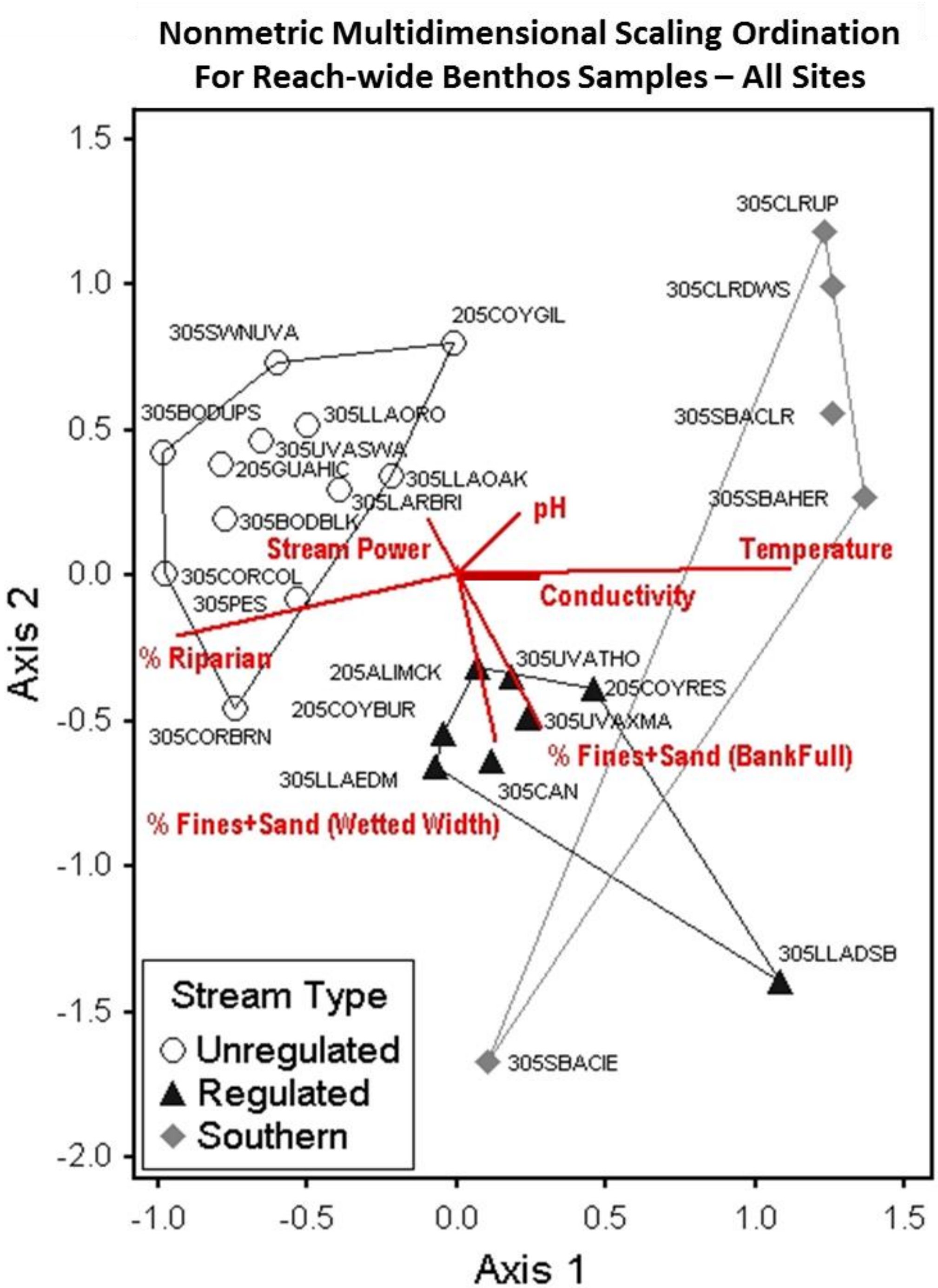


Figure 13. Ordination bi-plot of NMS analysis for community composition and density for RWB samples (log(x+1) transformed, not relativized, n=25). Environmental vectors include **% fines+sand (wetted width) to contrast % fines+sand (bankfull width)**, conductivity, temperature, pH, stream power, and % riparian cover. Final stress=15.0 for a two dimensional solution. RWB communities of regulated streams are related most to percent FS whether measured over the bankfull or wetted channel width. Variance explained: Axis 1= 48%, Axis 2= 35%.

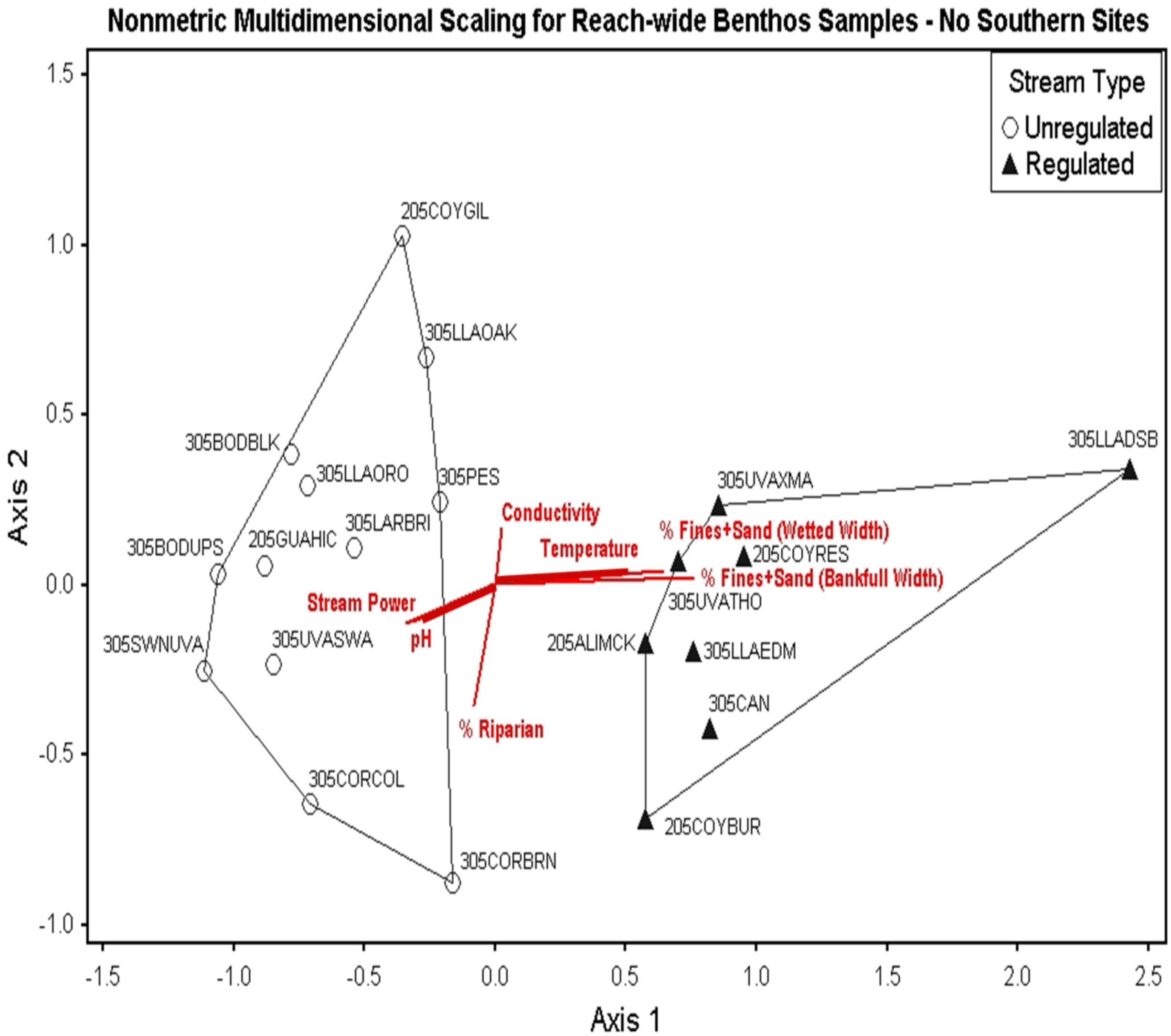


Figure 14a. Ordination bi-plot of NMS analysis for community composition and density for RWB samples (log(x+1) transformed, not relativized, n=20) with southern sites excluded. Environmental vectors include **% fines+sand (wetted width) to contrast % fines+sand (bankfull width)**, conductivity, temperature, pH, stream power, and % riparian cover. No correlation cutoff used. Final stress=12.66 for a two dimensional solution. RWB communities of regulated streams are related most to percent FS whether measured over the bankfull or wetted channel width, but temperatures are also warmer in regulated streams. Riparian cover and stream power are most significant in separating unregulated streams. Variance explained: Axis 1= 74%, Axis 2= 11%.

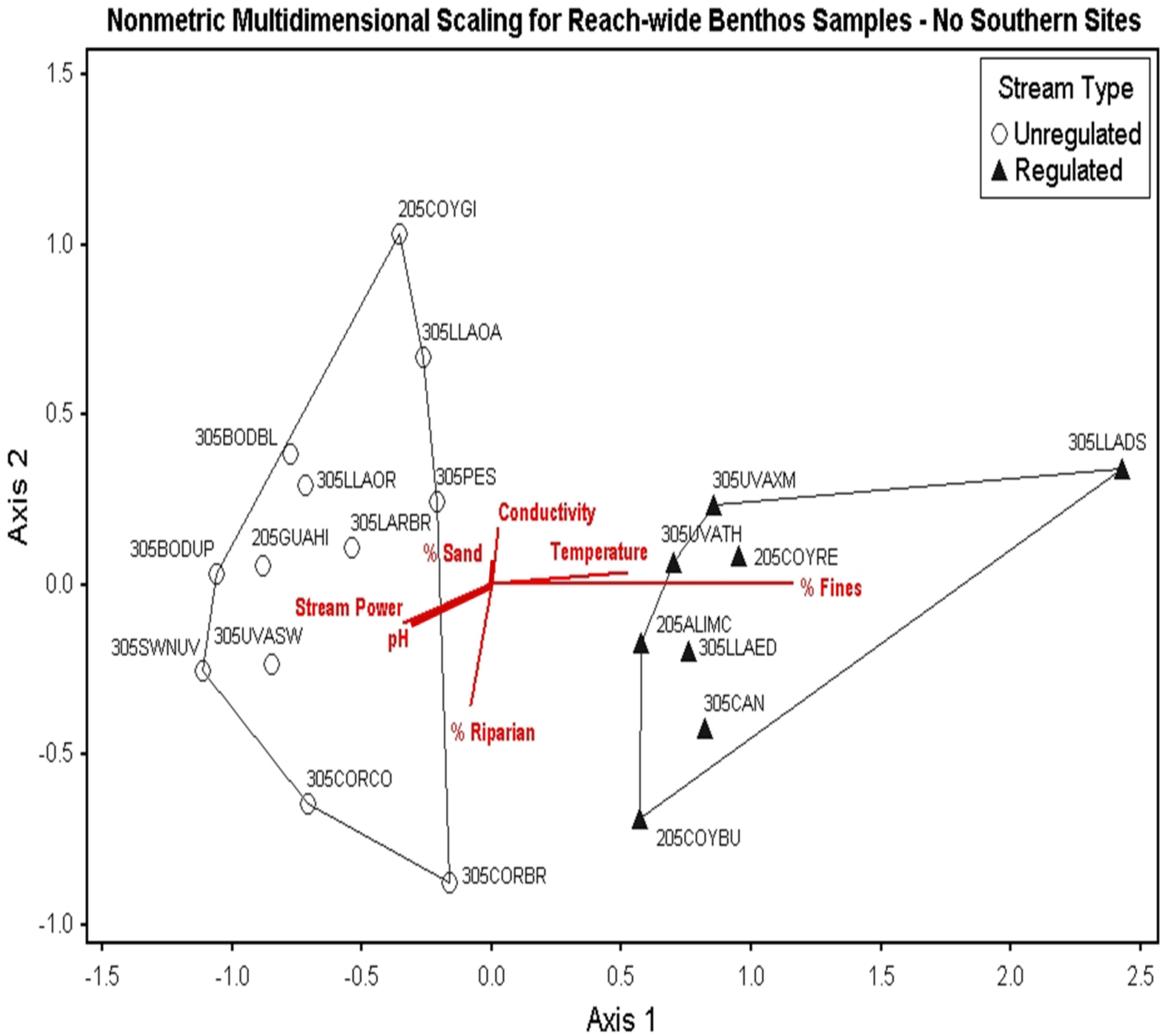


Figure 14b. Ordination bi-plot of NMS analysis for community composition and density for RWB samples (log(x+1) transformed, not relativized, n=20) with southern sites excluded. Environmental vectors include **%fines (wetted width), %sand (wetted width)**, conductivity, temperature, pH, stream power, and % riparian cover. Final stress=12.66 for a two dimensional solution. Percent fines and sand were separated here (combined in figure 13a) to show the individual correlation of each with stream type separation. Fines play the dominant role in regulated streams. Variance explained: Axis 1= 74%, Axis 2= 11%.

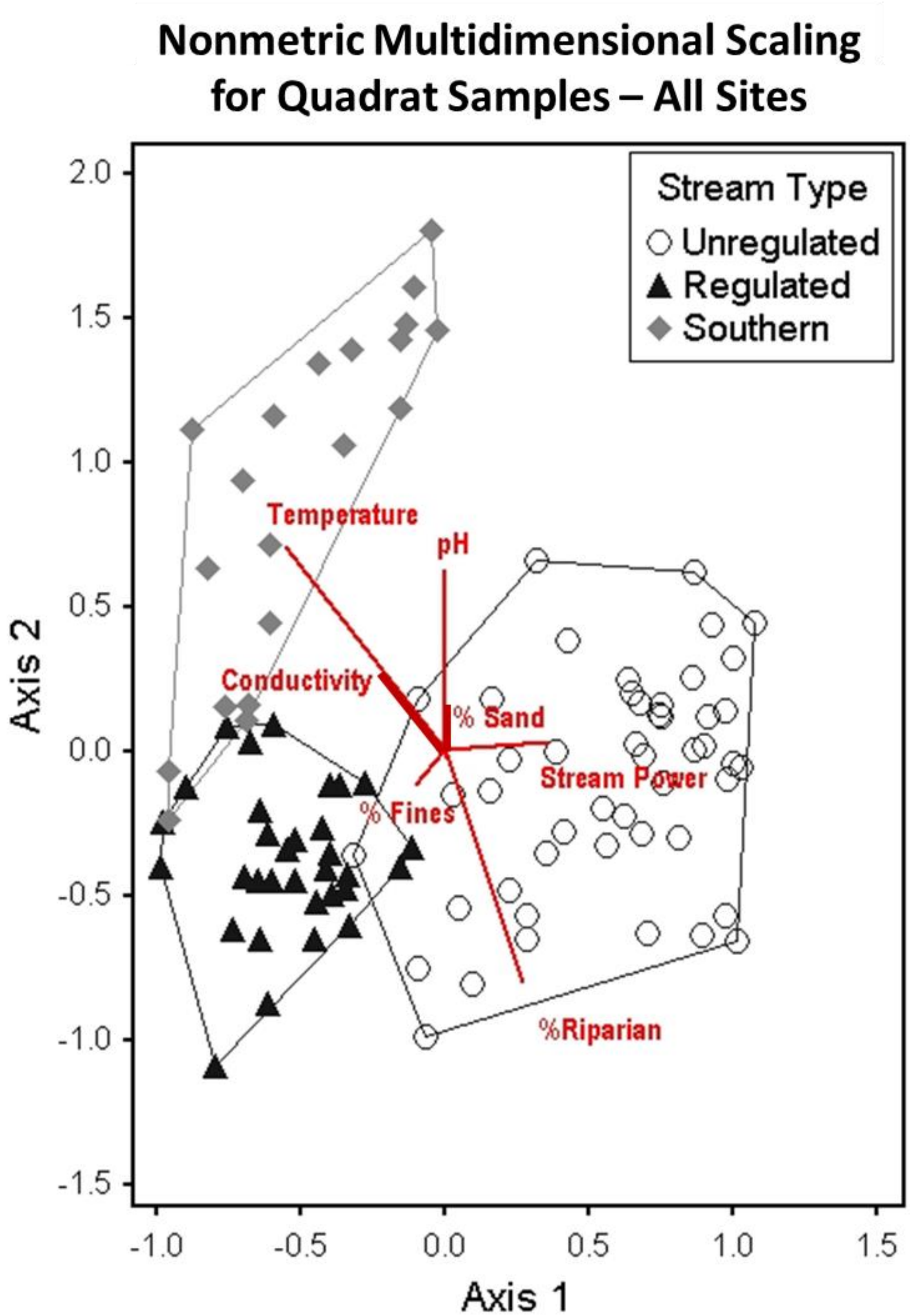


Figure 15. Ordination bi-plot of NMS analysis for community composition and density for quadrat samples (log(x+1) transformed, not relativized, n=125) for 25 sites. Environmental vectors include % fines, % sand, conductivity, temperature, pH, stream power, and % riparian cover. Final stress=15.89 for a three dimensional solution. Quadrat samples within each stream spanned a full range from low to high levels of cover, so this does not play an important role in separating stream types, but does in separation of quadrats over all sites (expressed in Figure 17). Variance explained: Axis 1= 40%, Axis 2= 27%.

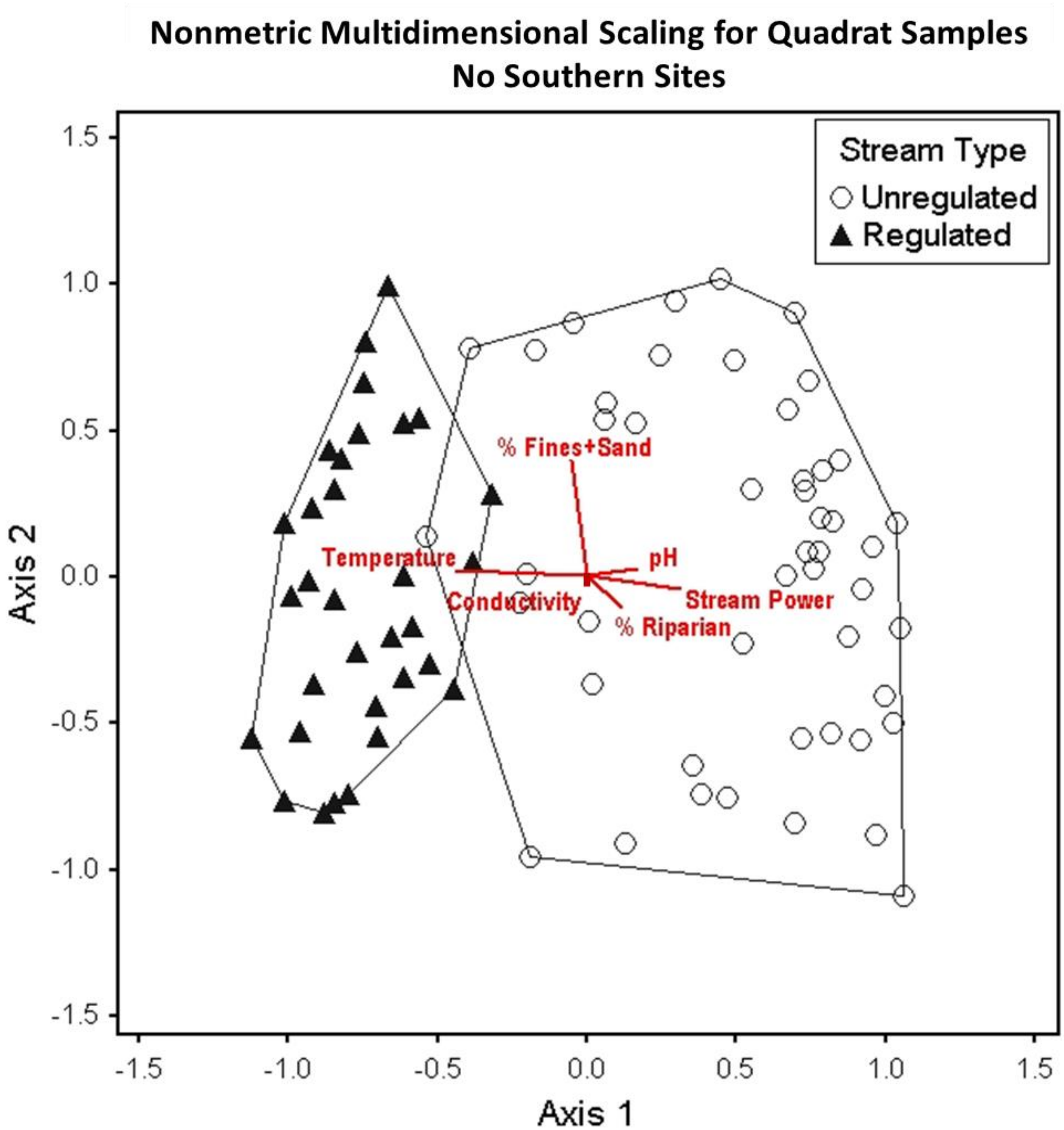


Figure 16. Ordination bi-plot of NMS analysis for community composition and density for quadrat samples (log(x+1) transformed, not relativized, n=100) southern sites excluded. Environmental vectors include % fines+sand, conductivity, temperature, pH, stream power, and % riparian cover. No correlation cutoff used, final stress=15.34 for a three dimensional solution. The FS sediment content does not separate according to stream type but is aligned along the gradient of axis 2 from low to high FS content. This same array of points shown in the next figure demonstrates the influence of sediment in separating the assemblages of species found in quadrats. Variance explained: Axis 1= 49%, Axis 2= 18%.

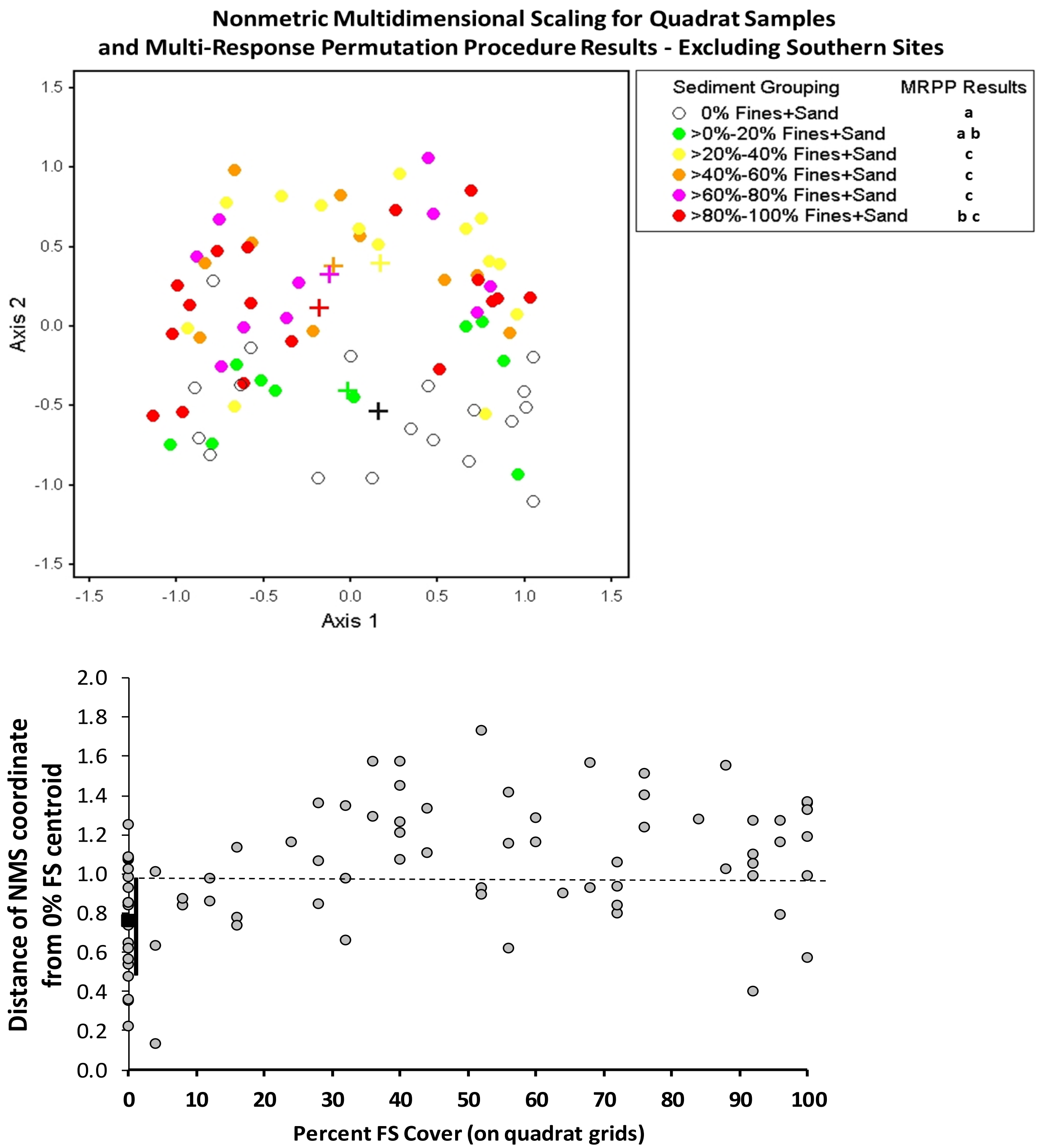


Figure 17. Community ordination of quadrat samples coded by sediment bins of 0, >0-20, >20-40, >40-60, >60-80, >80-100% FS. Sediment groups that are significantly different from one another according to MRPP pairwise comparison results are represented by different letters. Colored symbols + represent the centroids of each group in ordination space. Final stress=15.34 for a three dimensional solution. This is basically the same ordination as Figure 16, except quadrats are coded according the FS group. See Table 9 for complete MRPP results. The graph below the ordination shows the difference of each FS point to the 0% FS centroid, the black square the mean of the 0% FS group, black bar the 95% CI, dashed line showing upper limit.

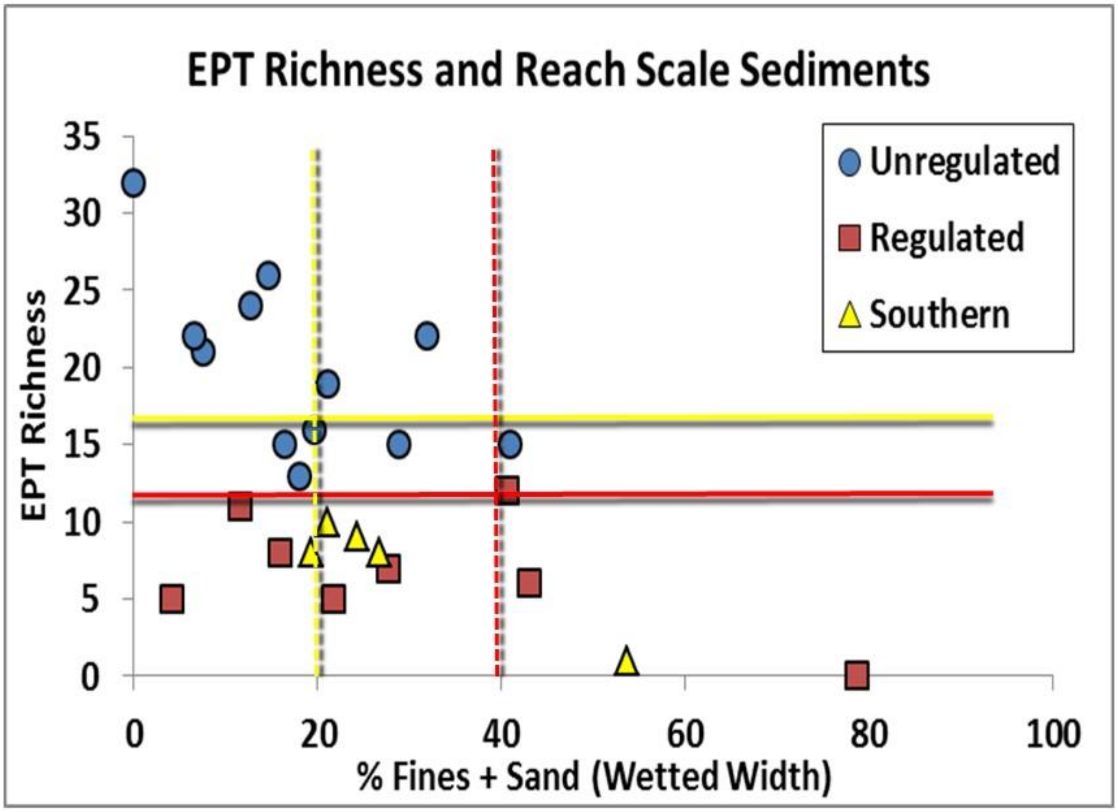


Figure 18. Target levels for EPT diversity and reach-scale FS sediment cover in relation to distribution of Pajaro and Coyote Creek RWB samples (see also Tables 6 and 7 for site names). The yellow (warning) and red (impaired) criterion lines represent the apparent biological thresholds for effects of percent FS on community composition and diversity, and the 10^{th} and 25^{th} percentiles of EPT richness for coastal reference stream conditions (based on Herbst et al. 2011). Sites below and beyond the yellow lines are in a range warning of possible sediment-impaired conditions, and below and beyond red lines could be considered impaired. The regulated and southern streams are exposed to other stressors besides sediment so low diversity is not due exclusively to sediment. Among the unregulated streams, only two are in a warning range that is associated with sediment cover above 20% FS. If percent FS is expressed for the bankfull instead of wetted channel, then five unregulated streams would be in this warning range (see right panel of EPT richness in the graphs of Figure 9).

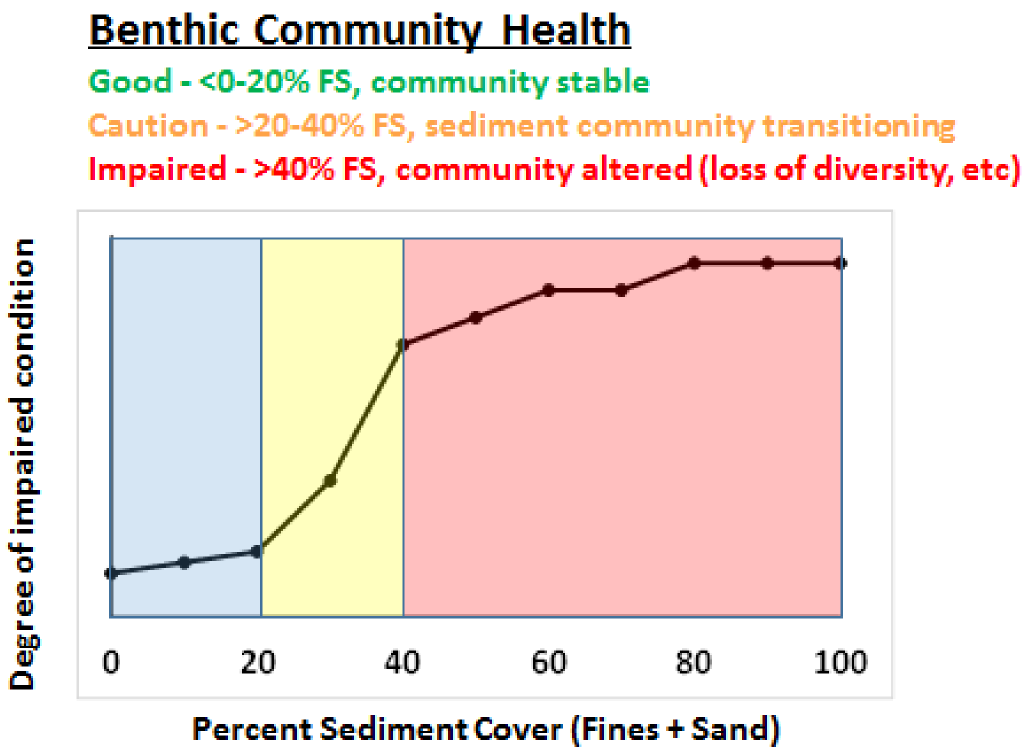


Figure 19. Conceptual graph of the relation between sediment cover by fines and sand and impaired benthic invertebrate community integrity (relative to reference stream species composition and diversity), based on the preceding graphs and analysis.

TABLES:

Table 1. Physical habitat features of sites surveyed in Pajaro River and Coyote Creek watersheds. SWAMP station code names and corresponding stream names shown below.

SWAMP Site Code	Stream Type	Stream Power Index	Conductivity (µS/cm)	Temperature (°C)	pH	Stream Banks Eroding	Stream Bank Vegetated	Stream Bank Vegetated and Armored	Riparian Canopy Cover
305BODBLK	Unregulated	6.49	1011	12.9	8.11	5%	0%	70%	91.8%
305BODUPS	Unregulated	3.95	621	12	8.06	55%	20%	35%	98.7%
305CORBRN	Unregulated	2.38	564	16.1	8.66	15%	20%	60%	88.1%
305CORCOL	Unregulated	11.29	562	16	8.60	0%	5%	75%	98.7%
205COYGIL	Unregulated	2.73	650	17	8.31	5%	60%	70%	55.6%
205GUAHIC	Unregulated	4.04	408	15	7.93	20%	45%	45%	96.8%
305LARBRI	Unregulated	2.21	480	13.2	8.25	0%	10%	70%	91.8%
305LLAORO	Unregulated	2.12	469	14.2	8.38	0%	85%	95%	91.9%
305LLAOAK	Unregulated	4.88	517	17.5	8.27	5%	45%	70%	70.4%
305PES	Unregulated	1.04	1430	16.4	8.26	45%	45%	45%	94.1%
305SWNUVA	Unregulated	44.63	370	14.5	8.62	10%	5%	80%	96.6%
305UVASWA	Unregulated	9.30	379	14.8	8.60	20%	30%	55%	95.9%
305CAN	Regulated	1.97	435	15.6	7.56	10%	50%	60%	90.7%
205COYRES	Regulated	2.57	345	16.9	8.05	5%	35%	55%	91.6%
205COYBUR	Regulated	8.08	508	15.2	8.21	0%	50%	80%	98.7%
305LLADSB	Regulated	0.12	1200	16.6	7.65	30%	40%	65%	98.2%
305LLAEDM	Regulated	0.97	347	13.7	8.31	30%	15%	20%	87.2%
205ALIMCK	Regulated	5.24	461	18.6	8.64	25%	65%	65%	79.9%
305UVAXMA	Regulated	1.01	295	17.8	8.43	15%	80%	80%	19.4%
305UVATHO	Regulated	1.41	300	19.8	8.53	30%	80%	80%	81.8%
305CLRUPS	Southern	6.22	1068	21.7	9.24	65%	5%	5%	0%
305CLRDWS	Southern	1.87	1046	26.7	9.17	5%	35%	55%	14.6%
305SBACLR	Southern	5.81	1045	27.8	8.51	15%	0%	15%	0.0%
305SBACIE	Southern	0.58	1304	22.8	8.93	0%	50%	50%	64.0%
305SBAHER	Southern	3.48	910	23.9	9.08	0%	100%	100%	41.5%

SWAMP Code	Southern Streams:
305CLRUPS	Clear Creek, upper
305CLRDWS	Clear Creek, lower
305SBACLR	San Benito River, below Clear Creek
305SBAHER	San Benito River, below reservoir
305SBACIE	San Benito River, below Cienaga

SWAMP Code	Regulated Streams:
305CAN	Carnadero Creek, above Hwy 25
305LLADSB	Llagas Creek, below Bloomfield
305LLAEDM	Llagas Creek, below Edmundson
305UVAXMA	Uvas Creek, Christmas Hill Park
305UVATHO	Uvas Creek, below Thomas
205COYRES	Coyote Creek, below Coyote reservoir
205COYBUR	Coyote Creek, end of Burnett Road
205ALIMCK	Los Alamitos Creek, below McKean

SWAMP Code	Unregulated Streams:
305CORCOL	Corralitos Creek, under Las Colinas bridge
305PES	Pescadero Creek, north
305CORBRN	Corralitos Creek, above Browns Valley Road
305LLAORO	Llagas Creek, Rancho Canada de Oro Park
305LLAOAK	Llagas Creek, below Oak Glen
305BODUPS	Bodfish Creek, upper
305BODBLK	Bodfish Creek, Blackhawk down
305UVASWA	Uvas Creek, above Swanson
305SWNUVA	Swanson Creek, above Uvas
305LARBRI	Little Arthur Creek, above third bridge
205COYGIL	Coyote Creek, upper (Gilroy Hot Springs Road)
205GUAHIC	Guadalupe Creek, below Hicks Road

Table 2. Locations, sample dates, landscape, and land use descriptors for sites within the Pajaro River and Coyote Creek watersheds.

SWAMP Site Code	Sample Date	Latitude	Longitude	Catchment Area (km^2)	Site Elevation (m)	Stream Type	Riparian Road Density (km/km^2)	Catchment Human Land Use	Catchment Forest
305BODBLK	5/2/2013	37.00343	-121.68015	16	148	Unregulated	1.76	7.1%	84.5%
305BODUPS	5/2/2013	36.99077	-121.70159	2	297	Unregulated	4.96	9.7%	85.3%
305CORBRN	4/29/2013	36.98956	-121.80276	48	72	Unregulated	3.48	9.8%	77.4%
305CORCOL	4/29/2013	37.00793	-121.80937	27	103	Unregulated	3.25	7.6%	82.4%
205COYGIL	5/3/2013	37.10168	-121.47259	208	283	Unregulated	0.15	0.6%	47.9%
205GUAHIC	5/3/2013	37.18262	-121.87312	11	197	Unregulated	0.81	2.8%	87.5%
305LARBRI	5/2/2013	37.03281	-121.70395	16	139	Unregulated	0.75	3.6%	83.4%
305LLAORO	4/30/2013	37.14706	-121.77431	18	217	Unregulated	0.20	2.3%	77.5%
305LLAOAK	4/30/2013	37.12623	-121.73218	37	170	Unregulated	1.01	3.5%	65.0%
305PES	4/29/2013	36.90183	-121.58526	28	34	Unregulated	0.45	3.5%	57.4%
305SWNUVA	4/30/2013	37.08595	-121.79258	3	325	Unregulated	0.06	4.7%	88.7%
305UVASWA	4/30/2013	37.08663	-121.79602	10	303	Unregulated	0.63	4.0%	76.9%
305CAN	4/29/2013	36.96022	-121.53374	187	41	Regulated	1.97	11.6%	61.7%
205COYRES	5/3/2013	37.12485	-121.55424	313	209	Regulated	0.37	1.4%	50.0%
205COYBUR	5/3/2013	37.16762	-121.6606	508	110	Regulated	0.51	2.9%	47.5%
305LLADSB	4/29/2013	36.97608	-121.51242	265	44	Regulated	3.51	51.4%	17.6%
305LLAEDM	4/30/2013	37.09346	-121.66818	58	119	Regulated	1.73	8.2%	55.7%
205ALIMCK	5/3/2013	37.20219	-121.82396	41	98	Regulated	1.38	7.1%	76.8%
305UVAXMA	5/2/2013	36.99823	-121.58426	179	61	Regulated	1.87	9.3%	63.4%
305UVATHO	5/2/2013	36.99067	-121.56784	180	59	Regulated	1.92	9.8%	62.9%
305CLRUPS	5/1/2013	36.37144	-120.7393	29	858	Southern	1.94	5.2%	25.7%
305CLRDWS	5/1/2013	36.36212	-120.75929	38	782	Southern	1.86	4.7%	29.6%
305SBACLR	5/1/2013	36.35856	-120.78617	141	747	Southern	2.13	3.8%	28.7%
305SBACIE	5/1/2013	36.67716	-121.2792	721	214	Southern	1.49	3.4%	18.6%
305SBAHER	5/1/2013	36.39209	-120.93436	337	563	Southern	1.50	2.5%	21.0%

Table 3. Mean percent fines, sand, and fines+sand for three stream types (Unregulated, n=12; Regulated, n=8; and Southern, n=5; Sites) for bankfull and wetted channel profiles and in each of two sediment count methods (reach scale n=100 points; patch-scale n=20 grids).

	Scale								
	Reach (Bankfull Width)			Reach (Wetted Width)			Sample Grid		
	% Fines	% Sand	% F+S	% Fines	% Sand	% F+S	% Fines	% Sand	% F+S
Unregulated	9.5	14.8	24.3	7.9	10.2	18.1	8.3	11.9	20.2
Regulated	27.5	10.8	38.3	20.2	10.2	30.4	22.6	7.6	30.2
Southern	34.6	11.8	46.4	17.8	11.3	29.1	24.2	11.2	35.4

Table 4. Indicator species analysis for quadrat samples excluding southern sites (n=80). Grouping categories were 0, >0-20, >20-40, >40-60, >60-80, and >80-100% fines+sand. These ranges correspond to grid counts in the 25-point quadrat frames of 0, 1-5, 6-10, 11-15, 16-20, and 21-25 intersects with fine and/or sand particles.

Indicator Species Analysis - Quadrat Samples		
	Max	
Taxon	Abundance	p-value
Rhyacophila betteni	0% F+S	0.0176
Calineuria californica	0% F+S	0.0256
Drunella flavilinea	0% F+S	0.0306
Ceratopsyche	0% F+S	0.0326
Epeorus	0% F+S	0.049
Thienemanniella xena	>0-20% F+S	0.0136
Eukiefferiella devonica	>0-20% F+S	0.0344
Dicrotendipes modestus	>40-60% F+S	0.0166
Paratanytarsus	>40-60% F+S	0.0296
Ostracoda	>60-80% F+S	0.0392

Table 5. Indicator species analysis for RWB samples including southern sites (n=25). Grouping categories were 0-20, 21-40, 41-100% fines+sand.

Indicator Species Analysis - RWB Samples		
	Max	
Taxon	Abundance	p-value
Nilotanypus	0% F+S	0.0076
Apatania	0% F+S	0.0098
Eubrianax edwardsii	0% F+S	0.014
Ordobrevia	0% F+S	0.0146
Ameletus	0% F+S	0.021
Drunella flavilinea	0% F+S	0.0252
Polypedilum tritum	0% F+S	0.033
Diphetor hageni	0% F+S	0.0422
Zaitzevia	0% F+S	0.0422
Micrasema	0% F+S	0.044

Table 6. Sediment TMDL targets using <u>wetted channel</u> habitat for Pajaro/Coyote streams defined according to FS thresholds established in central coast reference stream surveys (Herbst et al. 2011), and for salmonid habitat in existing Pajaro TMDL language.

Wetted Width Sediments			Reference Impairment Threshold					Salmonid Threshold	
Creek	Site		Reach F + S	Reach Fines	Reach Sands	Ave. Cobble Embedded-ness	Median Particle Size (mm)	Reach F + S	Reach Fines
Llagas Creek	Below Bloomfield	R	79%	59%	20%	51.8%	0.13	79%	59%
San Benito River	Below Cienega	S	54%	46%	7%	60.4%	1.25	54%	46%
Llagas Creek	Below Edmundson	R	43%	23%	20%	9.4%	6	43%	23%
Bodfish Creek	Blackhawk Down	UR	41%	2%	39%	27.2%	9	41%	2%
Uvas Creek	Christmas Hill Park	R	41%	15%	26%	1.6%	7.5	41%	15%
Corralitos Creek	Under Las Colinas Bridge	UR	32%	9%	23%	11.8%	42	32%	9%
Bodfish Creek	Upper	UR	29%	18%	11%	16.8%	18	29%	18%
Coyote Creek	End of Burnett Road	R	28%	20%	7%	9.8%	32	28%	20%
Clear Creek	Upper	S	27%	20%	7%	11%	47.5	27%	20%
San Benito River	Below Reservoir	S	24%	11%	14%	18.4%	60	24%	11%
Coyote Creek	Below Coyote Reservoir	R	22%	19%	3%	5.8%	64	22%	19%
Coyote Creek	Upper	UR	21%	7%	14%	17.7%	24	21%	7%
San Benito River	Below Clear Creek	S	21%	16%	5%	17%	20	21%	16%
Corralitos Creek	Above Browns Valley Road	UR	20%	11%	8%	29.6%	32	20%	11%
Clear Creek	Lower	S	19%	5%	15%	32.8%	21	19%	5%
Pescadero Creek	North	UR	18%	18%	0%	1.6%	19	18%	18%
Llagas Creek	Below Oak Glen	UR	16%	8%	8%	6.4%	58.5	16%	8%
Los Alamitos Creek	Below McKean	R	16%	10%	6%	21.4%	80	16%	10%
Swanson Creek	Above Uvas	UR	15%	2%	12%	11%	54.5	15%	2%
Little Arthur Creek	Above Third Bridge	UR	13%	4%	9%	15.4%	340	13%	4%
Uvas Creek	Lower - Below Thomas	R	11%	11%	0%	9.2%	28.5	11%	11%
Llagas Creek	Rancho Canada de Oro Park	UR	7%	0%	7%	2.8%	26	7%	0%
Guadalupe Creek	Below Hicks Road	UR	7%	7%	0%	13.2%	44	7%	7%
Carnadero Creek	Above Hwy 25	R	4%	4%	0%	0%	26	4%	4%
Uvas Creek	Above Swanson	UR	0%	0%	0%	6%	75	0%	0%

Note that reference impairment threshold refers to the percent of FS sediment found above the 90th percentile (dark gray) or 75th percentile (medium gray), or below (light gray) of all reference sites sampled during sediment studies (Herbst et al. 2011). These correspond to FS cover values of 42% and 35.5%, respectively, from reach-scale measures of FS on transects (SWAMP protocol).

Table 7. Sediment TMDL targets using bankfull channel habitat for Pajaro/Coyote streams defined according to FS thresholds established in central coast reference stream surveys (Herbst et al. 2011), and for salmonid habitat in existing Pajaro TMDL language. Coded as in Table 6.

Bankfull Sediment			Reference Impairment Threshold								Salmonid Threshold		
Creek	Site		Reach F + S	Reach Fines	Reach Sands	Quadrat F+S	Quadrat Fines	Quadrat Sand	Ave. Cobble Embeddedness	Median Particle Size (mm)	Reach F + S	Reach Fines	Spawning gravel percent
Llagas Creek	Below Bloomfield	R	87%	74%	13%	88%	84.6%	3.4%	51.8%	Fines	87%	74%	79%
San Benito River	Below Cienega	S	75%	69%	6%	67.6%	65.6%	2%	60.4%	Fines	75%	69%	5%
Llagas Creek	Below Edmundson	R	54%	32%	22%	49%	27.6%	21.4%	9.4%	Sand	54%	32%	30%
Clear Creek	Upper	S	49%	37%	12%	34.8%	7%	27.8%	11%	4	49%	37%	63%
San Benito River	Below Reservoir	S	47%	38%	9%	11.2%	5.4%	5.8%	18.4%	28.5	47%	38%	45%
Uvas Creek	Christmas Hill Park	R	47%	24%	23%	24%	11.4%	12.6%	1.6%	5	47%	24%	70%
Bodfish Creek	Upper	UR	41%	30%	11%	23.4%	14.6%	8.8%	16.8%	10	41%	30%	38%
Bodfish Creek	Blackhawk Down	UR	37%	2%	35%	14%	3.4%	10.6%	27.2%	15.5	37%	2%	35%
Pescadero Creek	North	UR	36%	27%	9%	30%	23.2%	6.8%	1.6%	15	36%	27%	52%
Corralitos Creek	Under Las Colinas Bridge	UR	36%	8%	28%	29.6%	4.2%	25.4%	11.8%	25.5	36%	8%	39%
Coyote Creek	End of Burnett Road	R	35%	26%	9%	13.4%	9.4%	4%	9.8%	29	35%	26%	27%
Clear Creek	Lower	S	31%	16%	15%	29.6%	14.4%	15.2%	32.8%	17	31%	16%	52%
San Benito River	Below Clear Creek	S	30%	13%	17%	33.8%	28.4%	5.4%	17%	25	30%	13%	32%
Llagas Creek	Below Oak Glen	UR	29%	12%	17%	21.6%	12.2%	9.4%	6.4%	35.5	29%	12%	23%
Corralitos Creek	Above Browns Valley Road	UR	29%	10%	19%	19.2%	7.8%	11.4%	29.6%	20.5	29%	10%	25%
Los Alamitos Creek	Below McKean	R	27%	19%	8%	24.2%	15.4%	8.8%	21.4%	40.5	27%	19%	28%
Coyote Creek	Upper	UR	25%	11%	14%	22.8%	5.4%	17.4%	17.7%	25	25%	11%	50%
Carnadero Creek	Above Hwy 25	R	19%	14%	5%	8.8%	4.2%	4.6%	0%	21	19%	14%	28%
Coyote Creek	Below Coyote Reservoir	R	19%	14%	5%	21.6%	21.6%	0%	5.8%	59	19%	14%	51%
Uvas Creek	Lower - Below Thomas	R	18%	17%	1%	12.6%	6.6%	6%	9.2%	25	18%	17%	80%
Swanson Creek	Above Uvas	UR	16%	4%	12%	23%	8%	15%	11%	55.5	16%	4%	48%
Llagas Creek	Rancho Canada de Oro Park	UR	16%	1%	15%	18.8%	2.6%	16.2%	2.8%	21	16%	1%	33%
Little Arthur Creek	Above Third Bridge	UR	14%	4%	10%	16.2%	5%	11.2%	15.4%	275	14%	4%	40%
Guadalupe Creek	Below Hicks Road	UR	8%	5%	3%	13.2%	10.8%	2.4%	13.2%	33	8%	5%	27%
Uvas Creek	Above Swanson	UR	5%	0%	5%	10.2%	1.8%	8.4%	6%	48.5	5%	0%	66%

Table 8. Pajaro/Coyote streams ranked according to targets for EPT diversity established from reference streams of the central coast region (Herbst et al. 2011). In the right columns, if the stream reach has less than 20% FS, it is coded green, 20-40% FS then coded yellow, and greater than or equal to 40% FS then coded red. Stream type shown as UR = unregulated, R = regulated, and S = southern. Metrics highlighted in red = biological levels exceeded, yellow = warning of exceedance, and green = biological levels not exceeded. Where EPT column is red or yellow, and whichever FS measure is used to represent sediment level is also red or yellow, sediment is likely to be a problem, and these may be prioritized for sediment management or control.

Creek Name	Site Name		EPT Richness	FS Bankfull 20-40% or >40%?	FS Wetted Channel 20-40% or >40%?
Llagas Creek	Below Bloomfield	R	0	87%	79%
San Benito River	Below Cienega	S	1	75%	54%
Carnadero Creek	Above Hwy 25	R	5	19%	4%
Coyote Creek	Below Coyote Reservoir	R	5	19%	22%
Llagas Creek	Below Edmundson	R	6	54%	43%
Coyote Creek	End of Burnett Road	R	7	35%	28%
Clear Creek	Upper	S	8	49%	27%
Clear Creek	Lower	S	8	31%	19%
Los Alamitos Creek	Below McKean	R	8	27%	16%
San Benito River	Below Reservoir	S	9	47%	24%
San Benito River	Below Clear Creek	S	10	30%	21%
Uvas Creek	Lower - Below Thomas	R	11	18%	11%
Uvas Creek	Christmas Hill Park	R	12	47%	41%
Pescadero Creek	North	UR	13	36%	18%
Llagas Creek	Below Oak Glen	UR	15	29%	16%
Bodfish Creek	Blackhawk Down	UR	15	37%	41%
Bodfish Creek	Upper	UR	15	41%	29%
Corralitos Creek	Above Browns Valley Road	UR	16	29%	20%
Coyote Creek	Upper	UR	19	25%	21%
Llagas Creek	Rancho Canada de Oro Park	UR	21	16%	7%
Corralitos Creek	Under Las Colinas Bridge	UR	22	36%	32%
Guadalupe Creek	Below Hicks Road	UR	22	8%	7%
Little Arthur Creek	Above Third Bridge	UR	24	14%	13%
Swanson Creek	Above Uvas	UR	26	16%	15%
Uvas Creek	Above Swanson	UR	32	5%	0%

Table 9. Multi-Response Permutation Procedure Pair-wise Comparisons. MRPP is a non-parametric procedure for testing the hypothesis of no difference between groups illustrated in Figure 17. The test statistic (T) describes the separation between groups (lower = more separation). The agreement statistic (A) describes the within group homogeneity. The p-value (P) indicates significant difference between compared groups when below 0.05 (highlighted in yellow). Note: p-values not corrected for multiple comparisons.

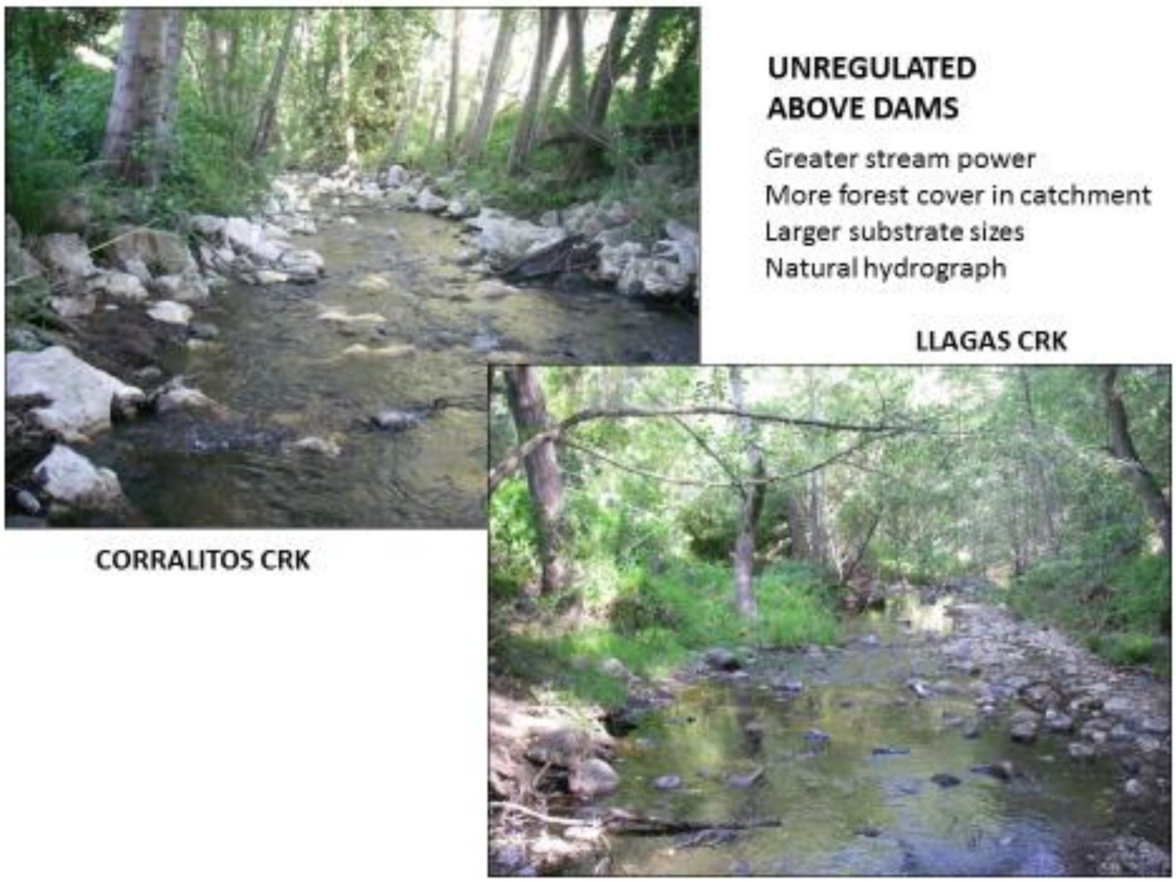
			Test Statistic (T)	Agreement Statistic (A)	P-Value (P)
0%	vs.	>0% - 20%	0.1020	-0.0009	0.4301
0%	vs.	>60% - 80%	-4.7809	0.0401	0.0016
0%	vs.	>40% - 60%	-5.2429	0.0464	0.0008
0%	vs.	>80% - 100%	-5.3639	0.0340	0.0007
0%	vs.	>20% - 40%	-5.6377	0.0410	0.0004
>0% - 20%	vs.	>60% - 80%	-2.4629	0.0305	0.0250
>0% - 20%	vs.	>40% - 60%	-2.0126	0.0258	0.0439
>0% - 20%	vs.	>80% - 100%	-0.9900	0.0094	0.1467
>0% - 20%	vs.	>20% - 40%	-2.6109	0.0276	0.0225
>60% - 80%	vs.	>40% - 60%	-0.0949	0.0012	0.3797
>60% - 80%	vs.	>80% - 100%	0.4623	-0.0044	0.6127
>60% - 80%	vs.	>20% - 40%	-0.3703	0.0037	0.2911
>40% - 60%	vs.	>80% - 100%	-0.3590	0.0033	0.2908
>40% - 60%	vs.	>20% - 40%	-0.7845	0.0077	0.1875
>80% - 100%	vs.	>20% - 40%	-1.4136	0.0112	0.0916

Table 10. Guidance table for distinguishing sediment impacts.

Water quality impacts associated with EPT richness and percent fines & sands.

EPT Richness	Percent Fines and Sands	Impacts to BMI from Sediment
>16	0-20	No
	>20-40	No determination
	>40	No determination
12 to ≤ 16	0-20	Unlikely
	>20-40	Possibly
	>40	Likely
<12	0-20	Unlikely
	>20-40	Likely
	>40	Likely

Examples of stream types found in the Pajaro Region:



REGULATED BELOW DAMS

More fine sediment
More turbidity
More urban/ag cover
Greater road density

UVAS CRK

LLAGAS CRK

Obviously these streams also have altered hydrographs

SOUTHERN
above & below dams

Arid climate
Warmer temperatures
High conductivity
Higher elevation
Serpentine geology

CLEAR CRK

SAN BENITO R

Carnadero Creek

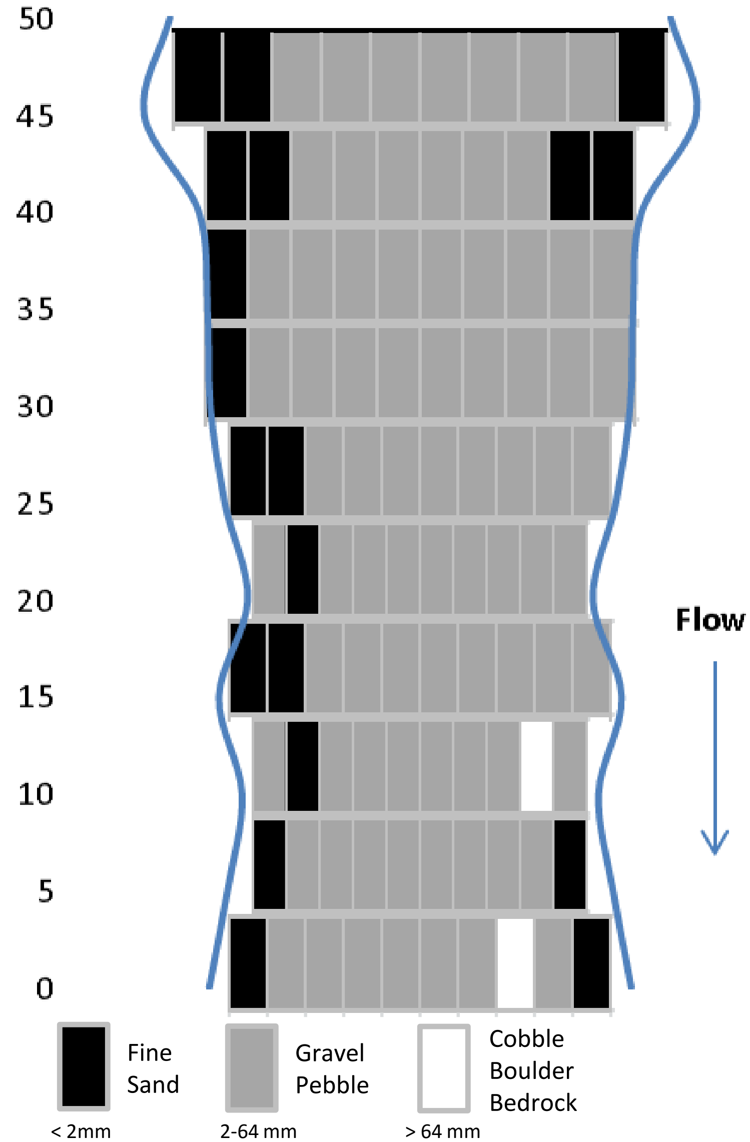
Above Hwy 25

50 m
down

← down 25 up →

0 m
up

Average Bankfull Width: 7.34 m



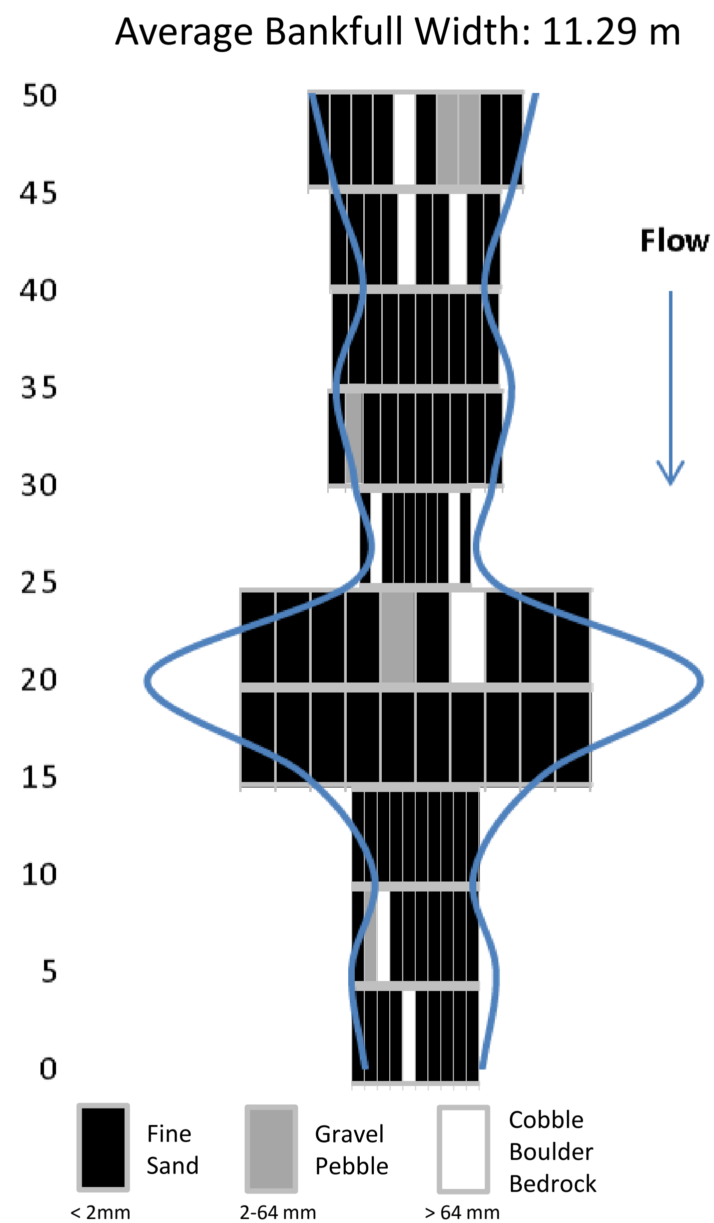
Llagas Creek

Below Bloomfield rd

50 m
down

←
up
25
down
→

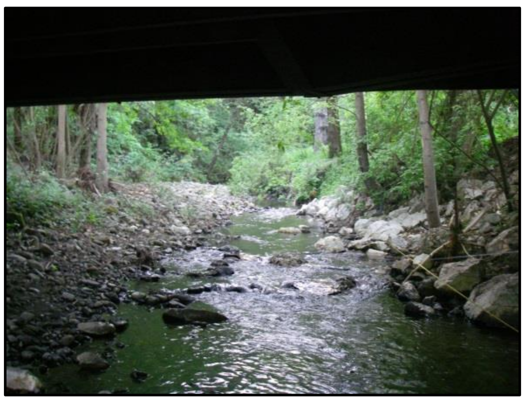
0 m
up



Corralitos Creek

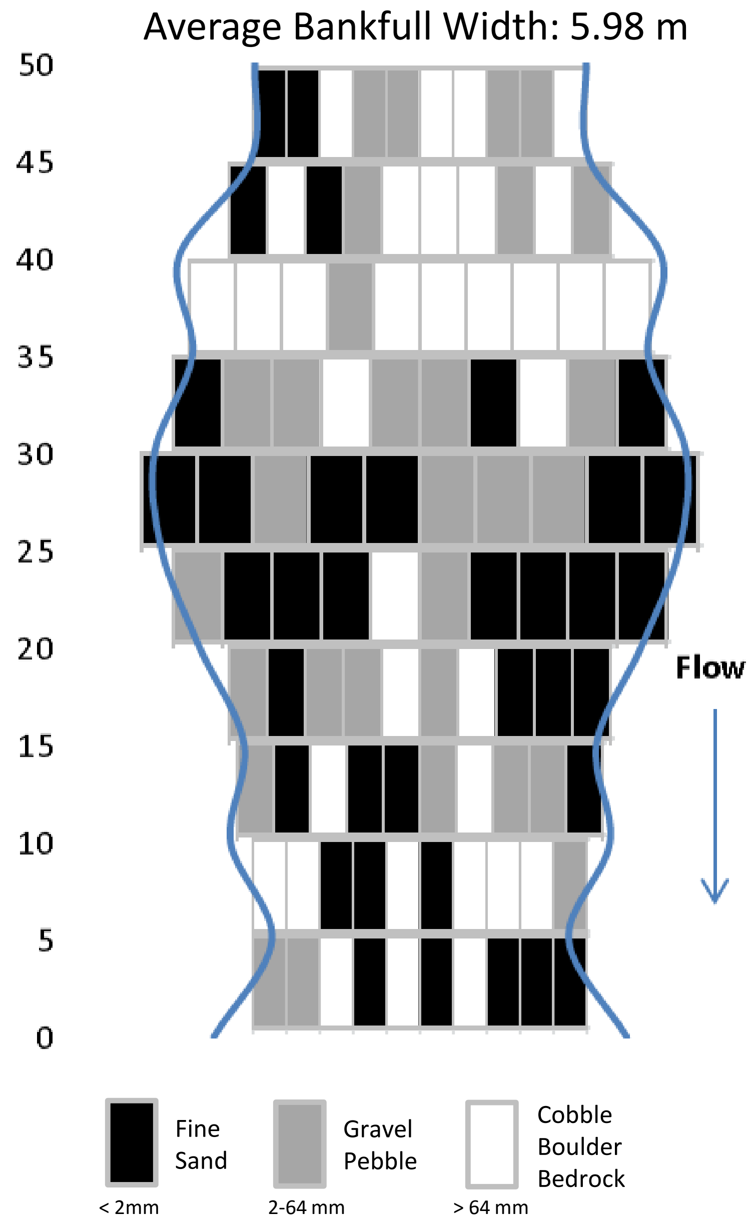
Under Las Colinas Bridge

50 m
down



←
up
25
down
→

0 m
up



Pescadero Creek

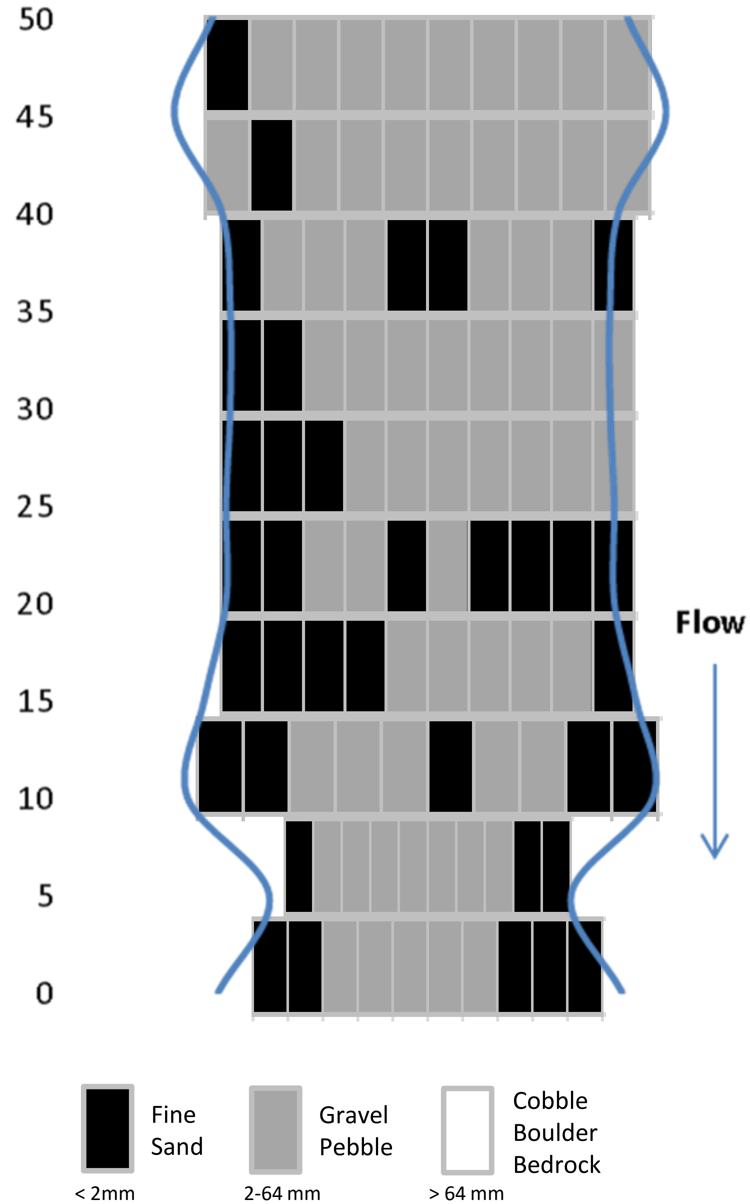
North

50 m
down

←
up
25
down
→

0 m
up

Average Bankfull Width: 4.68 m

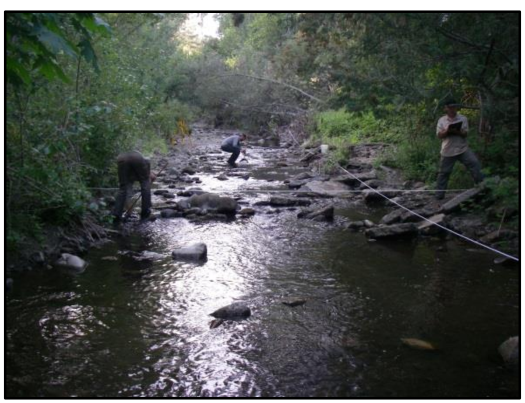


Corralitos Creek

Above Browns Valley Road

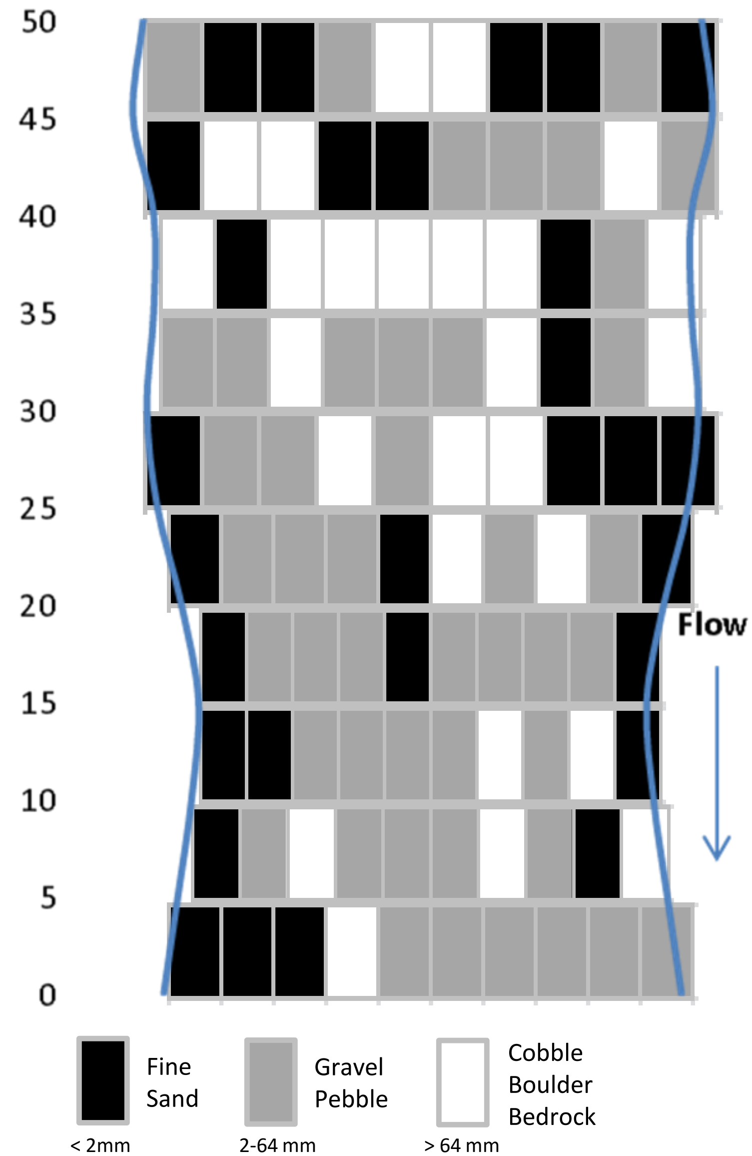
50 m
down

← up
25
down →



0 m
up

Average Bankfull Width: 7.51 m



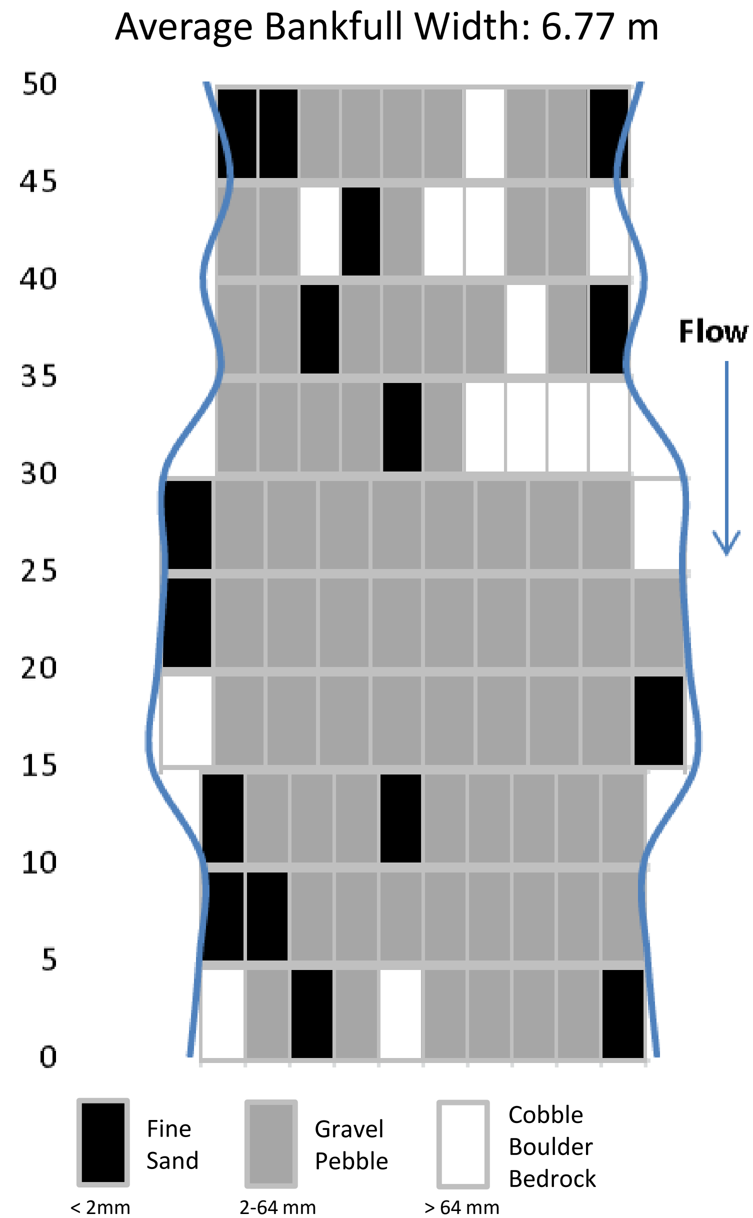
Llagas Creek

Rancho Cañada de Oro Park

50 m
down

← up
25
down →

0 m
up



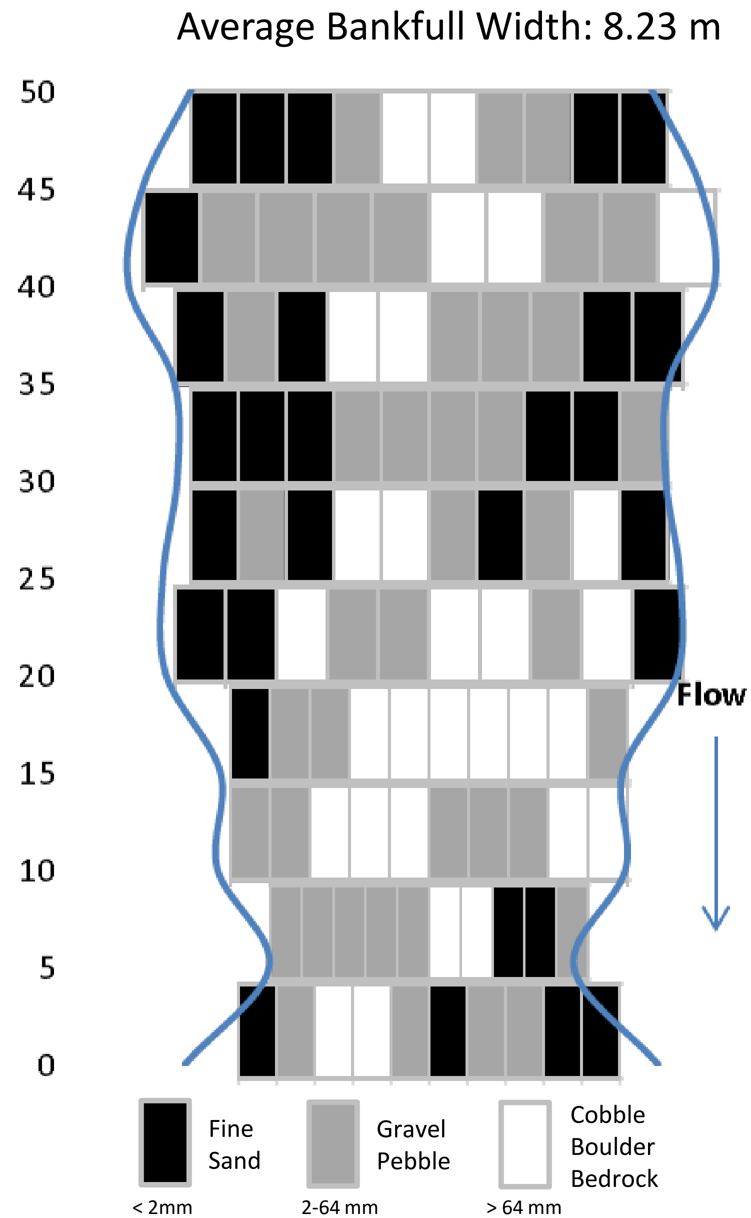
Llagas Creek

Below Oak Glen

50 m
down

←
up
25
down
→

0 m
up

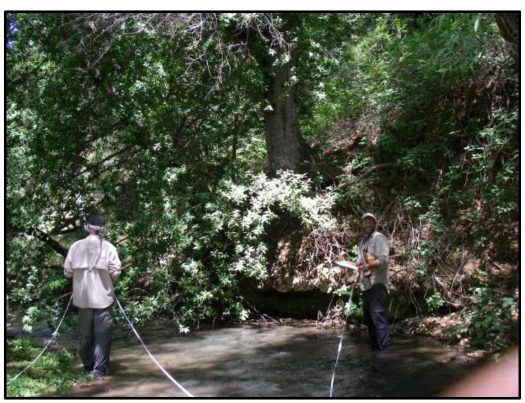


Llagas Creek

Below Edmundson

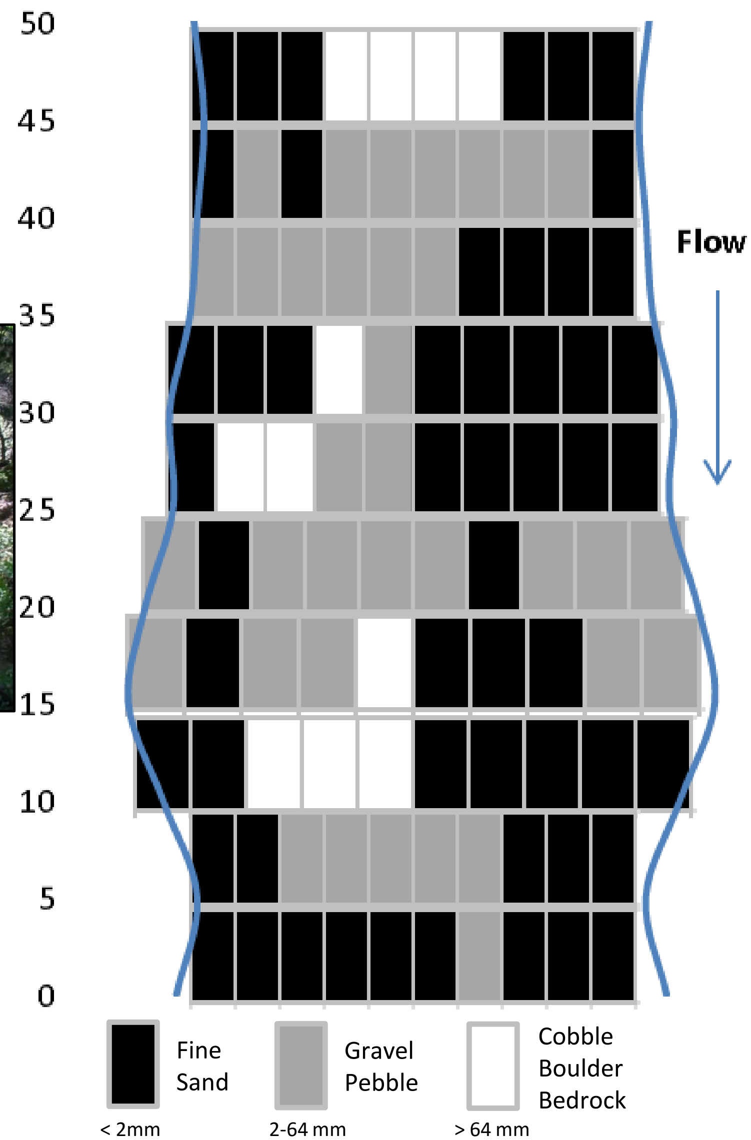
50 m
down

←
up
25
down
→



0 m
up

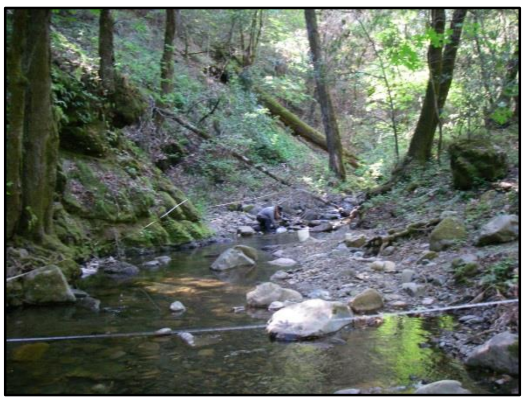
Average Bankfull Width: 7.11 m



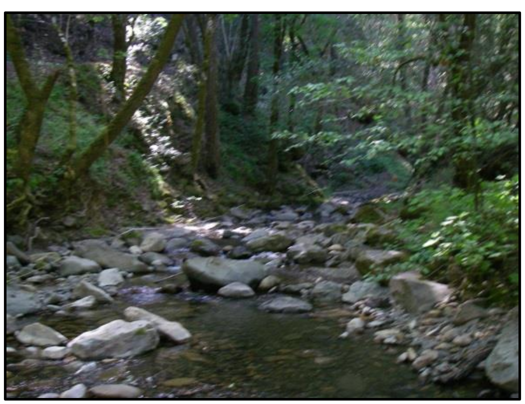
Uvas Creek

Above Swanson

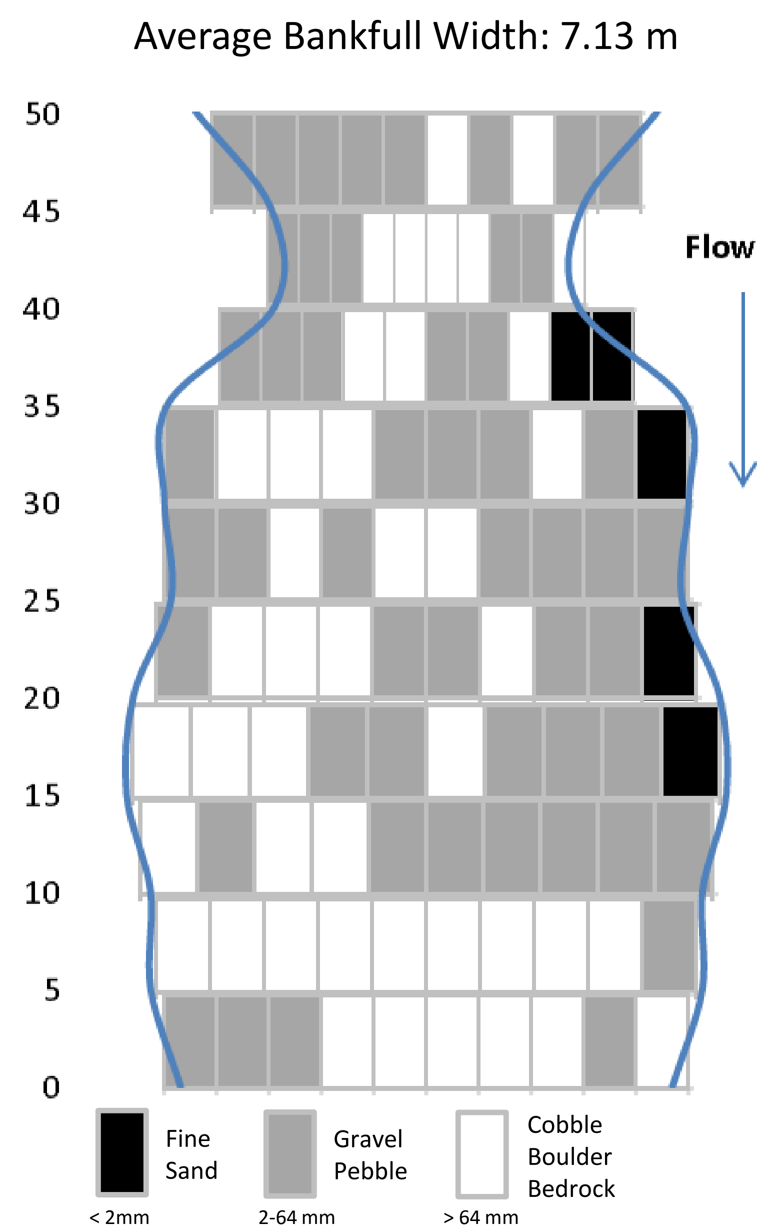
50 m
down



←
up
25
down
→

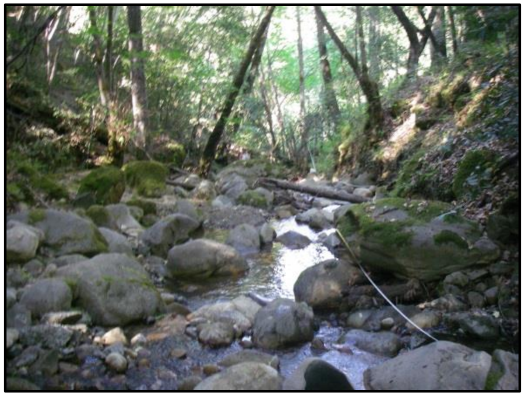


0 m
up

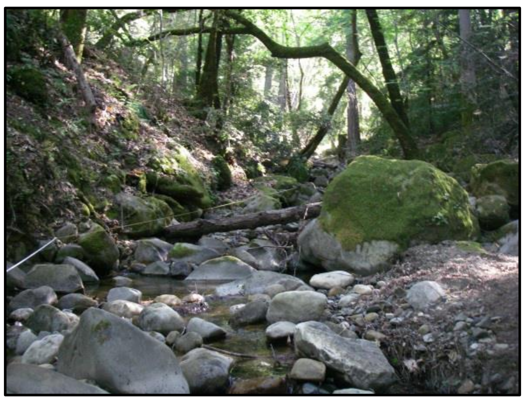


Swanson Creek

Above Uvas

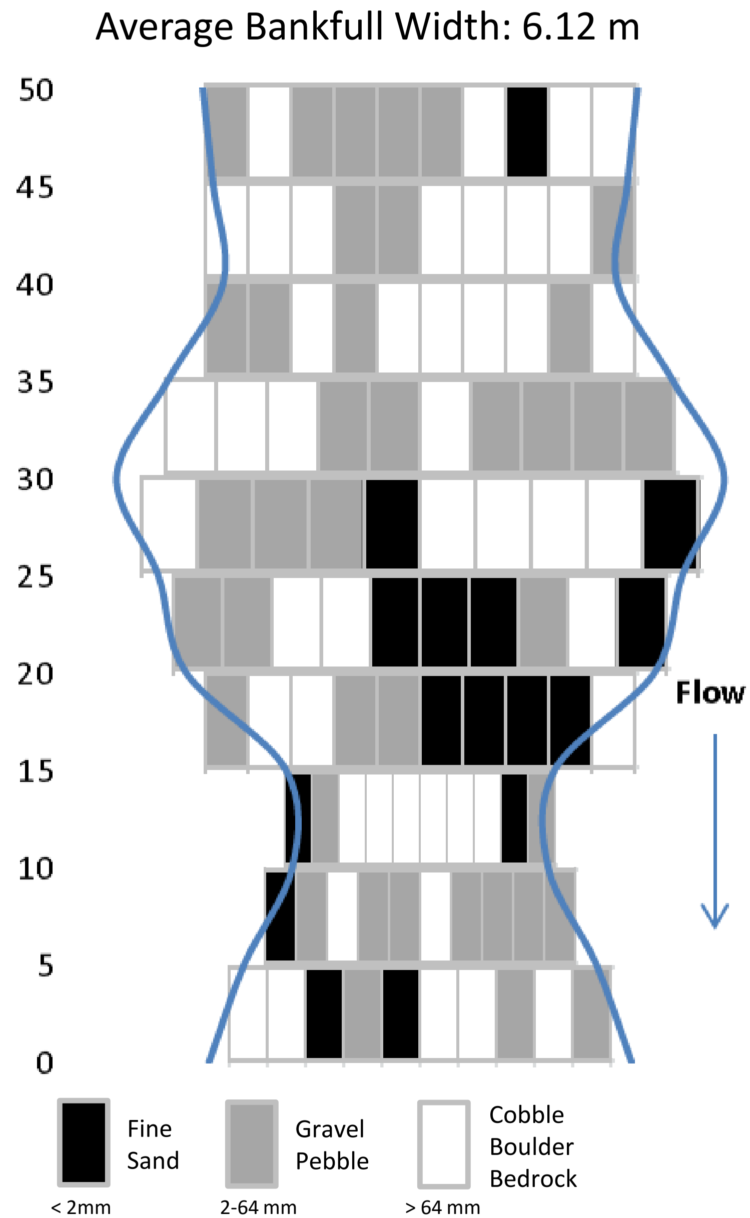


50 m
down



←
up
25
down
→

0 m
up



Clear Creek

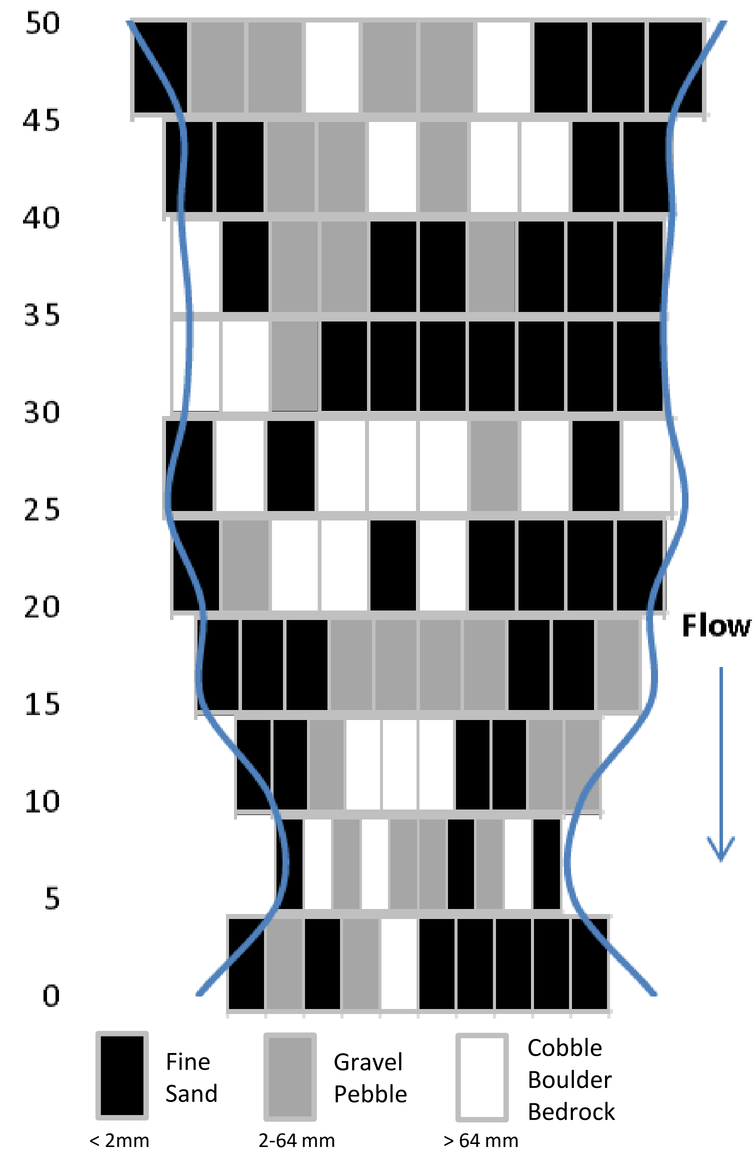
Upper

50 m
down

←
up
25
down
→

0 m
up

Average Bankfull Width: 5.28 m



Clear Creek

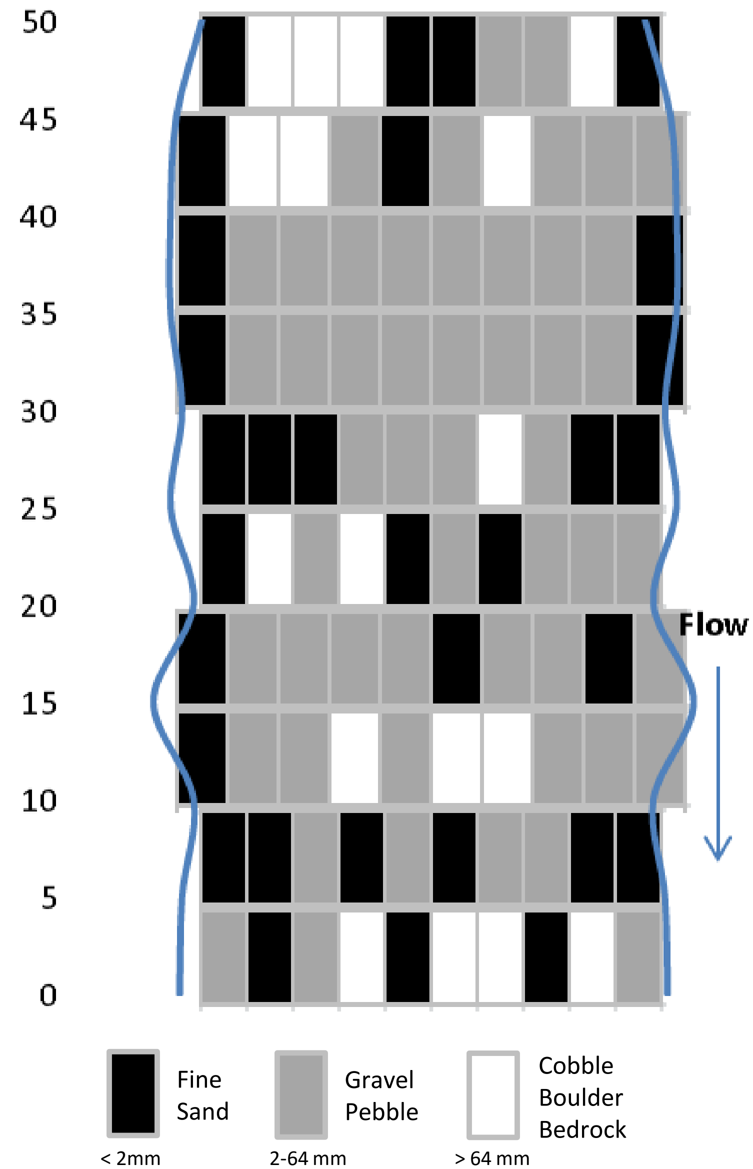
Lower

50 m
down

←
up
25
down
→

0 m
up

Average Bankfull Width: 4.25 m



San Benito River

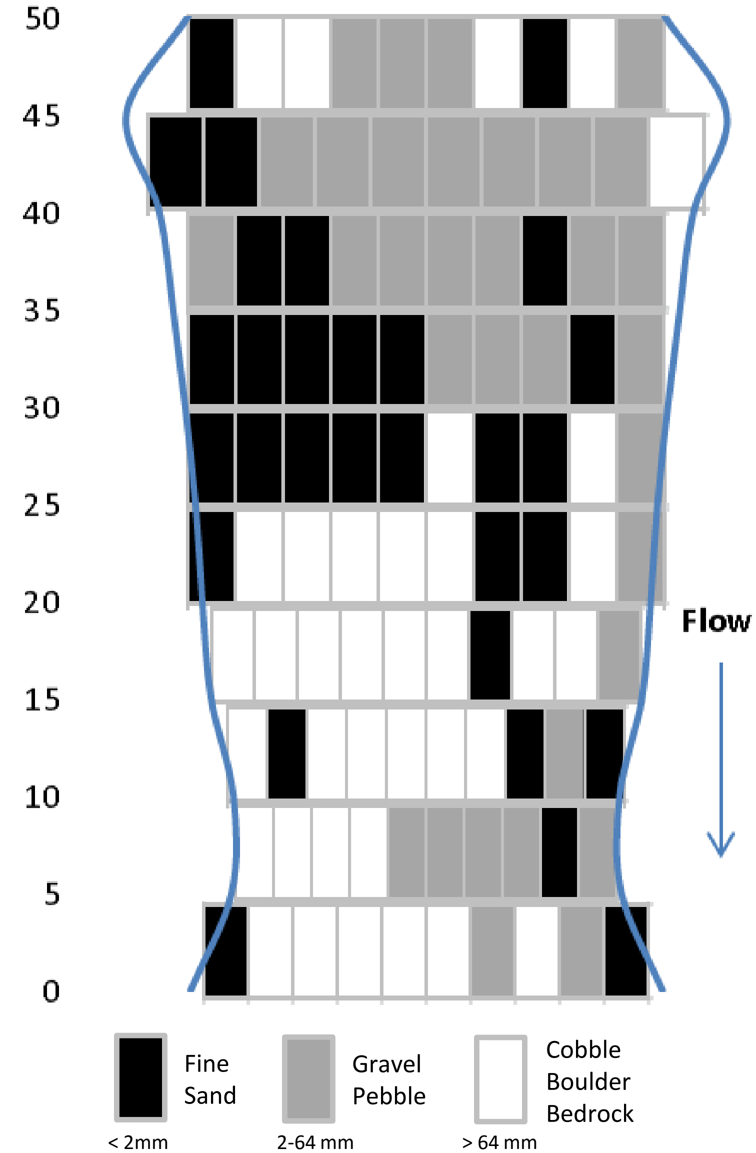
Below Clear Creek

50 m
down

←
up
25
down
→

0 m
up

Average Bankfull Width: 13.68 m



San Benito River

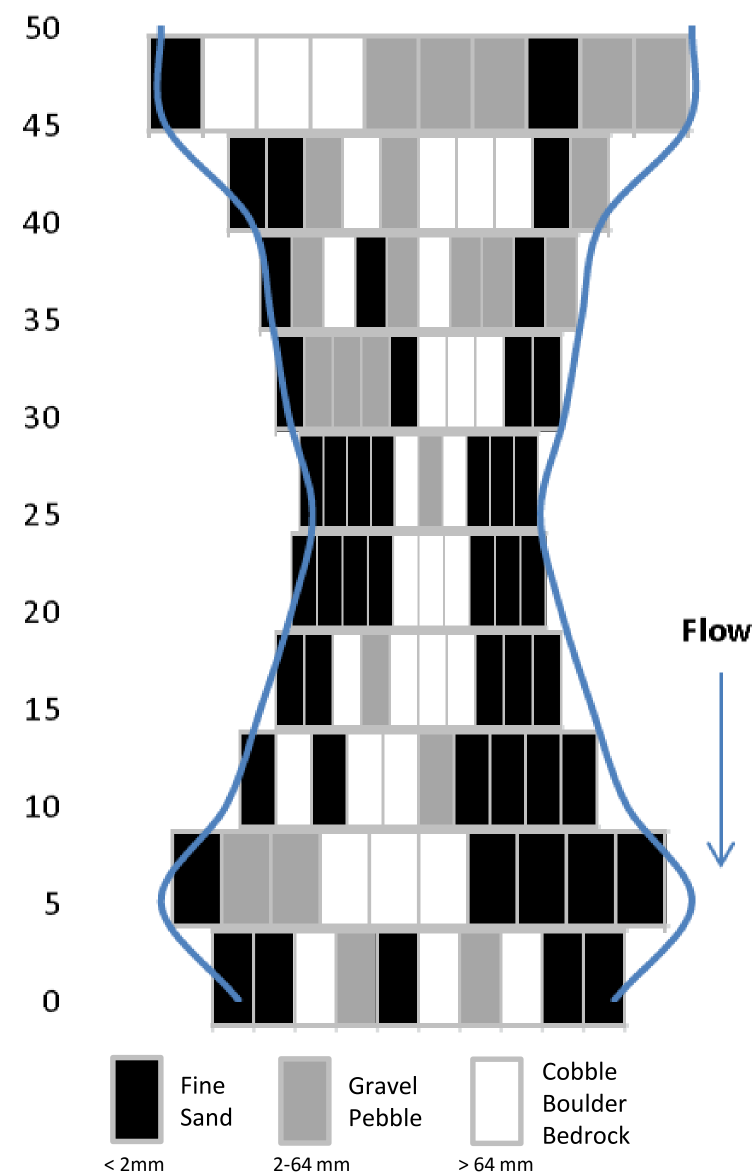
Below Reservoir

50 m
down

←
up
25
down
→

0 m
up

Average Bankfull Width: 5.44 m



San Benito River

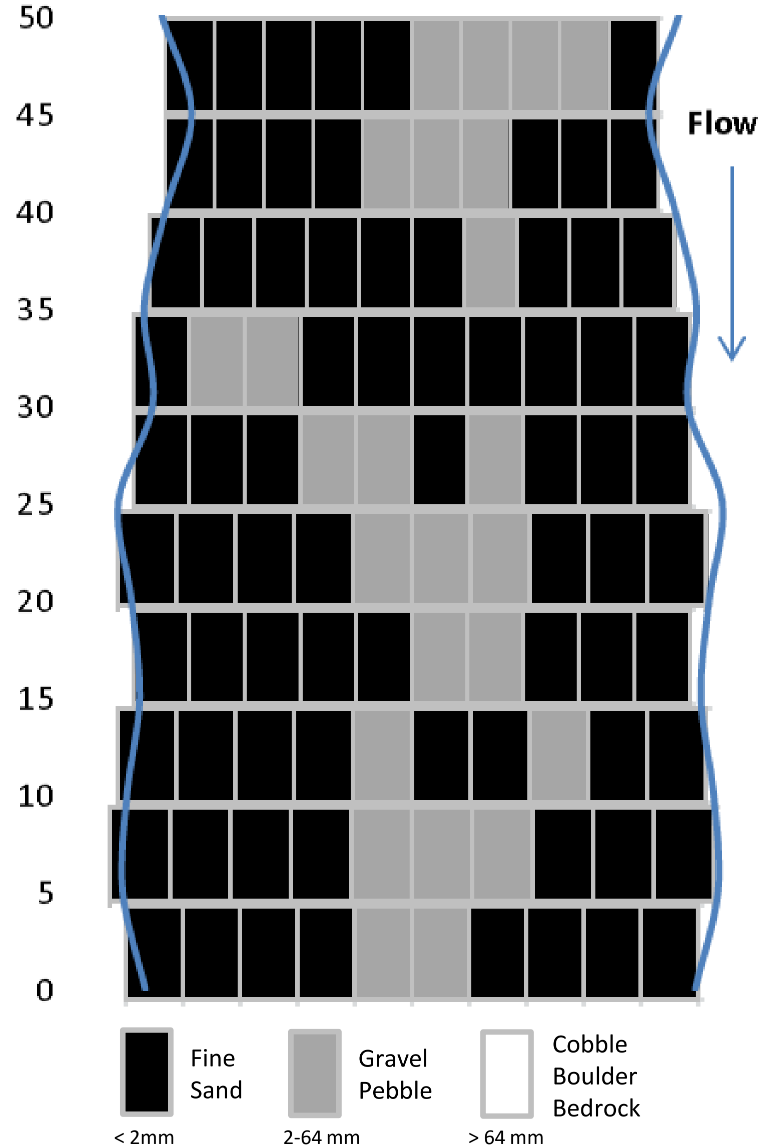
Below Cienega

50 m
down

←
up
25
down
→

0 m
up

Average Bankfull Width: 6.37 m



Little Arthur Creek

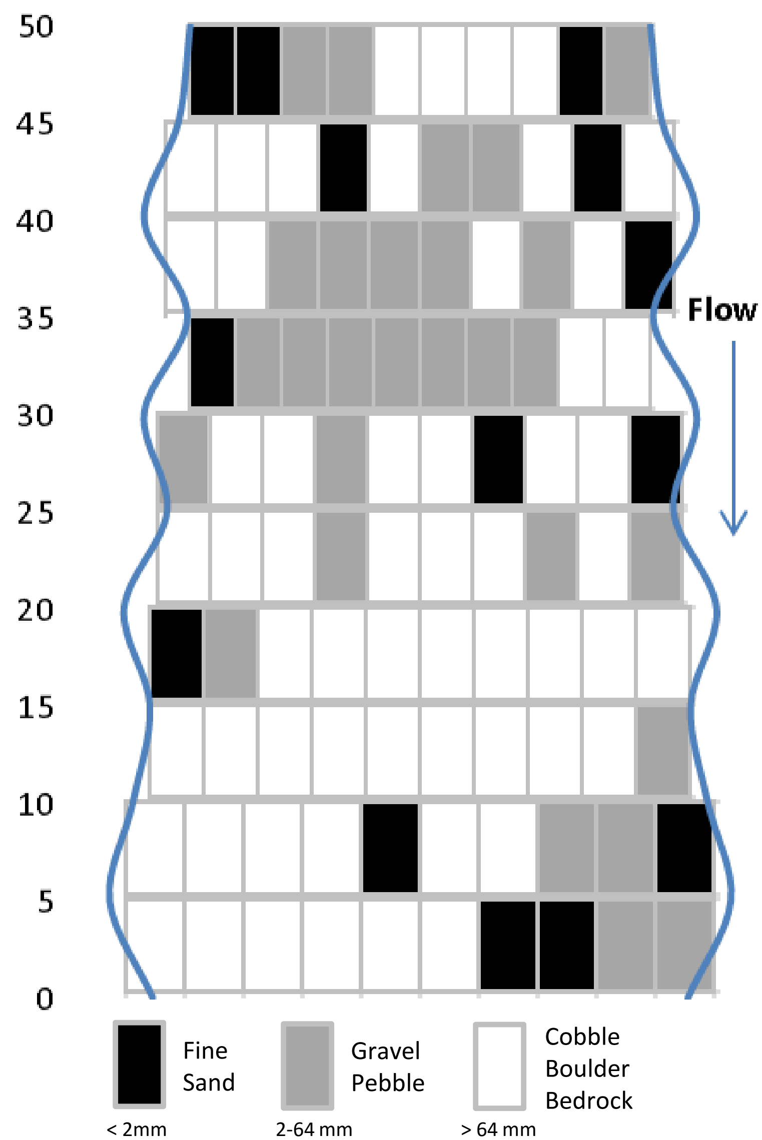
Above Third Bridge

50 m
down

←
up
25
down
→

0 m
up

Average Bankfull Width: 4.65 m



Bodfish Creek

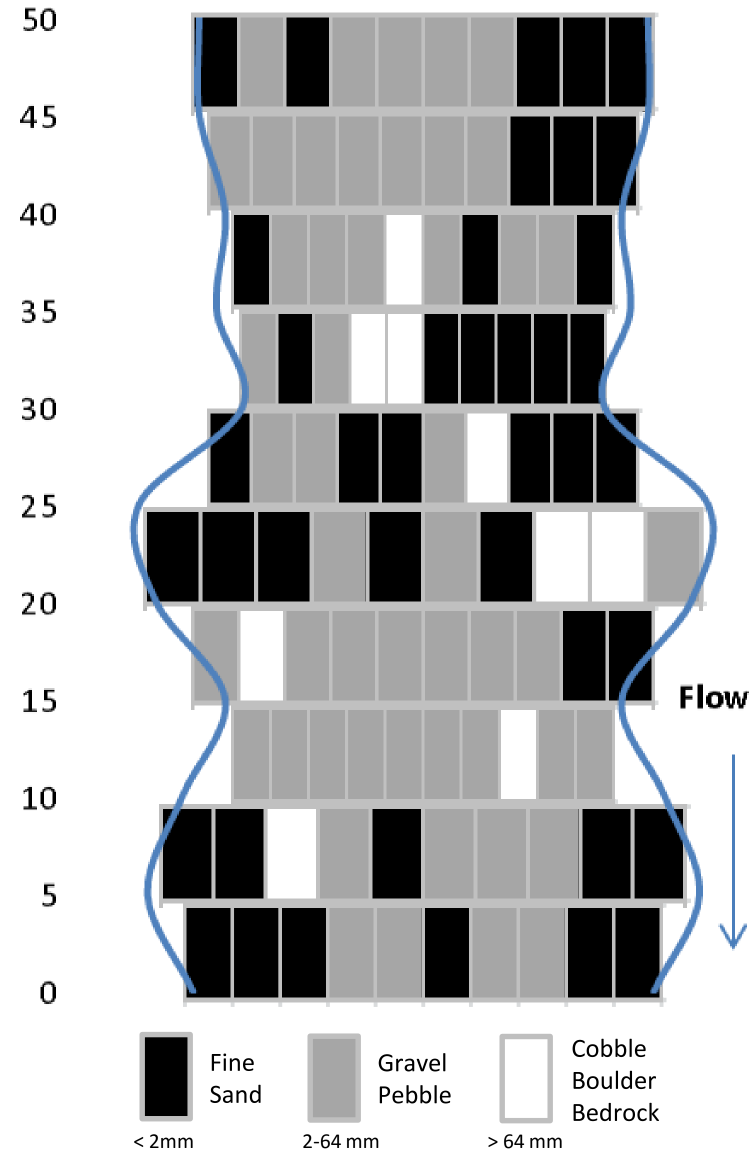
Upper

50 m
down

←
up
25
down
→

0 m
up

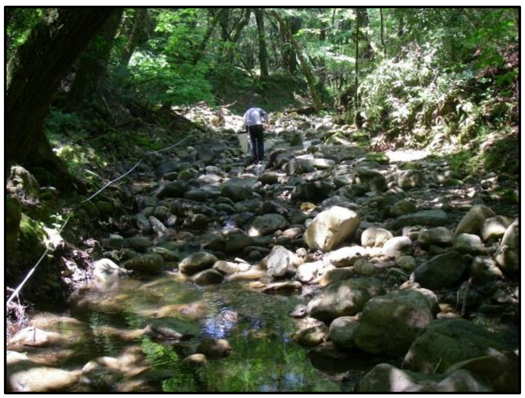
Average Bankfull Width: 2.67 m



Bodfish Creek

Blackhawk Down

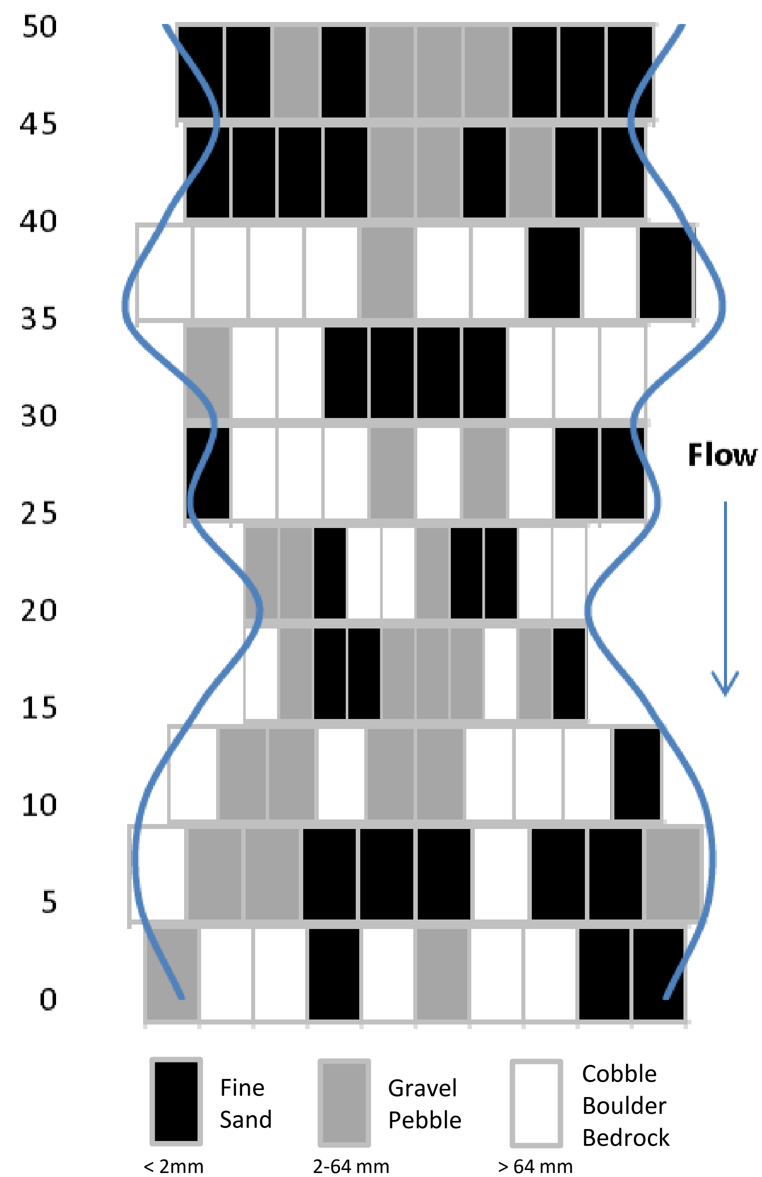
50 m
down



←
up
25
down
→

0 m
up

Average Bankfull Width: 5.61 m



Uvas Creek

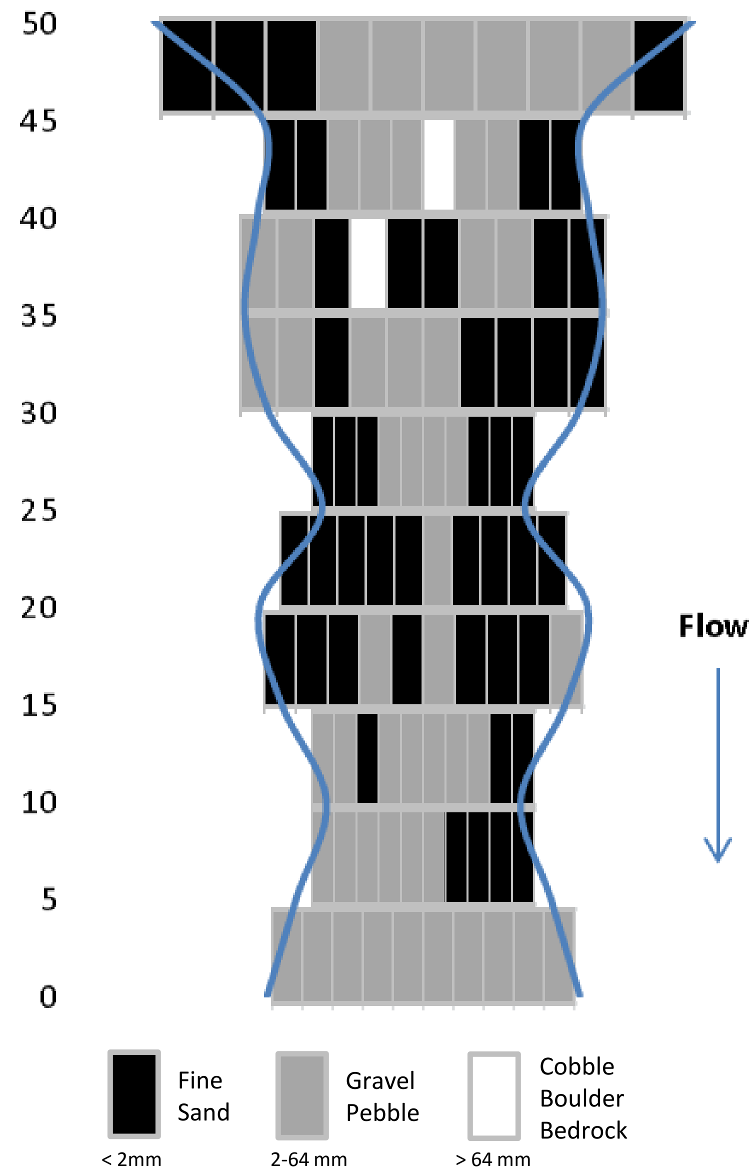
Christmas Hill Park

50 m
down

←
up
25
down
→

0 m
up

Average Bankfull Width: 7.25 m



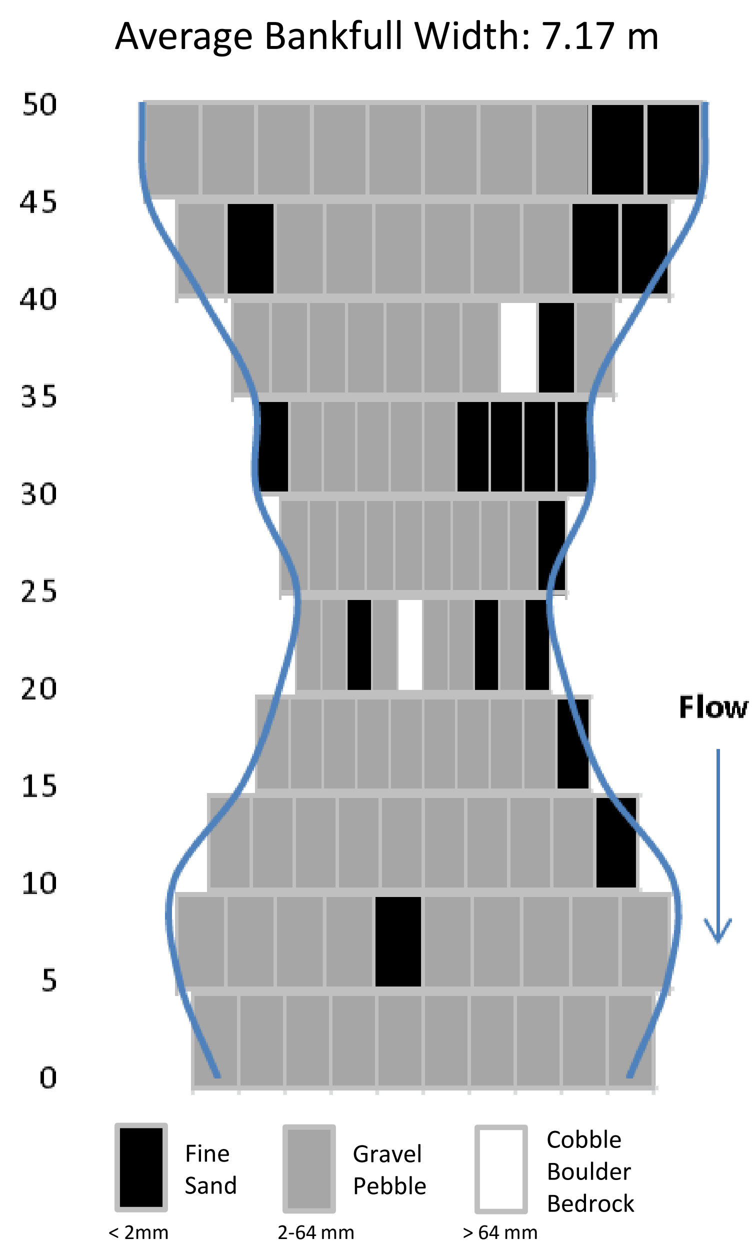
Uvas Creek

Lower Below Thomas

50 m
down

←
up
25
down
→

0 m
up



Coyote Creek

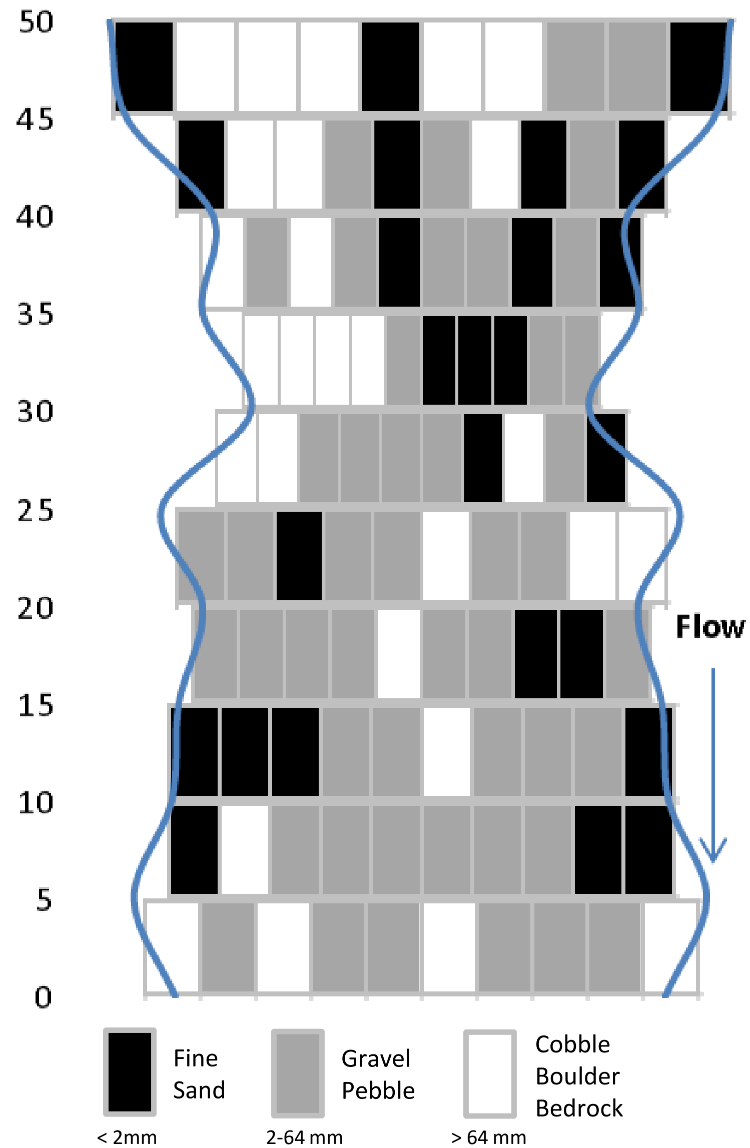
Upper

50 m
down

←
up
25
down
→

0 m
up

Average Bankfull Width: 7.10 m

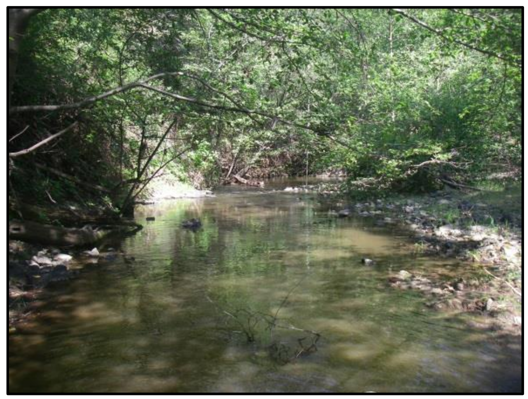


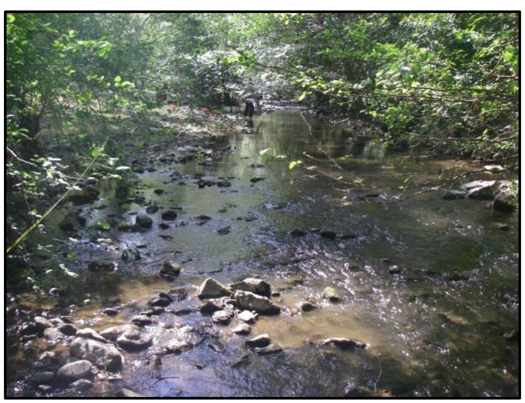
Coyote Creek

Below Coyote Reservoir

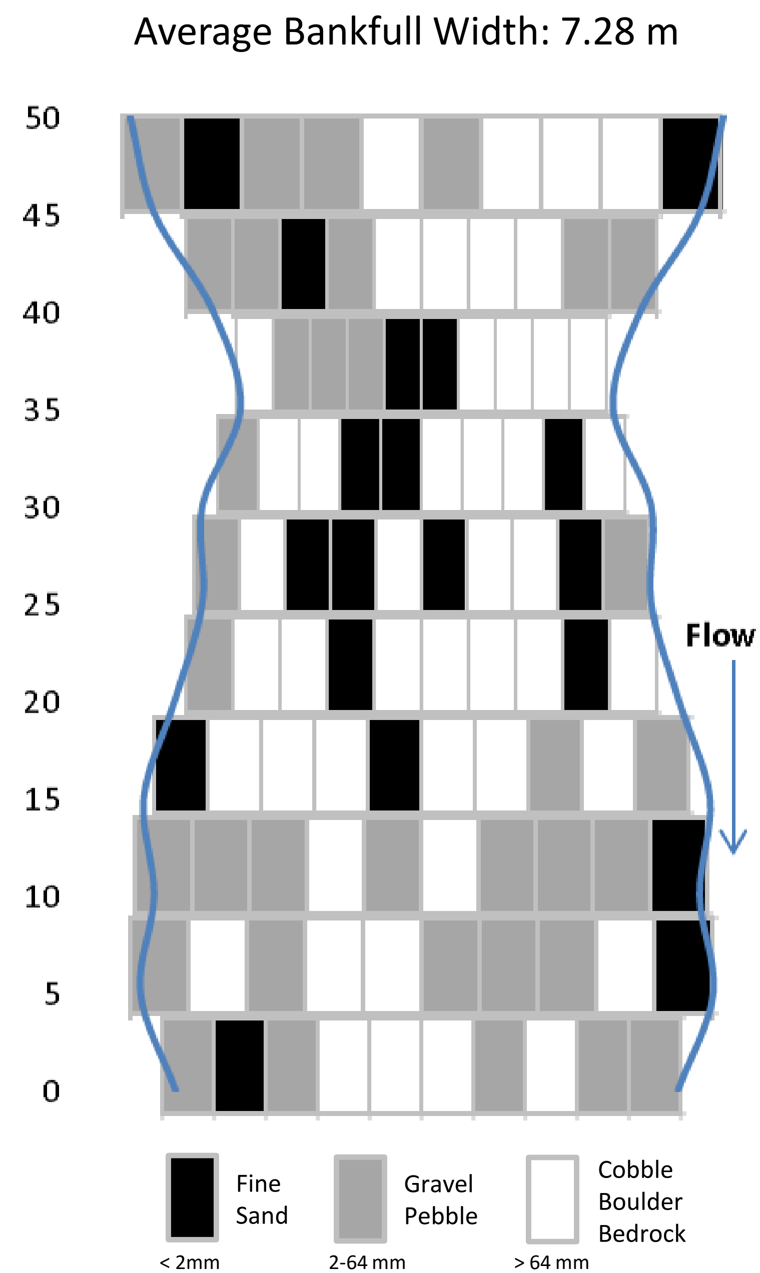
50 m
down

←
up
25
down
→





0 m
up



Coyote Creek

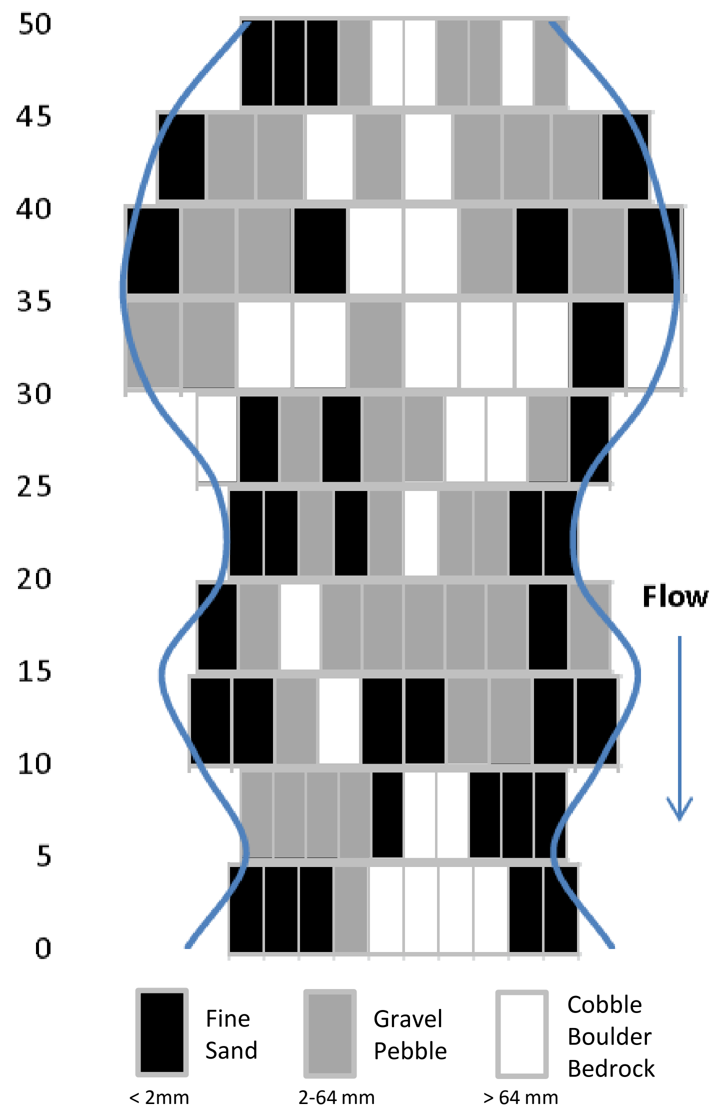
End of Burnett

50 m
down

←
up
25
down
→

0 m
up

Average Bankfull Width: 10.36 m



Los Alamitos Creek

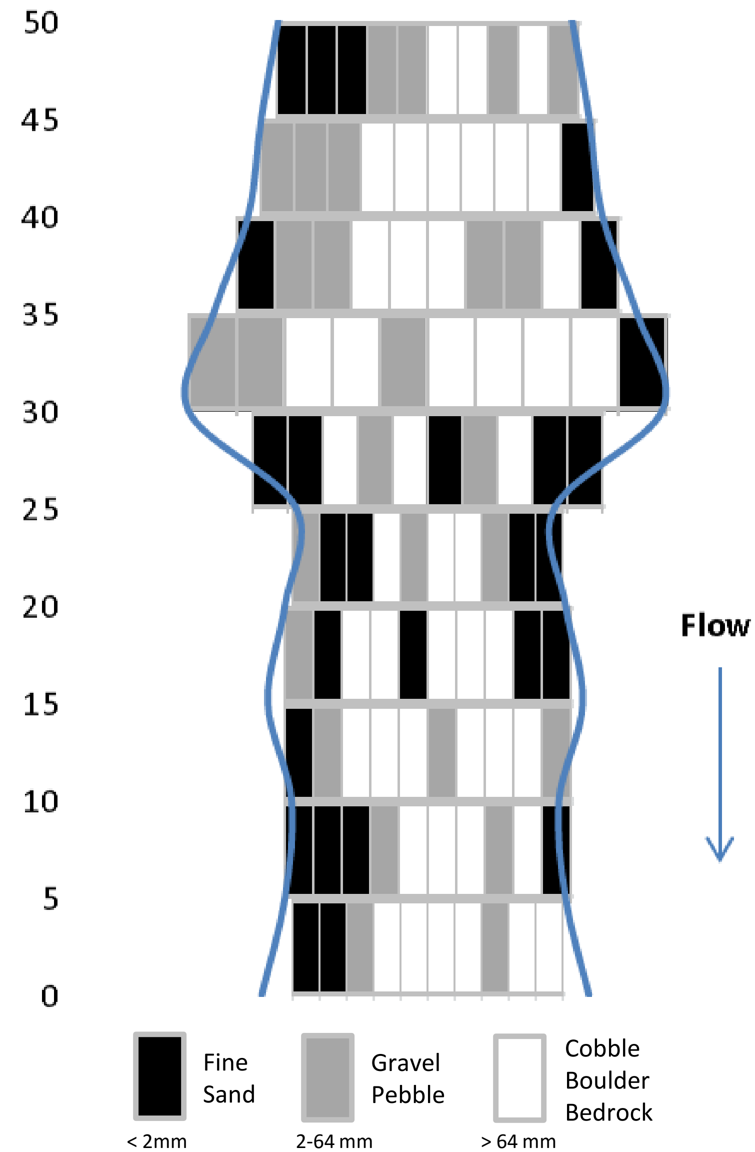
Below McKean

50 m
down

← up
25
down →

0 m
up

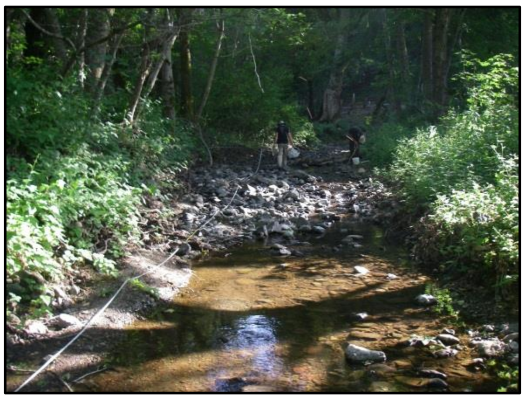
Average Bankfull Width: 7.59 m



Guadalupe Creek

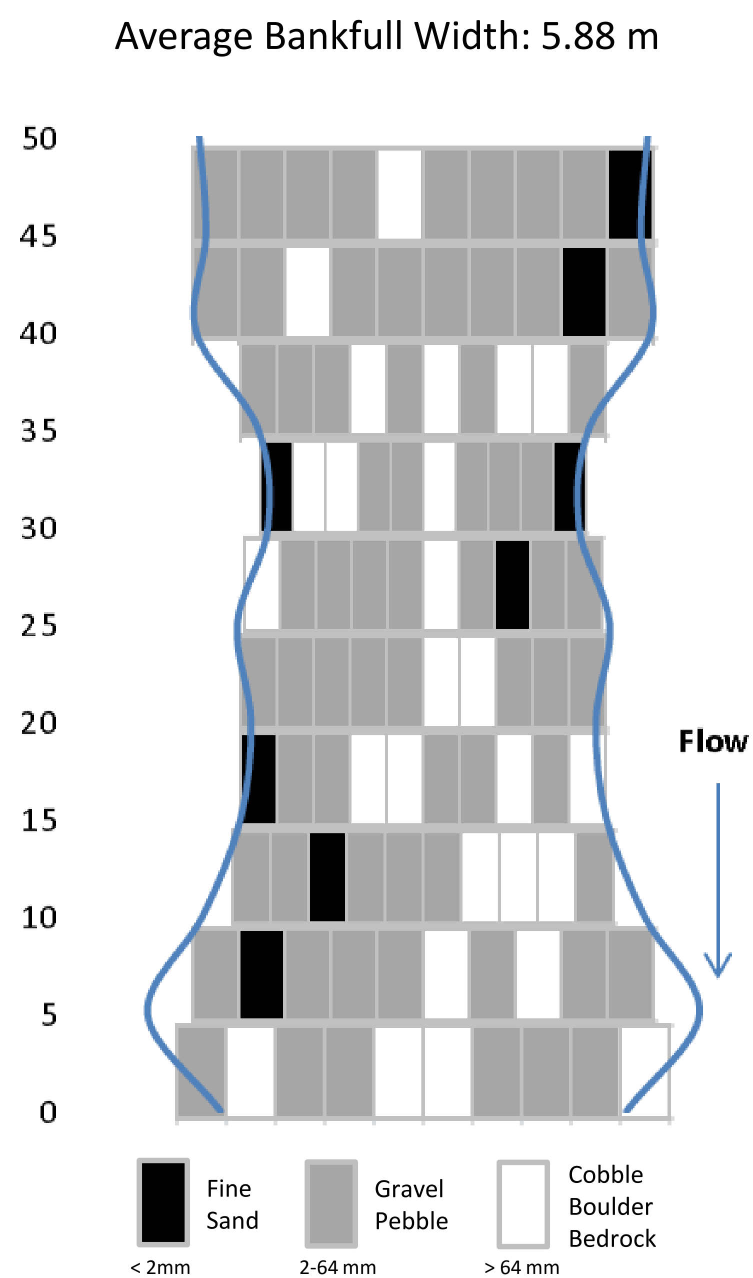
Below Hicks Road

50 m
down



←
up
25
down
→

0 m
down



Pajaro River Field Form   Stream & Site name: Date:

Habitat zones (delineate R/P):

Time of Day	

GPS	Lat	Lon

	BFW	Lw/H	Rw/H		1	2	3	4	5	6	7	8	9	10	Hum. Impact	Bank Cover & EVS
5				D											L	
R.cover Densio				S											R	
10				D											L	
R.cover Densio				S											R	
15				D											L	
R.cover Densio				S											R	
20				D											L	
R.cover Densio				S											R	
25				D											L	
R.cover Densio				S											R	
30				D											L	
R.cover Densio				S											R	
35				D											L	
R.cover Densio				S											R	
40				D											L	
R.cover Densio				S											R	
45				D											L	
R.cover Densio				S											R	
50				D											L	
R.cover Densio				S											R	

Embeddedness (cobble; pebble if none)				

Grid Frame Counts of F / S				
Photos: 0- 25- 50-				

Spec.Cond.	Slope 0-25
	up
Temp.	down
	Slope 25-50
pH	up
	down

BFW=bankfull width; Lw=left water; Rw=right water; H=height to water; D=depth; S=substrate size, mm; R.cover=Lbank/Lcenter-U/D-Rcenter/Rbank
Where depth is to dry bed, this is measured as height to bed and marked **X**); If wet, D=water depth and then heights = H+D(water).
For Human Impact disturbances, circle if within BF channel, do not circle if outside channel (letter-coded by type of impact)