Variations in Sediment Regime and Implications for Stream Habitats By Region in Tuolumne Watershed

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Introduction:

The Tuolumne River travels ~140 miles through the geologically complex Sierra Nevada Mountain Range. Making its way from Lyell Glacier (13,000ft) to its confluence with the San Joaquin River (50ft), the Tuolumne River erodes, transports, and deposits sediment that eventually forms habitat for many stream species. The variation of this sediment is directly related to sediment regime that is dominant at each locality (Allan 2009). Broadly speaking, there are three dominant types of sedimentary regime: erosion dominated (source zone), transport dominated (transfer zone), and deposition dominated (storage zone); though in reality these regimes are often superimposed upon each other in a temporally and spatially variable manner (Harrison 2011, Epke 2010). A change in the sedimentary regime may result in significant changes to the fluvial geomorphology of a particular system. The geomorphological responses to such a change in sediment regime can lead to a change in the types of habitats that can be supported by the river (Yarnell 2005). Thus, by identifying the key characteristics that define sediment regimes of varying river segments it is possible to establish the combinations of habitats that are present, and hence a possible link between sediment facies association and habitat formation (Allan 2009). With this in mind, this paper will attempt to discuss the landscape evolution as you move longitudinally down the Tuolumne River; while using the dominant sediment regime and the forms and functions of each locality to discuss the inter-relationships between the known physical system, human manipulations, and their implication on stream habitat.

Upper Tuolumne:

Beginning from the upper watershed, the Tuolumne headwaters are characterized by steep topography, sparse vegetation, and high elevation. Due to these harsh conditions this section of the watershed functions primarily as a water capture and storage zone driven by rain and snowmelt (Epke 2010). The geology is primarily comprised of Mesozoic granitic bedrock that has been glacially carved and eroded to form sand, gravel, and boulder sized sediment. As this material is transported downstream, by pulses of overland storm and spring snowmelt events, it begins to accumulate in cracks, crevices, and low slope areas; usually glacially carved troughs, which today appear as forested meadows of pine and fir (at least in the subalpine regions) (Moore 2014). As these deposits accumulate they form alluvium, soils, and gravel structures that provide habitat for terrestrial and stream organisms. Due to the compositional simplicity of sediments of the upper watershed, the habitats formed in this environment tend to be homogenous in form and function with limited nutrients, diversity in structure, and sufficient flatlands to form productive habitats. Nutrient supply in this region is typically characterized by low dissolved oxygen content due to high elevation and low photosynthetic primary producer populations, limited sediment variation, and few carbon, phosphorus, and nitrogen sources within this area (Epke 2010). This is primarily because there is less soil and organic matter that is supplying as much nutrient inputs into upstream tributary sources. In general, the limited variation in sediment supply, composition, and diversity limits habitat formation and growth. However, native species have adapted to these harsh conditions and find ecological niches to occupy.

The Middle Watershed - Modern Source and Transfer Zone

As you move into the middle segment of the Tuolumne Watershed, the sediment regime complexity increases due to a shift in the underlying geology and anthropogenic alterations of the natural flow regime. The Middle Tuolumne Watershed is characterized by succession of steep to moderate topography, with dense wooded vegetation and increased riparian succession, with a shift from primarily granite bedrock to metamorphic sedimentary, and volcanic igneous rocks (Epke 2010, Allan 2009). Sediment size begins to decrease and composition diversifies. There is also an increase in sediment carrying capacity, resulting from the confluence of several tributaries. Due to the more highly erodible geology and increase in sediment carrying capacity (stream discharge), this section of the watershed functions as both a sediment source and transfer zone; with regimes superimposed on each other, each being driven by a shift in drainage patterns and sediment supply. This shift increases stream heterogeneity, a major determinant in stream habitat variation and diversity (Yarnell 2005).

The interrelationship between sediment supply and stream discharge, in this region, leads to the aggradation of sediment and the formation of more sedimentary channel structures (Allan 2009). This added structure allows for the restriction of local flow and creates upstream scouring and downstream deposition, which can lead to maintenance and formation of new stream habitats such as gravel bars and banks, and many combinations of cascade-pool-riffle-run sequences (Loheide 2014). Contribution from the riparian environment also increases nutrient supply, large woody debris, and plant supported slope stability, preventing undercutting and erosion of channel edges (Yarnell 2005). This increased complexity has strong implication for stream habitat, as it creates more niches, refugia, and habitat variation for diverse populations to coexist at multiple life-stages.

Conversely, as sediment variation increases along this segment, water flow complexity decreases due to dam restricted flows. This reduction in flow decreases the carrying capacity of the river (Ligon 1995). This leads to a coarsening of bedload and decrease in occurance of flood and bankfull events where sedimentary and riparian environments are scoured and resurfaced for new habitat formation to occur. The decrease in disturbance events leads to a more homogenous stream condition and thus reduction in potential stream habitats, even with the presence of a relatively complex sediment regime. The implication for habitats is a reduction in diversity and productivity.

The Lower Watershed - Historically an Alluvial Storage System

As you exit the steep confined valleys of the middle tuolumne and enter the lowest segment, you enter a wide unconstrained alluvial system where sediments are typically deposited across a wide sweeping alluvial fan (Bennet 2006). Historically, in this region, there was no strict channel morphology and the river system meandered across the lowlands forming deltas, ephemeral floodplains, and estuary habitats during bankfull and flood events (Bennet 2006). However, discovery of these habitat and their nutrient rich soil and available water soon prompted significant anthropogenic alteration of this system for agricultural use. A combination of dams, levees, and water diversion systems now strict stream migration, sediment deposition and disturbance events. These alterations have significantly altered the sediment-flow inter-relationship, and thus habitat diversity in the region (Ligon 1995).

The stream system in its current state is characterized by a geology of mainly of quaternary silt, sand, and gravel alluvial sediments with some volcanic and meta-sedimentary outcrops (Harrison 2011). Upstream of the dams, sediments are very nutrient rich with complex chemistry and high carbon input from upstream and riparian sources, providing significant nutrient resources for a variety of species; however, due to the construction of New Don Pedro and Lagrange Dams the downstream segment of the lower watershed is now water, nutrient, and sediment starved as resources are being held upstream.

Downstream of these dams you we now see incision and coarsening of the bedload as lighter material gets moved out. The effect of this change is most observable on native species in which sediment bars and banks become scoured away, and large woody debris that often provide refugia habitat for juvenile species are being blocked upstream. Additionally, this causes a nutrient deficiency as carbon sources are removed upstream. In general, the downstream watershed begins to experience more homogeneity due to the reduction of sediment-flow processes (Yarnell 2005). In effect, the diversity of habitat formation is reduced due to the simplification of sediment variation into the stream channel. The effects of this are seen as decrease in habitat and species diversity.

Conclusion:

The habitats that exist within each segment of the Tuolumne Watershed is directly correlated to its dominant sediment regime. The more diverse the distribution, composition, and variation of sediment both spatially and temporally determine the complexity variation of habitat formation.The headwaters of the Tuolumne Watershed functions primarily as a water capture and storage zone, with a sediment regime that functions as a sediment storage zone; interestingly sediment flux into and out of this segment is virtually zero. Sediment contribution to stream habitat is not very significant to the formation of maintenance of stream habitat. As a result the diversity and complexity of habitat is low and only specialized species who've adapted to these harsh conditions occupy this zone. The Middle Tuolumne offers the most diverse variety of stream habitat. This is primarily due to the balance between sediment influx and increased carrying capacity of the river that continuously disturb instream and riparian environments. The regulated flow regime in this system reduces the frequency of these disturbance events and in result we see less habitat maintenance. This could lead to a reduction of species diversity if the species relies on the natural frequency and timing of these disturbance events. The Lower Tuolumne watershed is predominately used for anthropogenic use. The natural form and function of this region has been significantly altered and reduced. The remaining system is experiencing sediment, nutrient, and water starvation, which in turn in reducing habitat complexity and the available niches for species to occupy.

In general, as anthropogenic alteration continuous throughout the Tuolumne Watershed, the geomorphological responses to a change in sediment regime will lead to a reduction and simplification of stream habitats, and thus a reduction of species diversity.

References: Bibliography

Harrison, L. R., C. J. Legleiter, M. A. Wydzga, and T. Dunne. 2011a. Channel dynamics and habitat development in a meandering, gravel bed river: RIVER CHANNEL DYNAMICS AND HABITAT DEVELOPMENT. Water Resources Research 47.

Loheide, S. P., R. S. Deitchman, D. J. Cooper, E. C. Wolf, C. T. Hammersmark, and J. D. Lundquist. 2009. A framework for understanding the hydroecology of impacted wet meadows in the Sierra Nevada and Cascade Ranges, California, USA. Hydrogeology Journal 17:229–246.

Moore, C. E., S. P. Loheide, C. S. Lowry, and J. D. Lundquist. 2014. Instream Restoration to Improve the Ecohydrologic Function of a Subalpine Meadow: Pre-implementation Modeling with HEC-RAS. JAWRA Journal of the American Water Resources Association 50:1033–1050.

Allan, J. D., and M. M. Ibañez Castillo. 2009. Stream ecology: structure and function of running waters. 2. ed., reprinted. Springer, Dordrecht.

Yarnell, S. M., J. F. Mount, and E. W. Larsen. 2006. The influence of relative sediment supply on riverine habitat heterogeneity. Geomorphology 80:310–324.

Bennett, G. L., G. S. Weissmann, G. S. Baker, and D. W. Hyndman. 2006. Regional-scale assessment of a sequence-bounding paleosol on fluvial fans using ground-penetrating radar, eastern San Joaquin Valley, California. Geological Society of America Bulletin 118:724–732.

Epke, G., Finger, M., Lusardi, R., Marks, N., Mount, J., Nichols, A., Null, S., O’Rear, T., Purdy, S., Senter, A., Viers, J. (2010). Confluence: A natural and human history of the Tuolumne River Watershed. Davis, California.

Ligon, F. K., W. E. Dietrich, and W. J. Trush. 1995. Downstream Ecological Effects of Dams. BioScience 45:183–192.

James, L. A., J. D. Phillips, and S. A. Lecce. 2017. A centennial tribute to G.K. Gilbert's Hydraulic Mining Débris in the Sierra Nevada. Geomorphology 294:4–19.

Martin, S. E., and M. H. Conklin. 2018. Tracking channel bed resiliency in forested mountain catchments using high temporal resolution channel bed movement. Geomorphology 301:68–78.

Korzeniowska, K., N. Pfeifer, and S. Landtwing. 2018. Mapping gullies, dunes, lava fields, and landslides via surface roughness. Geomorphology 301:53–67.