Natural History Guide to the

Tuolumne River

Sierra Nevada Mountains, California

Edited by Robyn Suddeth

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Preface

Welcome to the natural history guide for the Wild and Scenic Tuolumne River. This guide serves to expose you to the natural history of one of California's great rivers. Its creation provided a unique training opportunity for several UC Davis students in the Spring of 2009. Professors Jeffrey Mount and Peter Moyle, and teaching assistants Robert Lusardi and myself, tasked a group of 11 students with two complimentary projects: this field guide and a conceptual model describing food web interactions between the main stem Tuolumne and its North Fork and Clavey River tributaries. As a welcome addition to my duties as teaching assistant, I served as chief editor for this guide. The conceptual model, developed by five students under Robert Lusardi's oversight, greatly informed our efforts and is available online at

http://watershed.ucdavis.edu/tuolumne/resources/models.aspx.

I have a long familiarity with the Tuolumne River. I was introduced to the river during my second year as a whitewater guide in California. Like most visitors do, I have sat long hours by the river wondering about the stories the rocks and the river could tell: stories of boats gone awry in the rapid below, off-key and occasionally off-color songs around a campfire, fishing lines thrown hopeful into the water, and friendships forged. The place already seemed full of such history and magic for me before this project. The students and authors of this guide, however, have heightened the wonderment for this river by telling the story of its ecosystems and their connections to the humans that have wandered up and down its canyon, whether by foot or by boat, for the past 12,000 years.

This guide is motivated by the desire to pass on that understanding and insight to future visitors who share in this Tuolumne River experience. We did not intend to tell a mile-by-mile story. Such guides, while valuable, are already in existence. Rather, we aim to provide a deeper understanding of the formation and continuing evolution of the river canyon, including our own role in these processes, and to assist readers in deciphering the natural history of a landscape through observation. It is hoped that readers will learn how the rocks, plants, animals, and water of the Tuolumne River are interconnected and dependent upon each other, with complex relationships driving changes in the physical landscape and its ecosystem. And most importantly, it is hoped that readers will enjoy this process of discovery as much as we have.

On behalf of the students and instructors of the Spring, 2009 Ecogeomorphology course, I want to thank Dr. Roy Shlemon who endowed the Shlemon Chair in Applied Geosciences at UC Davis. Funds from this endowment supported this class. In addition, I want to thank Jordy Margid and Ali Grechko of Outdoor Adventures, UC Davis for their logistical support. Finally, our gratitude to the Groveland Ranger District of the Stanislaus National Forest for their help and encouragement.

Robyn Suddeth

Introduction

This field guide for the Lumsden to Ward's Ferry reach of the Tuolumne River is intended as an appendix to *Confluence: A Natural and Human History of the Tuolumne River Watershed*. It follows the river down 18 miles of California's premier backcountry whitewater river trip, integrating themes from the book. Relationships are explored between the physical and ecological components of the Tuolumne and two significant tributaries entering along this reach—the Clavey and North Fork Tuolumne rivers. This guide focuses on four sites where rafters are likely to spend time out of their rafts: Meral's Pool (the put-in), the Clavey River, Indian Bar, and the North Fork Tuolumne River, using specific examples to illustrate concepts of river ecology. It is designed to accompany boaters on the river. Casual readers interested in Sierra Nevada rivers should also find it useful.

Whitewater rafting and kayaking has been a recreational pastime in California for over 40 years. As the state's population increases and awareness spreads, so does the popularity of these and other river-related activities. This section of river, which offers an overnight wilderness trip with consistent and challenging whitewater within a few hours of the Bay Area, has been well-loved since paddlers first ran it. Commercial rafting companies with permits offer one, two, and three day trips down 'the T', and some offer seasonal day-trips on the Cherry Creek run, which is possibly the country's most difficult commercial run. The Forest Service issues permits for private trips, encouraging good river etiquette to allow all users the experience of a clean, wild environment.

This reach of the river is roughly halfway between the Tuolumne's headwaters, in the peaks of northern Yosemite, and the river's confluence with the San Joaquin, in the town of Modesto (Figure 1.1). Mountain rivers tend to decrease in slope and increase in volume as they flow downhill. Between Lumsden and Ward's Ferry, these two factors converge to create suitable conditions for challenging, yet relatively safe, river running. The upstream drainage area of the watershed here covers about 1000 square miles, and the average gradient is 40 vertical feet per mile.

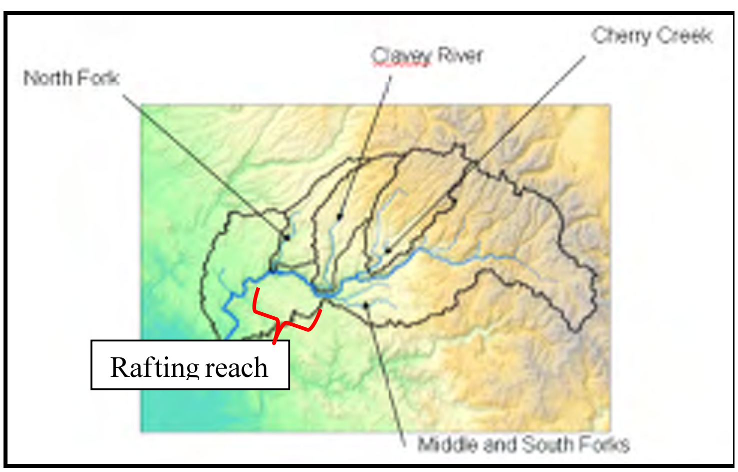


Figure 1.1 The Tuolumne Watershed above New Don Pedro

In 1984, the Tuolumne was awarded 'Wild and Scenic River' status by the U.S. Congress. The National Wild and Scenic River Act of 1968 was passed so that rivers with *"outstandingly* *remarkable scenic, recreational, geologic, fish and wildlife, historic, cultural or other similar values, shall be preserved in free-flowing condition, and that they and their immediate environments shall be protected for the benefit and enjoyment of present and future generations."*

The 18 miles between Meral's Pool and Wards Ferry are located in the middle of two major reservoir systems. Other than the Tuolumne's small South and Middle Forks, which enter just upstream of Meral's Pool (the main put-in), almost every drop of water that flows here is controlled by a system of dams and diversions operated by the city of San Francisco. In fact, most of the water in this part of the Tuolumne River comes from Cherry and Eleanor Creeks, because water from Hetch Hetchy goes to the Bay Area for drinking water.

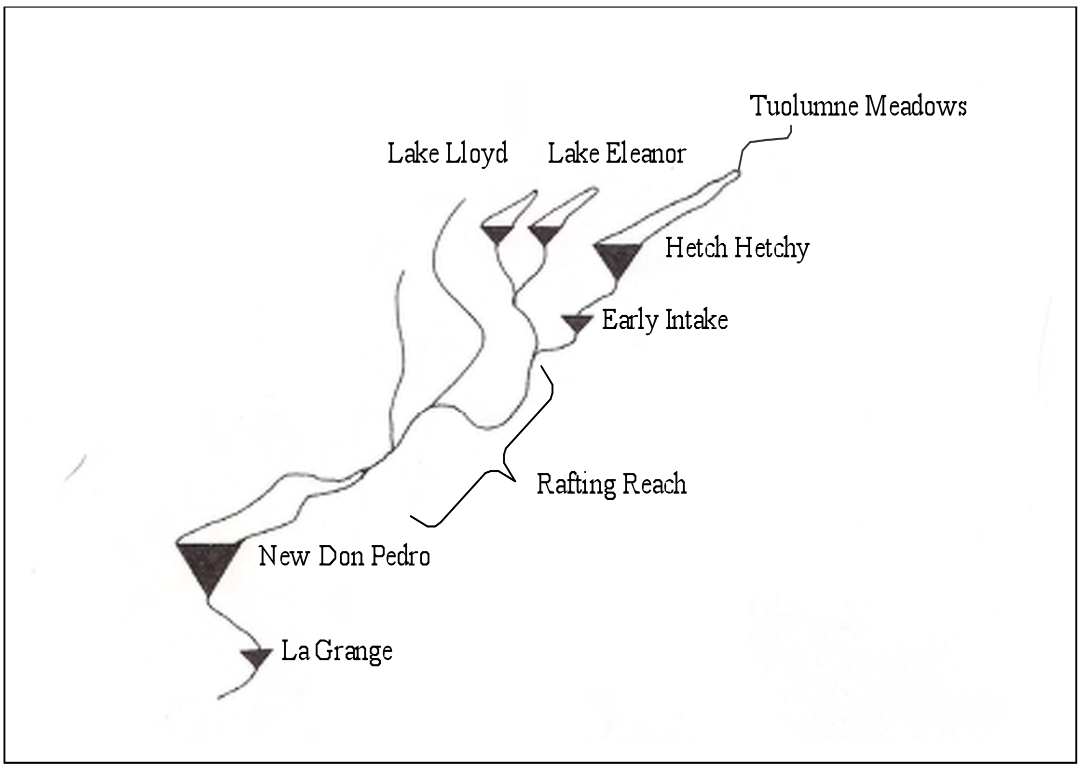


Figure 1.2 - Schematic of reservoirs on the Tuolumne River.
From Bruce McGurk, San Francisco Public Utilities Commission

Many factors, including these reservoirs, have a significant influence on physical and biological processes within the Tuolumne River. Water moving though a river channel, as described by magnitude, duration, timing, and frequency, controls a complex web of ecosystem interactions. Some of these relationships are direct, as the way in which more water provides (to a point) more habitat for fish, but others are more divergent, like high flows that remove riparian (riverside) plants in some places but also deposit sediment elsewhere that is necessary for new plants. Ultimately, all of these relationships are highly complex, with positive and negative feedback loops and food web relationships that can be difficult to identify. As the Clavey and North Fork tributaries converge with the mainstem they enter this complex system of feedbacks, exerting their own influences while displaying similarities to and differences from the Tuolumne that offer clues as to what the river would look like without upstream infrastructure. These biological and physical relationships are explored in the following pages.

I. Meral's Pool - General Concepts

Rock Garden Rapid, just downstream of Meral's Pool. Photo: Mark Reiner

Meral's Pool

Meral's Pool is the put-in location for 1, 2 and 3-day rafting trips on the "Lower" Tuolumne River, (called the "lower" Tuolumne to distinguish it from the Class V stretch that begins in Cherry Creek and ends at Meral's Pool). The pool is named after a famous river preservationist and one of the Tuolumne's first kayakers, Gerry Meral.

Make note of the geology at Meral's Pool. Almost all of the rocks here and upstream of this point are granite, an igneous rock which forms the backbone of the Sierra Nevada. Within a few miles of Meral's Pool, the Tuolumne leaves these granitic surroundings and enters metamorphic formations, with different colors, textures, fracture patterns, and dikes (see accompanying book). The river's bedrock, - its 'walls' and 'floors' – will change.

Tuolumne River Hydrology

Hydrology is the study of the behavior and distribution of water on and below the surface of the Earth. The 'hydrology' of a river can also refer to its character, such as daily changes in the volume, amount, or kinetic energy of water as it flows along. As discussed in chapter 1 of the book, the Tuolumne's hydrology is a function of its climate, topography, vegetation, and reservoir management. California's Mediterranean climate varies annually, but generally there is a consistent natural pattern of higher discharges from storms in the winter and from snowmelt in spring, coupled with low flows during the dry summer. These local flow patterns distinguish rivers in one region or elevation from those in others, and help define a river's dynamic character.

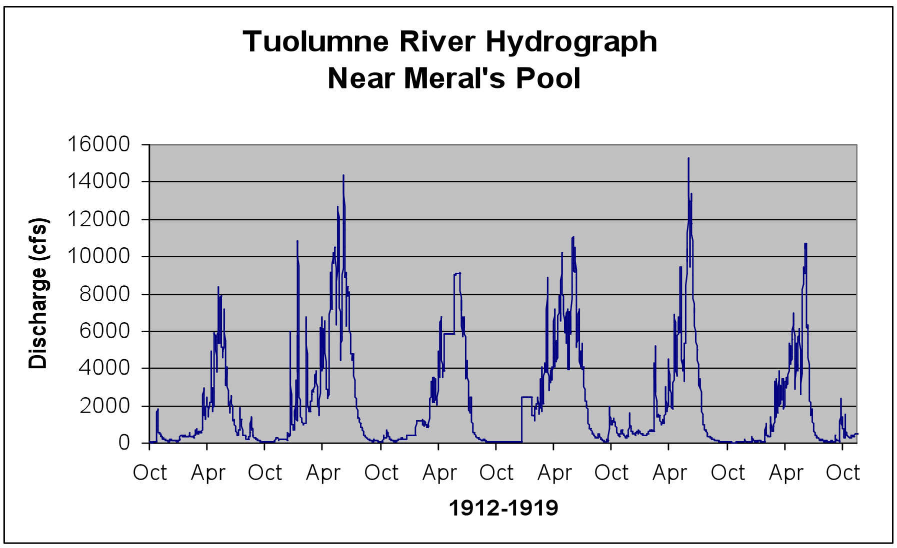


Figure 1.3 - A typical 5-year hydrograph of the Tuolumne River, before Hetch Hetchy and other upstream reservoirs.

The hydrograph in Figure 1.3 describes discharge – the volume of water that flows past a point in a given amount of time. The horizontal axis represents time, in this case a period of six years, and the vertical axis displays discharge. One cubic foot per second (cfs) is equivalent to about seven and a half gallons per second.

Melting snow in the upper watershed heavily influences the Tuolumne's hydrograph. The flows in figure 1.3 above were observed near Meral's Pool over several years prior to the construction of upstream reservoirs. Notice how, although precipitation falls during winter months, peak discharge tends to occur in the springtime. This reflects the snow's ability here to effectively "store" water throughout the winter until warmer spring temperatures force it to melt and run off into streams. These patterns in a hydrograph, which describe the timing and magnitude of discharge within a given timeframe, are called the river's 'flow regime.'

Figure 1.4 – Staff plate in the upper eddy, Meral's Pool

Quantifying River Discharge

Discharge is calculated as the product of the water's average velocity and the area of the river's cross section at a certain point. If you look at a given reach of a river, you'll immediately notice that the shape of the bed changes dynamically throughout the reach, as does the cross-sectional area of the river. Because the overall discharge doesn't change dramatically without external input, you should also be able to see the inverse relationship between the cross-sectional area and velocity. For example, pools that are wide and deep have slower velocity flows than do wide shallow rapids.

We can measure river height from a staff plate, such as in Figure 1.4. By correlating these measurements with calculated discharge, we can determine the relationship between river height and flow in CFS to form a rating table. At Meral's Pool, you can look up the discharge on a rating table posted near the water, and find out the flow of the river.

An important, yet hidden aspect of many reported hydrographs is that they often only display daily averages, which means that we cannot see short-term or rapid fluctuations. For instance, small floods from short storms or daily summertime fluctuations from hydropower production are not visible. The hydrograph in Figure 1.5 below depicts the discharges below Holm Powerhouse on Cherry Creek every 15 minutes over 45 days in spring 2008. During the summer, when demand for electricity goes up, a sequence of hydropower-generating surges and water-retaining lows is the dominant hydrologic signal on the river. In early June and early July, it appears that the dam operators allowed water to pass through the turbines and down the river only during peak hours, but during the last few weeks of June, they let the turbines run almost full-time. These flows are called diel flows, in reference to their daily changes. Compare these hydropower-based flows to the natural ones before the dam in Figure 1.3.

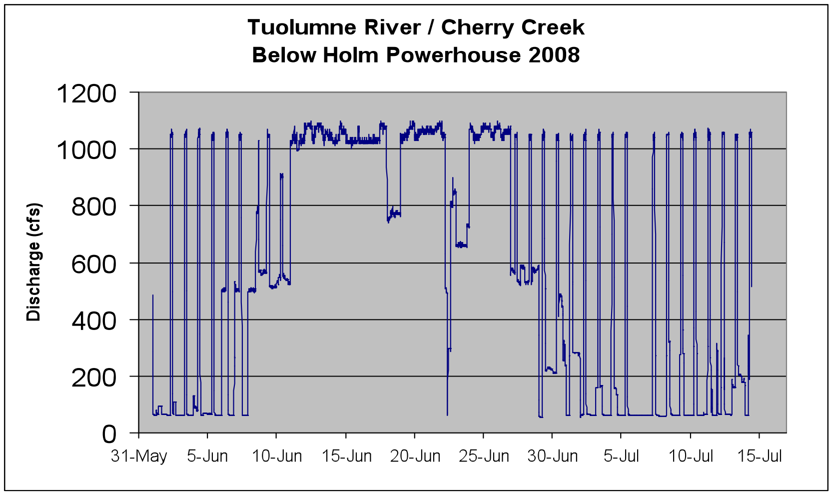


Figure 1.5 - Hydrograph of summertime discharges from Holm Powerhouse at 15-minute intervals

Geomorphology



Photos: Gerhard Epke

What is geomorphology? Think “geography in action.” Geomorphology is the study of the evolution of a landscape, governed in most part by its topography, geology, soils, climate, and hydrology. Geomorphology can be difficult to grasp because of this transcendence of scale and discipline, but evidence of this overlap is all around. As you paddle down the river, pay attention to patterns in the physical landscape, such as the locations of sand and cobble bars, the sizes of their sediments, and the amount of exposed bedrock.

Geomorphic processes usually occur over long time scales, such as hundreds, thousands, and millions of years, but when things do happen rapidly, they tend to be unexpected. Examples include earthquakes, landslides, or floods like the one in January of 1997. In observing a grouping or deposit of rocks, gauge their angular or rounded shape for clues about age and origin. Rounded rocks are more likely to be river-derived, transported and smoothed by water and other rocks over time. Conversely, jagged, angular rocks may have come from a relatively recent rock fall, or from old mining debris.

Occasional large floods and smaller, more constant flows erode and transport sediment: bedrock is eroded from high up in the watershed while soils, sands, and gravels are delivered overland to streams during storm events and the spring snowmelt. These sediments are transported downstream in pulses over time, sometimes carried by the river and other times resting in depositional bars or floodplains, eventually reaching the delta or ocean over the course of thousands of years. As these deposits accumulate, they become alluvium, rich soils that provide fertile breeding ground for plant communities.

Rock and soil composition influences life. From the macroscopic-scale arrangement of bedrock cracks or cobbles, to microscopic qualities of texture or permeability, varied characteristics of substrate provide a large diversity of habitat upon which life can grow.

Geomorphology can be difficult to comprehend, let alone measure, but rivers always play a major role in the evolution of the landscape, because of their ability to erode and transport material. This guide introduces specific examples seen on the Tuolumne in an attempt to develop a picture of the watershed's evolution, which is both dynamic and responsive on geologic and human timescales.

Plants

Plants are organisms that convert inorganic materials and energy sources to biologically useful material. They are the basis of biological food webs. In the Tuolumne, primary production occurs as photosynthesis by aquatic and terrestrial plants, as well as algae and bacteria of various forms. We refer to productive microorganisms attached to underwater substrate in moving water as periphyton, while slower waters are home to phytoplankton that float freely in the water column.

The 'productivity' of a watershed or river is a term we use to describe the amount of life there, but more productivity does not necessarily indicate a healthier river. The upper reaches of mountain rivers have naturally lower productivity than their flatland portions, due to a limited nutrient supply and harsher environmental conditions. However, native species have adapted to these conditions over an evolutionary time scale, and indices of the 'health' of native populations of plants and animals are generally considered to be the more important determinants of a river's health.

Tuolumne River Vegetation

Vegetation on the Tuolumne River is unlike that of lower gradient rivers. In systems with wide valleys, the river provides water over a large area by percolating through sand and soil to recharge underlying groundwater basins. Since the Tuolumne is a bedrock system with a v-shaped channel and minimal sediment contribution, those alluvial floodplains of high-sediment systems are absent. Because of this, there is a thin riparian corridor just below the upland hillslope vegetation. River channel shape, a small sediment load, and water availability drive the structure of vegetation.

There are several characteristics to look for in observing and comparing plants and their communities. As you look further up from the river the vegetation changes, almost in layers. Look at the trees close to the waterline and compare them to trees up the hillslope. Pay attention to where plants are positioned along the river's edge and try to think of why this would be the case. We will be looking at some plant and tree species in depth and will be covering major themes as we move through this guide, identifying differences and trends in the vegetation.

There is a difference between the plants growing directly along the river and those growing further uphill. This has to do with the amount of water available in the soil at each location.

Riparian plants need a constant supply of water. They are usually large, leafy plants and trees that use and lose a lot of water throughout the day. These species can only afford this kind of lifestyle if they live very close to a major water source. Hillslope plants of the Tuolumne River Basin are not immediately adjacent to the river, and so cannot afford this type of water consumption. Think back to the predominant rock type in this system: granite. Granite is not a porous material and does not hold groundwater except in narrow cracks and crevices. There is only a thin layer of topsoil that covers the granite in which the plant and tree species grow. This topsoil is not deep enough to hold much water either. Therefore, the vegetation growing on the hill slopes of the Tuolumne River must be relatively drought-resistant.

Figure 1.5 – Large woody debris
Photo: Patrick Hilton

Trees growing alongside the river may fall into the current (Figure 1.5) due to a variety of causes, such as flood scour or disease. This debris can either be swept downstream in high velocity flows, or can remain in the river system if caught in an eddy or on a bedrock outcropping. Large logs and other woody debris used to be seen as detrimental to river systems, but now we know that its presence is important to river ecosystems. Large woody debris buildups add to the heterogeneity of the river system, which in turn provides more diverse habitat available for plants, insects, amphibians, reptiles, and fish.

Vegetation Habitat Types

Bar/Bedrock – Along the banks of the river, you'll see the occasional bar or beach of boulders, cobbles, gravel, or sand, but you'll also see bedrock lining the river's edge. These can be challenging habitats for plants, but many are specially adapted to survive and thrive in these locations.

> **In the Tuolumne, water levels can fluctuate** on an annual, monthly, daily, or even hourly basis, sometimes changing the shape, composition, and location of bars with changes in flow. Because of this, some bars are a difficult place to survive, and you won't see much plant life in the most hydrologically active places. In the less-frequently disturbed bars and beaches, however, you'll notice small, low-lying grasses and forbs in addition to the young willows, alders and ashes that have established themselves since the last scouring flood. These are all plants that are suited to this rough environment, through adaptations like rapid growth and reproduction, tolerance for inundation, and resistance to being washed away.
>
> **Plants growing on bedrock** also tend to be small, but more frequently because they have little space to grow in the sandy crevices of large rock. The plants that do establish themselves tend to be higher up on the rocks, where floods are less frequent.

Riparian – Moving up from the gravel bars onto the banks of the river, you will notice changes in the species and density of plants. On many California rivers, riparian habitats immediately adjacent to the river hold some of the most diverse plant communities of any in the state. This is thanks to a regular water supply from both groundwater and the river, which provides nutrient-rich alluvial sediment. On the Tuolumne, however, water levels are dam-regulated, and hard bedrock in the upper reaches does not provide much sediment. Consequently, the types of plants you see and the structure of plant communities are different from more extensive riparian ecosystems. For example, common trees such as the Fremont cottonwood are seen only in a few scattered places.

Hillslope – Above the riparian zone, you'll notice a rapid gain in elevation, with steep hills on either side of the river. The plants on these hills get their water from the ground, but also from the occasional rainstorm, especially in the wintertime. Depending on height up the slope and direction, the plants get varying degrees of sunlight that can dry them out. For this reason, you might notice that hillslope communities, especially those on river right, tend to be dominated by annual grasses and forbs, with only the occasional oak or pine.

Aquatic Insects

Dragonfly Larvae(L) and Stonefly Larvae (R) **Caddisfly Cases**
Photo: Patrick Hilton (left) and Adam Clause (right).

Aquatic insects and other animals are part of complex food webs with multiple trophic levels, akin to links on a food chain. In the Tuolumne River watershed, there are many insects that spend the juvenile stage of their biphasic (two-stage) life cycle as aquatic larvae, before transforming into terrestrial adults. In both phases, these insects are important to the food web of the Tuolumne River. The aquatic larvae act as primary consumers, feeding on plant material such as algae, decomposing leaf litter, and aquatic plants.

Aquatic insects contribute to the food web on multiple levels. The primary consumer larvae (grazers) fall prey to insect secondary consumers (predators), who go on to become food for tertiary consumers that prey solely on aquatic insects, such as pikeminnow, juvenile Sierra newts, and American dippers. After the aquatic larvae transition to terrestrial adulthood, they not only feed terrestrial-dwelling animals, such as insectivorous birds, but also fall to the water's surface at the end of their life cycle, feeding rainbow trout and other fish.

The Tuolumne river is an example of a high-gradient upland watershed with large substratum, or rocks, below the soil. Consequently, the complement of aquatic invertebrates is typical of this type of system, including Coleoptera (beetles), Diptera (true flies), Ephemeroptera (mayflies), Megaloptera (alderflies, dobson flies, fishflies), Odonata (dragonflies and damselflies), Plecoptera (stoneflies), and Trichoptera (caddisflies).

Aquatic insects have specialized feeding preferences and can be classified in 1 of 4 functional feeding groups:

1. ***Collectors*** include collector-filterers that attach themselves to a substrate and filter decomposing fine particulate organic matter (FPOM) directly from passing water or the substrate, and collector-gatherers that move around on the surface of rocks and wood to gather FPOM from the water.

2. ***Scrapers*** feed on periphyton on the substrate. They have specialized mouthparts that allow them to scrape the algae off of the surfaces of rocks.

3. ***Predators*** attack and ingest other insects. This group includes piercers that attack and suck the fluids from other insects.

4. ***Shredders*** feed on coarse particulate organic matter (CPOM) such as macrophytes, detritus, and large woody debris. They use their mouthparts to shred plant matter for consumption. Remnants of their meal and resulting fecal material then provide FPOM for collector-gatherers.

Figure 1.6 - Blackfly larvae (order: Diptera; family: Simuliidae) use silk glands in the mouth to attach themselves to bedrock and filter fine particulate organic matter from the water (*Pers. comm.,* Sharon Lawler). Photo: Denise De Carion.

What are the primary food sources for aquatic insects?

- **Periphyton**: microscopic algae (primary producers) that attach themselves to bedrock, boulder, cobble, or gravel substrate underwater
- **Phytoplankton**: free-floating algae
- **Macrophytes**: aquatic plants that grow in the water
- **Detritus**: decomposing organic material, such as fallen leaf litter and dead animals

What habitat types do you see?

Erosional

- Coarse sediments such as cobbles, pebbles, and riffles
- Periphyton on the coarse sediment in riffles
- Accumulated detritus

Depositional

- Finer sediments, such as sand and silt
- Macrophytes within the fine sediments
- Detritus in backwaters

Reference: Merritt and Cummins 2008

The community composition of aquatic insects indicates stream health. Biologists often refer to aquatic insects as indicator species because they are physiologically sensitive to disturbance in aquatic systems, such as those present in the dam-regulated Tuolumne River. Aquatic insects have different tolerance ranges for water-quality parameters like dissolved oxygen, pH, and pollutants, as well as for the degree of human-caused disturbance.

Over thousands of years, the communities of aquatic insects have adapted to the historic natural hydrologic flow regime-- the spring-snowmelt recession (Figure 1.3). Today, frequent disturbances in the form of diel flow pulses released from upstream reservoirs alternately scour and then desiccate the substrate. The frequency of scouring and desiccation reduces the diversity of aquatic insects, which then adversely affects higher trophic levels. The sensitivity of an indicator species can be scored on a zero-to-ten scale of tolerance, where zero represents insects with the lowest tolerance for degraded water quality, and ten represents the highest tolerance. High tolerance, toward ten, indicates the ability to persist in highly polluted conditions. In the Tuolumne River watershed, a wide range of tolerance values is present, ranging from Pteronarcyidae with a rating of zero, to Chironomidae, with a high tolerance of eight.

Amphibians


Pictured above: Pacific treefrog tadpole (left) and Foothill yellow-legged frog (right). Photos: Adam Clause.

Herpetology is the scientific study of amphibians and reptiles. In the Tuolumne River watershed, there are five common aquatic amphibians: foothill yellow-legged frog, western toad, Pacific tree frog, American bullfrog, and Sierra newt.

Similar to aquatic insects, aquatic amphibians have a biphasic life cycle comprised of a juvenile aquatic stage (tadpole or larva) and an adult terrestrial stage (frog, toad, or newt). Except for newt larvae, which are carnivorous, juvenile amphibians feed on periphyton, while adults often eat the adult aquatic insects.

Hydrologic flow regime, water temperature and food availability influence the distribution and abundance of aquatic amphibians in the watershed. Some amphibians are specialists that can only persist within a narrow range of a given environmental conditions, such as warm temperature or specific flow, while other amphibians are generalists that can thrive in varying environmental conditions. Generally, sensitive specialists are more likely to occupy tributaries that still retain a natural hydrograph (e.g., foothill yellow-legged frog), while less sensitive species can be found throughout the watershed (e.g., Pacific tree frog).

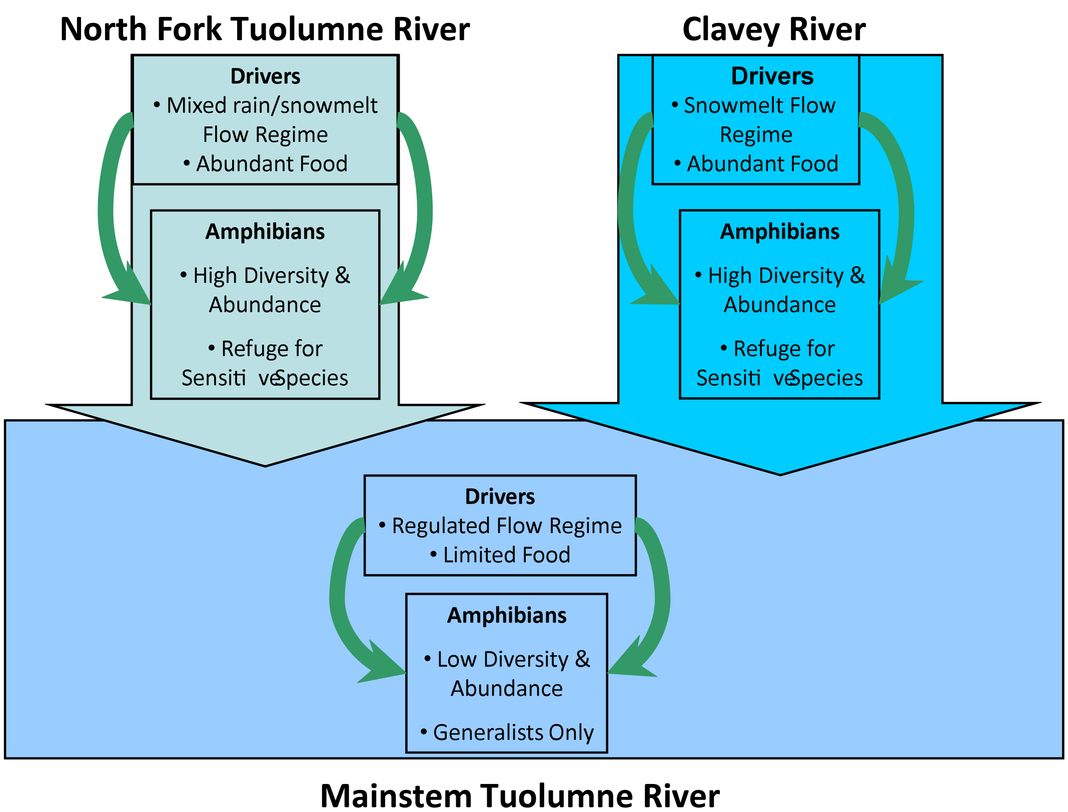


Figure 1.7 - A model of the main drivers that influence amphibian populations in the Tuolumne River and two major tributaries. Arrows indicate direction of impact.

Fishes

The Tuolumne contains only a few major species of fish. The native Tuolumne River fish *assemblage* (grouping of fish species which have coevolved to typically occur together) includes California roach, hardhead, rainbow trout, Sacramento pikeminnow, and Sacramento sucker. There are also a few invasive fish species, primarily present due to human influence. These invaders are smallmouth bass, brown trout and brook trout. The distribution of these species depends on three main physical factors: water temperature, flow velocity, and habitat complexity.

Water temperature is contingent on many things. Much of the water flowing through the mainstem Tuolumne comes from either Hetch Hetchy or Cherry reservoirs. With deep reservoirs like these, a temperature gradient forms between the warm surface water and the hypolimnion, or layer of cold deep water at the bottom. Because these reservoirs release hypolimnetic water from the bottom of their respective dams, water temperatures in the mainstem are more or less constantly cold, even in the summer, eliminating historically warm summer flows.

The distribution of native fish is determined by the temperature gradient created as cold water from the reservoirs warms up after being exposed to high air temperature. Because colder water contains higher levels of dissolved gases, it allows fish to easily get the oxygen they need from the water. Trout, in particular, require cold temperatures and high oxygen levels to thrive, but many other native fish species require somewhat warmer water. Consequently, the cold water releases from the bottom of reservoirs effectively reduce available habitat for important species like Sacramento pikeminnow and hardhead. Figure 1.8 shows the temperature range (in degrees Centrigrade) that each species needs to live comfortably and reproduce.

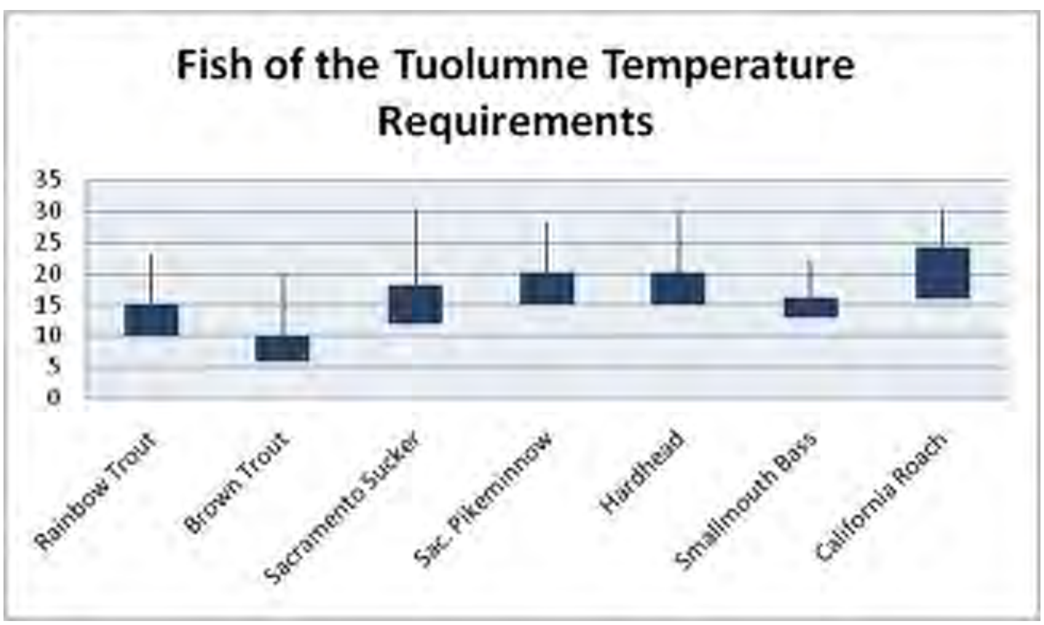


Figure 1.8 – Temperature values obtained from Moyle, Peter. Inland Fishes of California. UC Press 2002

Fish also depend on proper water flows. High velocity flows often push *young-of-year* fish (the youngest age class of a fish population) downstream, because they do not swim as well as adults and require slow-water habitats. These flows can also flush adults of some species downstream, particularly if they cannot find necessary refuges such as flooded side habitats or eddies to keep them in place.

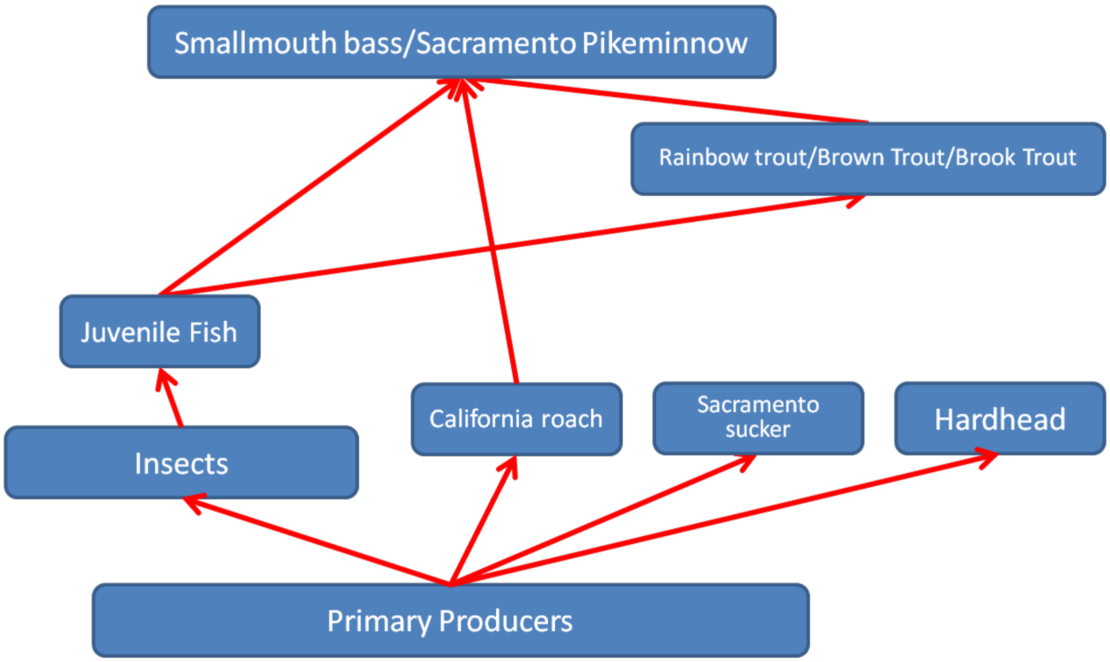


Figure 1.9 Trophic relationships between Tuolumne fish and their foodweb. Arrows represent the flow of energy and nutrients from primary producers to higher trophic levels.

The California Department of Fish & Game has designated the Tuolumne as a Heritage & Wild Trout river, thanks to rainbow trout, the only remaining salmonid native to the upper Tuolumne drainage. Rainbow trout are easily recognized by their dual dorsal fins, prominent lateral stripe and distinctive spots (Figure 1.10).

Figure 1.10 Tuolumne River Rainbow Trout

Trout require clean gravel beds to spawn successfully. During the spawning season, adults will form redds, or shallow nests in the gravel. In these redds, females lay eggs that the males then fertilize. After they hatch, the alevin, or larval fish, rely entirely upon the yolk sac from their eggs. Once the alevin has absorbed all of its yolk and is able to swim, it becomes a fry. The fry will continue to grow, and as it grows it will change from fry to parr (characterized by distinctive vertical bands called parr marks) to juvenile, and finally to adult (Figure 1.11). Although they feed primarily on aquatic invertebrates, trout will also consume other fish once they reach a certain size. Adult trout tend to spend most of their time in pools below riffles, moving into the riffles when they are foraging for aquatic insects (Moyle, 2002).

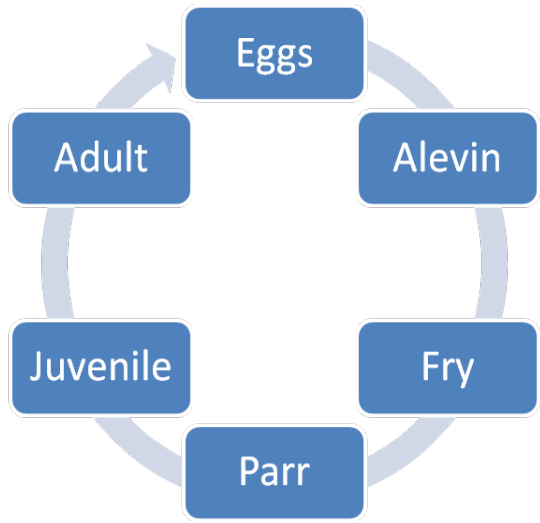


Figure 1.11 - Typical trout life cycle

Being a Natural Historian

Floating down the river, hiking up one of its side canyons, or sitting quietly on the shore are excellent ways of learning about the Tuolumne watershed and developing a personal understanding of the interwoven natural histories within. With an appreciation for the geomorphic and hydrologic processes that are occurring, and how they affect and respond to changes in plant and animal distributions, you can equip yourself to explore and draw connections between the things you see. After reading this guide, you will understand relationships between discharge, sediment distribution, water quality, habitat formation, and species interactions. You'll also gain an understanding for how the physical template drives primary production, disturbance, movement, and the continuity of the rivers character.

In this reach of river, San Francisco's dams tightly regulate discharge for most of the year, with dramatic effects across the food web. These beautiful 18 miles of wilderness have a long history of being altered by human hands. While you float through and come in contact with the canyon, keep an eye out for those fingerprints as well.

II. The Clavey River

About 5 ½ miles below Meral's Pool, the Clavey River enters the Tuolumne from the north. Many raft trips camp at the confluence of these two rivers, which contains a large pool, gravel bars, and lies immediately upstream of the steepest and most difficult rapid of the trip, Clavey Falls.

Whether or not your party camps at this confluence or just stops to scout the rapid, take some time to appreciate your surroundings and think about the relationships between these rivers.

If you do camp here, you might want to hike up the river. A short hike upstream will take you to beautiful waterfalls, swimming holes, and interesting rock formations to stretch out upon or investigate.

Hydrology

The Clavey River hydrograph is entirely unimpaired by human dams, which is very unusual for a California river. Throughout the 150 square miles of watershed, there are only 2 or 3 tiny, old dams located far up in the headwaters, near Pinecrest Lake and the Emigrant Wilderness.

Concept 1. *The Clavey River hydrograph is driven by rain and snowmelt.*

The Clavey River watershed lies at the proper elevation to receive both rainfall and snowmelt, which profoundly affects its hydrology. Winter storms in California are generally short but often intense. As you can see in the figure below, precipitation that falls as rain behaves very differently from precipitation that falls as snow. Rainwater splashes, percolates into the soils, travels through plants, runs across the surface carrying leaves and dirt, and enters the rivers in strong, dirty pulses. These pulses can get very big in a manner of hours.

What does it mean that the Clavey is undammed?

Some common physical effects that dams have on the river**:**

By design, dams change the timing of flows. Depending on their usage, this could mean:

- Trapping flood flows
- Increasing flows during summer months
- Creating pulses of water associated with energy and recreational demand

Dams interrupt the flow of sediment and wood, depriving the downstream area of an important natural component.

Dams often change the temperature of the water downstream:

- water released from the bottom of the dam is relatively cold
- water released from the top of the dam is relatively warm

Snowmelt is very different. Runoff peaks are generally much more protracted than rain runoff. Snowmelt can, however, also contribute very high discharges in springtime, depending on how quickly temperature increases, or as the result of a 'rain-on-snow' event. As snow disappears from the mountains, discharge decreases and a gradual transition to baseflow occurs. Baseflow is groundwater that drains into the channel, which increases in volume shortly after the snow melts. Over a few weeks, baseflow generally recedes to a stable minimum flow and the Clavey continues to stay wet through the summer and fall. During fall, the storm cycle starts once more.

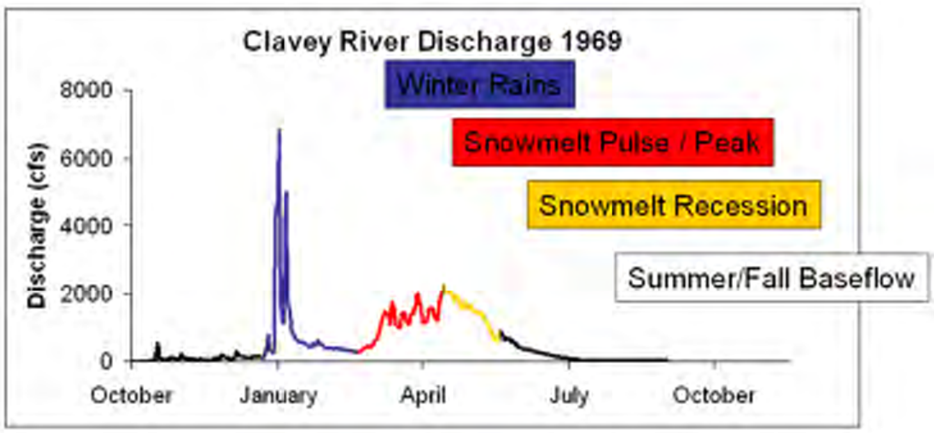


Figure 2.1 Clavey River discharge hydrograph

Geomorphology

Concept 1. *The Clavey River has a mixed bedrock/alluvial channel.*

Over millions of years, the river has cut into rock underlying the watershed. Simultaneously, the river carries sediment in the form of sands, gravels, cobbles, and boulders downstream and covers the bedrock at different times and places within the river continuum.

Mixed bedrock/alluvial channels are typical of mountain rivers, particularly at this elevation in the Sierra Nevada. This stretch of river represents a balance between transporting forces and depositional forces. Reaches with higher transport capacity, such as higher gradient sections in the upper watershed, tend to contain more exposed bedrock. Conversely, reaches with higher sediment inputs and milder slopes tend to contain more alluvium.

Concept 2. *Longitudinal Profile and Geomorphic Features*

The longitudinal profile of a river describes its elevation from source (headwaters) to sink (lake, delta, or ocean) (Figure 2.2). On a large, landscape scale, rivers adjust over time and smooth their slopes. Most rivers have an upper, higher-gradient erosional zone, a middle transition zone, and a final lower-gradient depositional zone.

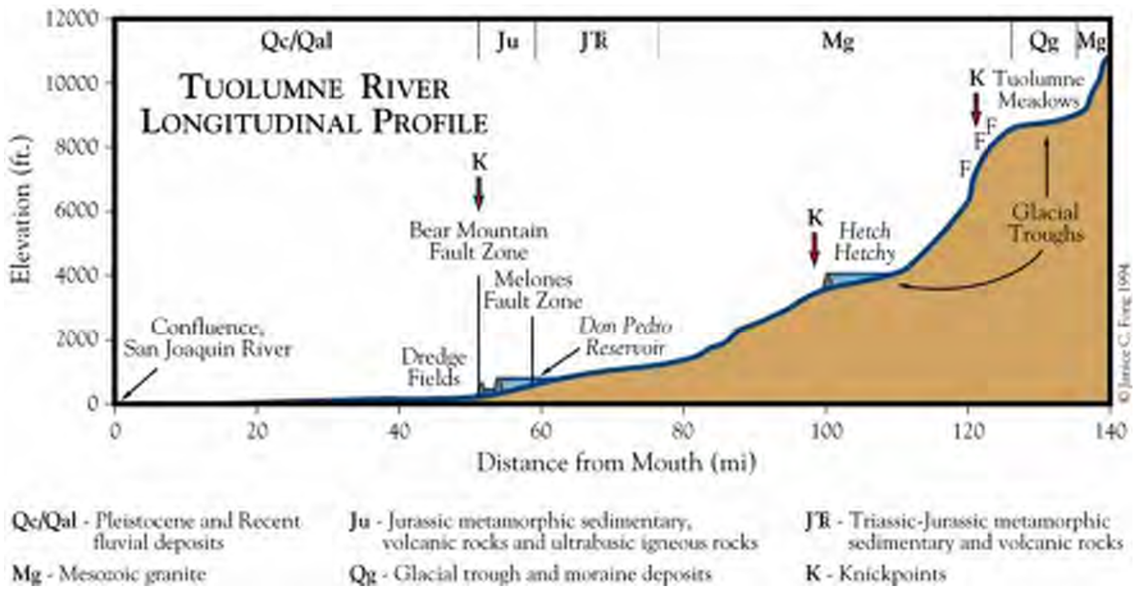


Figure 2.2. Tuolumne River longitudinal profile. From Mount, Jeff. California Rivers and Streams. UC Press 1995

On a smaller human scale, longitudinal profiles are generally jagged and form a suite of geomorphic features. The Clavey's steep gradient and bedrock-confined channels give it more stream power and therefore a slightly different geomorphic character than that of the Tuolumne. Some geomorphic units you may see on the Clavey include the following:

- Bedrock Steps
- Cascades
- Rapids
- Plunge Pools

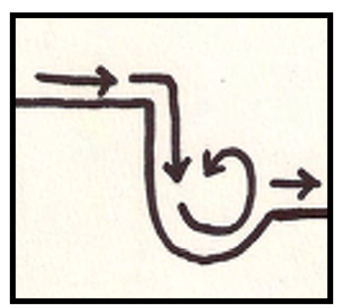


Figure 2.3. Bedrock step and plunge pool.

Bedrock Steps are steep drops in the river's longitudinal profile. Large, abrupt changes in channel slope like these are called knickpoints (Wohl, 2000). Knickpoints generally migrate upstream through time because of powerful erosion downstream.

Pools form from flow obstructions at their downstream end or by upstream scour. They often occur below steps, cascades and riffles, because high energy flows below drops scour sediment and bedrock. At the same time, downstream energy diminishes and the sediments deposit out of the current, forming an obstruction (Bierley, 05).

Cascades and rapids are knickpoints with trapped boulders and other large sediment. Rapids are a term used loosely by boaters, but it has a specific geomorphic definition. There are no true rapids on the reach of the mainstem Tuolumne River from Meral's Pool to New Don Pedro, because the gradient of the river is not steep enough. Instead, most of what rafters call "rapids" are, in geomorphic terms, "cascades."

Figure 2.4. Rapid.

Riffles are lower angle features. Typically riffles are shallow enough to cause surface roughness in the water. These environments are excellent habitat for invertebrates, because of abundant water and oxygen flow. At higher discharges the sediments are easily mobilized, making riffles very transient features in most systems.

Figure 2.5. Riffle.

Glides are like riffles, but deeper and longer. Water flowing across a glide is generally moving quickly, but not as whitewater.

Figure 2.6 - Clavey River riffle. Photo: Patrick Hilton.

Concept 3. *Rivers develop geomorphic sequences, such as the riffle-rapid-pool sequences seen on the Clavey.*

A river might be described as 'step-pool' or 'pool-riffle' in reference to its physical character. These sequences arise because the energy of the water (and therefore its scouring, sorting, and depositional tendencies) is not homogenous throughout the system.

It is important to recognize that all of the features you see on the Clavey River are dynamic, both in space and time. Waterfalls, eroding at their base, move upstream over the course of thousands of years. Depending on the size of the substrate, riffles, glides, and pools may change subtly from year to year, or may change dramatically every five or ten years. These changes occur during major hydrologic events, such as winter rains or peak snowmelt runoff. At that time, current riffles may turn into pools. Similarly, present-day rapids may turn into riffles.

Try and find the easiest place to cross the Clavey. Usually easy crossings occur in areas with low velocity flow or large boulder chains across the river. Pools contain low velocity water, but are often too deep to wade across. When crossing in a riffle, you can usually jump from boulder to boulder…but don't fall in! The water is usually moving fast and proper footing within a riffle can be hard to find.

Figure 2.7 Crossing Clavey River. Photo: Robyn Suddeth.

Concept 4. ***Most of the work a river does in moving sediment downstream occurs in a few high flow events.***

Think about the amount of sediment the river might move:

- In a given year?
- In a given decade?
- In a century?

Some of the boulders you see around you have not moved since they fell into the river from up on the hillsides, but what about the medium sized ones? How often do they move and how much material is moving down stream?

To think about this answer, let us conduct a thought experiment. What is the discharge on the Tuolumne River today? If it is mid-summer, chances are it is somewhere around 1000 cfs.

Now, what are the sizes of rocks you think it could be moving along its bed? Are they

- One foot across?
- Three inches across?

This size is called the 'competence' of the river.

In the first few days of 1997, a large winter storm came across California and caused significant flooding around the state. Hydrologists estimate that on the Clavey River this storm created flows around 47,000 cfs, something you might see an average of every 35 years. Imagine what size rocks would be moving at 47 times the Tuolumne's current discharge and you can perhaps get a sense for what happens during very large flows.

Vegetation

The strong, high flows of the Clavey River significantly affect the riparian vegetation. Because the Clavey receives large flow pulses, the riverbanks get scoured annually and inhibit most vegetation growth along the channel. Consequently, the riparian corridor along the Clavey River is slim. Still, the Clavey River vegetation is extremely diverse. It houses the most vegetative biodiversity of the three rivers and supports a largely native plant assemblage.

Focus On: *Foothill Pine*

Also known as "gray pine" or "spirit pine," these California native trees have a gray hue to their needles and are noticeable by their twisted conformations. They have the remarkable ability to grow in soils that do not hold a lot of moisture, which is in part why they do so well on the rocky slopes of the Tuolumne River.

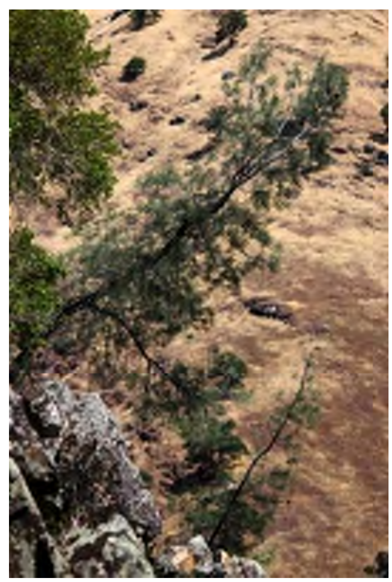


Figure 2.8 Foothill pine.
Photo: Patrick Hilton

As saplings, gray pines grow in a relatively straight manner. As the trees grow bigger, they seem to disregard gravity. Although there is not much known about why these trees grow like this, research indicates that this may be due to genetics or due to environmental factors, such as wind.

The Native Americans that inhabited the Tuolumne River Basin named these trees "ghost pines" or "spirit pines." Although told with slight variations, myth has it that they believed the spirits of the gray pines awoke on nights with a full moon and danced throughout the night. As soon as the light of daybreak hit their branches, they would freeze in place once more, thus stuck in their twisted conformations until they could come to life again.

Concept 1. *Contribution of Dead Trees*

Dead trees (large woody debris) typically have a larger presence on unregulated streams, where high variance in flows provides the disturbance necessary to fell trees and transport them downstream. The presence of large woody debris along the Clavey River's channel and amidst standing trees along its hill-slopes tells a story about its hydrology.

The Clavey River is a high-gradient, high power stream with the capacity to carry large woody debris. The intra and inter-annual variance in flows is revealed by deposits of that debris in various places along its banks. Large woody debris can get trapped in eddies or behind other obstructions during high flow events. As waters recede and lose transport capacity, debris gets left behind on shore or in the branches of standing trees. The placement of large woody debris on hill-slopes above the river indicates how high the river became during the last major flood. Looking closely at the debris on the hillsides may also give you an idea of how long ago the river reached those higher stages.

2.10 Large woody debris build-up above the Clavey riverbank. Photo: Patrick Hilton.

Concept 2: *Terrestrial organic matter contributes to the river ecosystem.*

Just as alluvial deposits from upstream provide important nutrients to the riparian ecosystem, plants introduce organic matter back into the river. This organic matter comes in as falling leaves, sticks and snags, dead flowers, and dispersing seeds. As they sink to the bottom, these materials start to decompose and release stored nutrients. Bacteria take up these nutrients, which provide energy to the plants and animals in the aquatic food web. Riparian plants' contribution may be especially important now and in the future: with the loss of salmon runs to the upper reaches, the Tuolumne has lost a contribution of organic matter from the once abundant decaying fish carcasses. Thus, plant material has become one of the greatest sources of nitrogen in the aquatic food web. As plant material decays, decomposers digest and break it down into progressively finer particles. When these extra fine particles are in the water, they cause turbidity, or murkiness, which can serve as important protection from predators for aquatic invertebrates.

Figure 2.11. Decomposing organic matter on the river's substrate.
Photo: Denise De Carion

Aquatic Insects

Figure 2.12 Looking upstream from Clavey River confluence. Photo: Carson Jeffres.
Figure 2.13 Blackfly larvae that is found in shallow bedrock areas and sidepools. Photo: Adam Clause.

The Clavey River is home to a distinctive assemblage of aquatic insects, driven by the river's hydrologic regime, geomorphic setting, and altitude. The assemblage reflects what we would expect to see in a high-gradient, snowmelt-fed, unregulated river: cold water temperatures, high water quality, fast-flowing riffles, cascades, and bedrock-dominated substrate. In erosional habitats, the aquatic insects are adapted to well-aerated and high-velocity flows; these species attach themselves to the surface of the rocks. Conversely, depositional habitats are occupied by aquatic insects with morphological adaptations for better mobility that are thus much stronger swimmers.

Concept 1. *Functional Feeding Groups*

The composition of functional feeding groups in Clavey River riffle habitat demonstrates an abundance of collectors. Scrapers and predators have similar percent composition, while shredders are the least numerous. This data is consistent with what we would expect to find occupying cobble-dominated, high-velocity habitat.

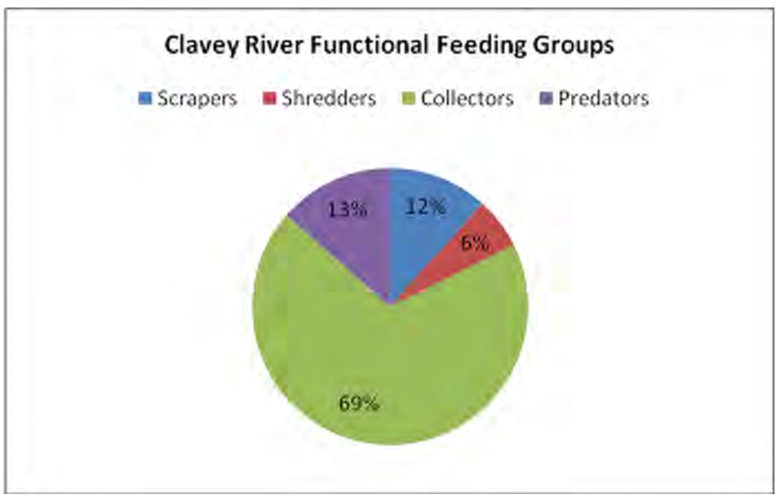


Figure 2.14 Clavey River FFGs in riffle habitat. Sampled June, 2009

Concept 2. EPT Metric

Ecologists often use the abundance of three aquatic insect orders to create an **EPT Index**—**Ephemeroptera** (mayflies), **Plecoptera**(stoneflies), and **Trichoptera** (caddisflies)—as an indicator of stream ecosystem health. If EPT index is high, the stream ecosystem is regarded as healthy because these three orders are physiologically sensitive to degraded water quality. The Clavey River's high water quality provides suitable conditions to support a rich assemblage of EPT families. This assemblage highlights the absence of adverse human impacts that are common to other rivers, such as water diversions, agricultural and urban runoff, and sedimentation. In fact, the only significant human impacts stem from the thousands of river rafters who stop at the Clavey River confluence each summer.

The Clavey River is a healthy ecosystem, but it is not extremely productive. The river is **oligotrophic**; the low nutrient content offers relatively less food for aquatic insects. Therefore, the number of individuals that can be supported in its waters is limited.

Focus On: *Mayflies (Ephemeroptera)*

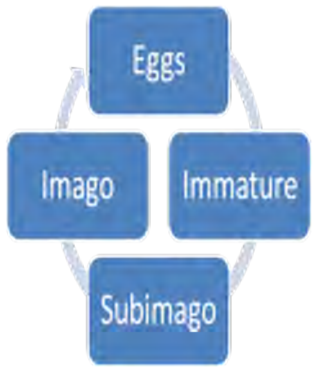


Figure 2.15 Mayfly life cycle.

Figure 2.16 Heptageniidae larvae. Photo: Adam Clause.

Habitat: Mayfly nymphs are often found in rocky-bottomed, running-water habitat in headwater streams such as the Clavey River.

Life Cycle: Mayflies spend the majority of their lives as aquatic larvae, a period that generally lasts 3-6 months and involves feeding on fine particulate organic matter and periphyton. Nymphs then emerge from their exoskeletons directly from the substrate of the river or from the water's surface, at which point they are in the subimago stage (the sexually immature adult stage). As subimagoes, they are covered in microtrichia, or tiny hairs, which allow them to overcome the surface tension at the water's surface. All males and some females then become imagoes, or sexually mature adults, at which time they begin to fly around in search of a mate. The adult stage is very short, generally lasting 2-3 days. After males and females swarm together to sexually reproduce, the females lay eggs. The life cycle is completed when the adults die and become a food source for other animals.

Distinguishing Features: Mayflies have two to three cerci, or tail-like projections, gills along the abdomen, and one claw per tarsus (leg-like appendage).

Fun Fact: Mayflies tend to emerge in great numbers. If you have ever observed a mayfly hatch, you know the tell-tale signs: flashes and boils at the water's surface, while trout and insectivorous birds congregate to prey on the newly metamorphosed imagoes.

Focus On: *Heptageniid and baetid mayflies*

Within the order Ephemeroptera, there are two common families found in the Clavey River: Heptageniidae and Baetidae. These two families have distinct differences in terms of life-history strategies, morphological features, habitat and food preferences, and reproduction. For example, heptageniids are hydrodynamically adapted to live in rock crevices in fast-flowing riffles where the water velocity is close to zero. They have large, shovel-shaped heads, flattened bodies, eyes on the top of their heads, and large arms for crawling and clinging to rocks. These morphological adaptations allow them to occupy a specific habitat: the underside of rocks in high-velocity riffles. During the nighttime, they crawl to the tops of rocks and feed on periphyton.

Conversely, baetids are adapted to be strong swimmers in relatively lower-velocity habitats such as pools and their margins. They have tubular, streamlined bodies. Baetids also seek refuge underneath rocks. During the nighttime, they often drift around in the water to collect FPOM, because they are well concealed from insectivorous fishes in the dark.

By comparing these two families, it is easy to understand how the presence of such aquatic insects can provide important information about the physical, hydrological and ecological components of the river.

Family	Heptageniidae	Baetidae
Morphological Distinction	Shovel-head, flattened, large legs, eyes on top of head	Streamlined, relatively long antennae, tubular body
Habitat	Erosional; boundary layer	Erosional and depositional
Feeding Group	Scrapers	Collector-filterers
Mode of Movement	Clingers	Swimmers
Life Cycle	1 generation/year	Multiple generations/year

Figure 2.17 Comparison Chart of Heptageniid and Baetid Mayflies.

Focus On: *Stoneflies (plecoptera)*

2.18 Stonefly (Pteronarcyidae) exuvia.

Figure 2.19 Stonefly adult. Photos: Denise De Carion.

Stonefly larvae are often found in fast-flowing, clean and cool rivers like the Clavey. Within one stream reach, stonefly nymph distributions can vary greatly depending on the availability of the following microhabitats: bedrock surfaces, leaf packs, and the hyporheic zone (where water flows through and under the ground, mixing at times with surface water). Adults inhabit riparian vegetation, rocks, or debris flows. The life cycle of the plecopterans that inhabit Clavey River are usually 1-3 years. Adult males attract females by drumming their abdomen against the substrate. Females lay their eggs in gelatinous balls directly on the substrate or in the water.

Distinguishing Features: Generally speaking, stoneflies have two **cerci**, or tail-like projections, no or few gills along the abdomen, and two claws per tarsus.

There are three common families of plecopterans found in the Clavey River: Pteronarcyidae, Perlidae, and Perlodidae. Plecopterans are extremely sensitive to degraded water quality conditions because they have rudimentary gills. They often inhabit well-aerated riffles in order to extract oxygen that is dissolved in the water. It is for this reason that they often exhibit certain motions (e.g., pushups) in order to increase the oxygen concentration gradient and why they experience mortality in low dissolved-oxygen zones.

Focus On: *Stoneflies: Herbivores and Carnivores*

Pteronarcyid stoneflies (giant stoneflies or salmonflies) have the largest body size of all stonefly families found in the Tuolumne River watershed. They live in both erosional and depositional habitats where they cling to the substrate. They are shredders—feeding mainly on detritus and algae. Their tolerance value is the lowest possible (zero), because they cannot tolerate any degree of degraded water quality (Barbour et al. 1999).

Perlid stoneflies occupy lotic-erosional habitats, where they also cling to the substrate. However, members of this stonefly family are predators. Their prey includes other stoneflies as well as aquatic insect families such as midges (chironomids), caddisflies (trichopterans) and mayflies (ephemeropterans). Their sensitivity rating is higher than pteronarycids, but it is still only a value of 1.

Family	Habitat	FFG	Habit	Sensitivity Rating (0-10)
Pteronarcyidae	Lotic-erosional and –depositional	Shredders	Clingers	0
Perlidae	Lotic-erosional	Engulfer-predators	Clingers	1

Figure 2.20 Pteronarcyidae and perlidae comparison chart.

Amphibians

Focus On: *Foothill Yellow-Legged Frog (Rana boylii)*

Figure 2.21 Foothill yellow-legged frog. Photo: Adam Clause.

Tadpoles, metamorphs and adults occupy stream reaches characterized by boulders, cobbles and large woody debris. They prefer to inhabit riffles and pools that have a mixture of sun and shade for concealment and thermoregulation. During the breeding season, they lay their eggs underneath large rocks in reaches that minimize impacts from changes in hydrologic flow regime, in order to avoid scouring (washing away) and desiccation (de-watering). The Clavey River provides all heterogeneous habitat features that these frogs require.

Foothill yellow-legged frogs are specialists; they require specific hydrologic parameters to thrive. For example, they depend on natural, seasonally-timed water flows, such as the spring-snowmelt recession. This recession limb provides the required conditions for eggs to survive. Also, they have a specific tolerance range for water temperatures (13-21 degrees Celsius).

Why are yellow-legged frogs found in the Clavey River?

A Species of Special Concern, this native frog species thrives in the Clavey River due to its **natural hydrograph**, **complex physical habitats**, and **food availability**.

The foothill yellow-legged frog historically occupied the mainstem Tuolumne River, but flow regulation has interfered with its ability to successfully reproduce. Unnatural daily tides **scour** or **desiccate** egg masses that females attach to the cobbles in the river. The Clavey River provides a suitable refuge for this population.

Handling:

Please be a steward to the population of foothill yellow-legged frogs in the Clavey River. Do not handle them. If you see a frog in the water, it is most likely a foothill yellow-legged frog. Note that Pacific tree frogs are very small and have dark eye stripes.

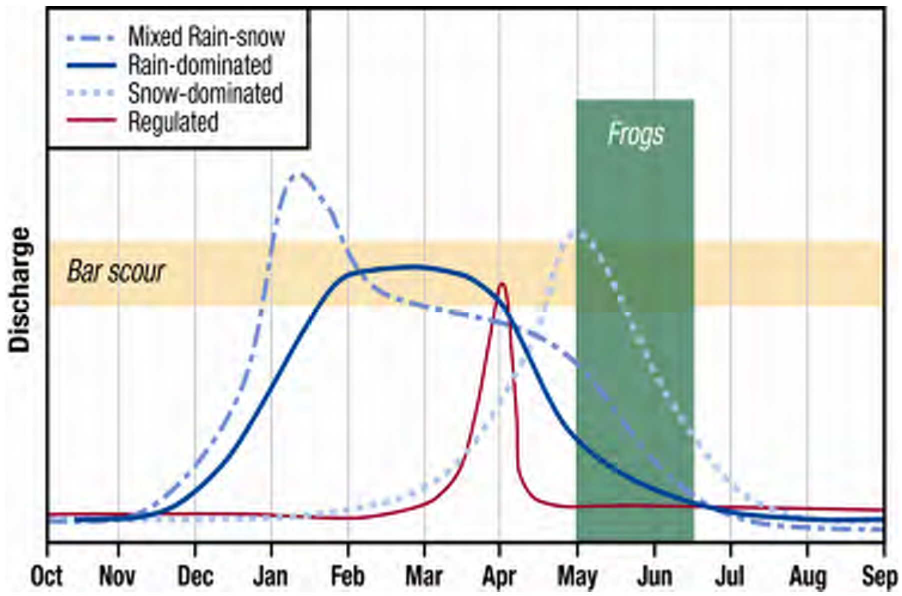


Figure 2.22 Foothill yellow-legged frogs have a small window of time to reproduce successfully [**Green Box**]. The spring-snowmelt hydrograph must recede gradually to prevent **bar scour** or **desiccation** [**Dotted Line**]. From: Yarnell S, Viers J, and Mount J. Ecology and management of the spring-snowmelt recession. BioScience 2009

Fun Fact: The tadpole stage lasts for one season, and then the swimming juveniles metamorphose into adults. Often you will see foothill yellow-legged frogs jump quickly into the water to seek refuge from danger, but usually they spend most of their time sunning themselves on warm rocks.

Distinguishing features:

- Body size: 1.5 – 3.5 inches
- Gray, brown, reddish or olive
- Spotted yellow legs
- Call is seldom heard
- Pale triangular patch on snout

Human Impacts: In addition to human interference with reproduction via dam regulation, foothill yellow legged frogs have been extirpated from many of their natural habitats in other ranges due to predation by invasive bullfrogs, nonnative fishes, and pesticide pollution.

Fishes

The Clavey River and its fish assemblage have been evolving together for thousands of years. Not only have the fish species evolved with the river, but they have also evolved alongside each other. Since the Clavey river remains an unregulated system, its native fish assemblage is still largely intact and includes:

- Headwaters: Rainbow trout
- Middle reaches: rainbow trout, Sacramento sucker, California roach
- Lower reaches: Sacramento pikeminnow, hardhead, sucker, and roach.

The presence of alien brook trout alters the native fish assemblage in the headwater tributaries only. The brook trout population was introduced to the Clavey River by fish stocking in the upper meadows.

Focus on: *Clavey River Cross Section*

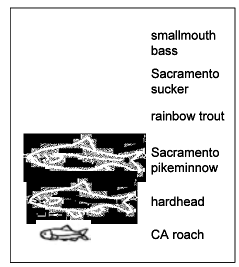


Figure 2.23 Schematic cross section of the Clavey River showing fish distributions within the river. Claire Stouthamer

The Clavey riverbed is largely composed of bedrock, boulder, and cobble (very little fine-grained sediment). The riverbank contains relatively little vegetation. Large woody debris can be found in the channel or above the riverbank. Sacramento suckers graze on the bottom of pools while rainbow trout inhabit the high-velocity, highly oxygenated flows. California roach (not depicted) inhabit the calmer edgewaters. Large Sacramento pikeminnow and hardhead can be seen in the bottom of deep pools, especially early the summer (May – June) when they are migrating up from the Tuolumne River.

Concept 1: *Physical and hydrological environment drives fish assemblages*

Fish are highly influenced by the velocity of water. As discussed earlier, the Clavey River reaches high velocity flows during the winter and spring. The native fish assemblage is adapted to spawn during high spring flows so that offspring can take advantage of abundant food and stable nursery habitat during the spring snowmelt recession.

Fish are highly dependent on water temperature. Because the Clavey is an unregulated river, its water is cold in the winter and spring during high flows and warm in the summer during low flows. Since the Clavey hydrograph has not been impacted by human activity, the native assemblage of fish is very well adapted to this natural fluctuation in temperature.

Focus On: *Resident rainbow trout*

Clavey River has an intact native rainbow trout population. Many rainbow trout populations in California have been damaged by water impoundments (dams, diversions, levees, etc.), degraded water quality, high water temperatures, competition with invasive species, and genetic mixing. Luckily, Clavey River's rainbow trout have been able to avoid these detriments. The unaltered flows provide the rainbow trout with the same flows with which they have evolved. These natural flows, along with minimal human disturbance, sustain the population while simultaneously making it harder for invasive fishes to establish.

Focus on: *Sacramento Pikeminnow and Hardhead*

Sacramento pikeminnow and hardhead are two native minnows that occur both in the Clavey River and the mainstem Tuolumne and inhabit the same habitat types: low-flow streams and deep pools. Neither species does well in the presence of alien smallmouth bass. While hardhead are herbivores, pikeminnow are top predators in native systems feeding on invertebrates and other small fish.

Figure 2.24 Sacramento pikeminnow. Photo: Claire Stouthamer.

Figure 2.25 Hardhead. Photo: Peter Moyle.

Sacramento pikeminnow and hardhead co-occur quite often with Sacramento suckers and look similar to one another, so telling them apart can be tricky. Figure 2.26 below provides some helpful hints for differentiating these fish.

	Sacramento Pikeminnow	**Hardhead**
Body shape	Large (up to over 1m), elongate, pointed head	Large (up to over 60 cm), deeper, heavier, rounder head
Mouth	Large, no bridge of skin connecting the upper lip to the head	Moderate, small bridge of skin connecting the upper lip to the head
Coloration	Brown-olive on the back and yellow on the belly	Brown and dusky bronze on the back
Life strategy	Predators that feed on large prey, including other fish	Omnivores that feed mostly on aquatic insects and aquatic plant material
Temperature preferences	18-28°C summer temperatures	24-28°C optimal temperature
Spawning season	April-May, mainly at night	April-May

Figure 2.26 Sacramento pikeminnow and hardhead comparison chart.

Figure 2.27. Hardhead and pikeminnow mouth comparison. The hardhead is depicted on the left, without frenem and the Sacramento pikeminnow is depicted on the right with frenem.

Fun Fact*:* both Sacramento pikeminnow and hardhead have an elegant warning signal called "fear substance." This substance is released when a minnow is injured so the skin is broken. Other minnows can smell this substance very quickly, upon which they will flee or hide. Therefore, minnows can, quite literally, "smell fear."

Focus on: *California Roach*

Figure 2.28 California roach. Photo: Peter Moyle.

California roach is one of the smaller fish that inhabit the Clavey River. As an adult it can reach up to 10 cm long. They have relatively large eyes and heads, small mouths, and a rather thin body. The upper half of the fish is usually a dark dusky grey or steel blue while the lower half of the fish is a dull silver color. During breeding season, California roach develop red-orange patches on their fins to send out mating signals to the other fish.

California Roach thrive in a wide range of habitats from cold, clear, well-aerated trout streams, such as the middle reaches of the Clavey River, to large river channels, such as the Mainstem Tuolumne, to warm, oxygen-deprived tiny foothill streams. This adaptation allows them to live in streams that become much smaller and warmer during the summer. In the Clavey River, roach feed on drift organisms in fast currents and browse for other insects on the bottom of the river.

Although California roach can inhabit a wide variety of environments, they are often excluded by piscivorous fish. The presence of the voracious alien smallmouth bass reduces roach abundance in the North Fork.

Fun Fact: Tuolumne County has its own endemic Red Hills roach, which is a subspecies of the California roach. The Red Hills roach is distinctive from the California roach due in part to its "chisel lip". The chisel lip allows the Red Hills roach to scrape algae from rocks. This population can be found near China Camp, in the Red Hills of Tuolumne County, in small streams flowing through serpentine soils.

Concept 2: *Clavey River food web*

The lower Clavey River contains only its native fish assemblage. The top predator in the system is the Sacramento pikeminnow. California roach, Sacramento suckers, and hardhead are the grazers, and rainbow trout are facultatively piscivorous, but feed mostly on invertebrates in the water currents. This native assemblage drives the food web of the Clavey River.

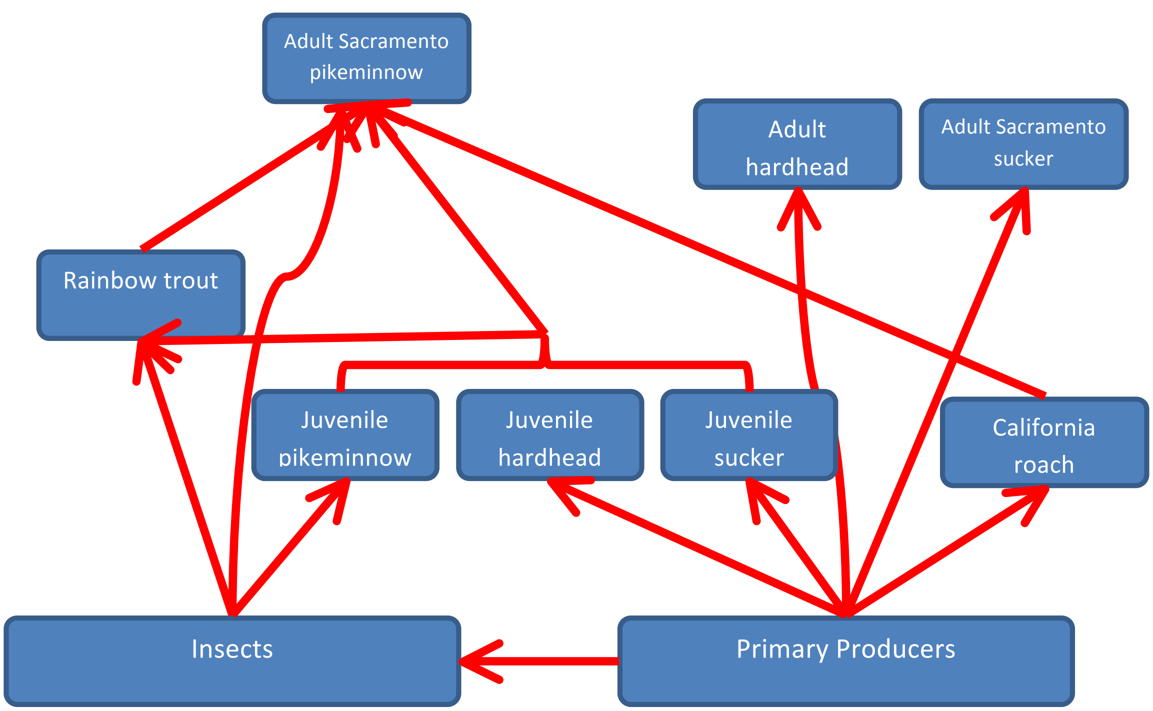


Figure 2.29 Clavey River food web.

Focus On: ***Brown trout stocking in the Clavey River***

The resilience of the native rainbow trout population was thoroughly tested in the mid-seventies, when Department of Fish and Game attempted to "superimpose" a population of brown trout on the rainbow trout population. During this time period, people were more concerned with creating a good sport fishery than preserving native fish populations of the river. In 1975 and 1976, more than 100,000 brown trout fingerlings were stocked in the river. Initially, they were able to grow faster than the native rainbow trout, but despite these higher growth rates, the brown trout population was not able to sustain itself. Many people now believe that it is fortunate the brown trout population did not make it, allowing the Clavey River to maintain its native fish assemblage. This fish assemblage has a good chance of surviving, as long as Clavey River remains wild, scenic, undammed, and unstocked.

Microcosm: Swimming Hole and Water Slide

A short distance up the Clavey, beyond the first major waterfall, there is a large pool commonly used by rafters as a swimming hole. Although a beautiful place to relax and cool off, there is much more to this location then simple recreation.

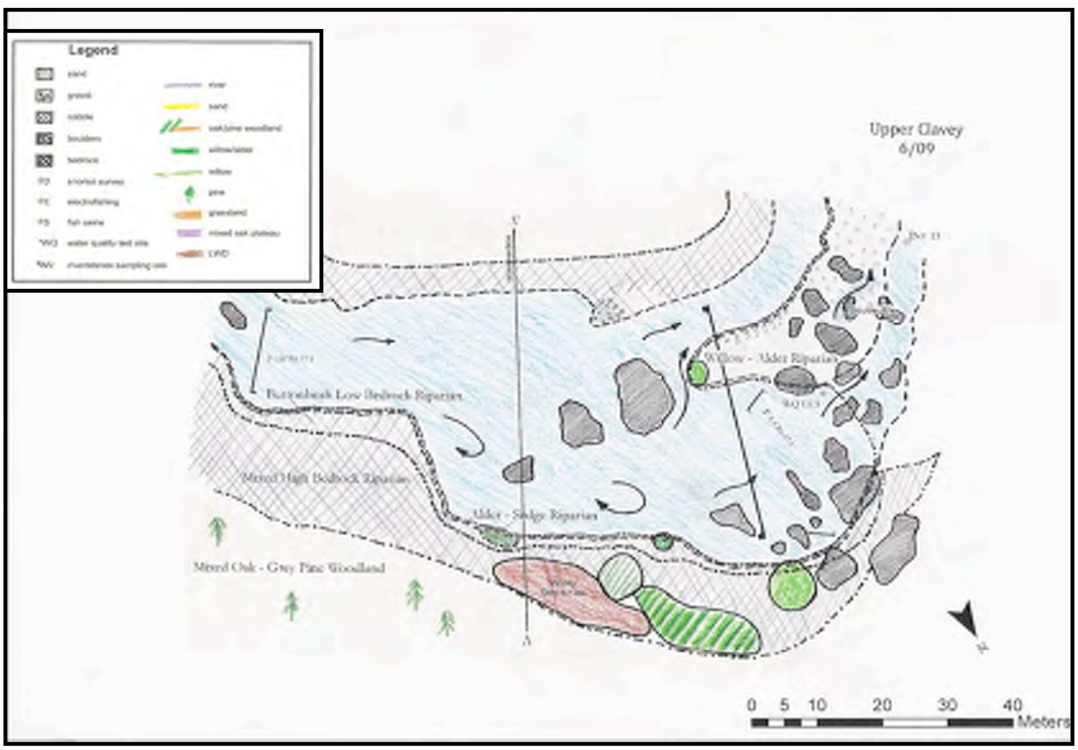


Figure 2.30 Upstream Clavey River microcosm site.

This pool is a perfect example of the rapid-pool-riffle sequence discussed earlier. Higher kinetic energy and scouring at the upstream end of the pool results in deeper water, which gradually gets shallower near the tail-out as sediment is re-deposited.   It is interesting to note the location of the high-water mark. This can be observed from the trim-line (where vegetation was scoured along the shore), or from deposits of wood and flood debris. While using this elevation to extrapolate the height of winter floods, think about how the current geomorphic units would look under this much water and which hydrologic characteristics would be present. This raises the question of the role that channel width plays during these discharges. Observe the different distribution of sediment sizes on river right (your right side if you are looking downstream) of the pool and compare those sizes to the distribution of sediment above the cascade at the head of the pool.

Sediment deposition on this lower gradient section supports a greater diversity of riparian plant species, including sedges, buttonbush, several species of willow, and even flow- and water-dependent marsh plants like the cattails in the boulder section adjacent to the pool. The stalks of these plants provide shelter from high flows and predation to many organisms, including aquatic invertebrates, amphibians, and fish. The roots of the riparian vegetation also serve a purpose, stabilizing the substrate and allowing for the retention and addition of more cobbles and sands in a positive-feedback loop. Upstream and on river right of the pool there is a large mass of large woody debris, which has accumulated over several years of high floods. Because these pieces of wood are carried up onto the bank, they and the nutrients they hold do not recycle through the mainstem, further reducing the Clavey's nutrient contribution to the mainstem Tuolumne.

Within this pool and the riffle directly below it, representatives from six of the seven possible orders of aquatic insects and all of the major families were found. This level of diversity reflects the heterogeneity of the habitat and presence of marginal riparian vegetation. Higher densities of invertebrates can typically be found within the marginal vegetation. Case-building caddisflies (Order Trichoptera) and true fly larvae (Order Diptera) are common there.

Fish also commonly use different parts of the environment. Juvenile Sacramento pikeminnow and California roach prefer the shallow, slow-moving water along the margins and in the willow stands on the downstream side of the pool. The deeper waters of the main pool are dominated by larger fish such as adult pikeminnow, rainbow trout and Sacramento sucker. The rainbow trout prefer the areas right underneath the cascade at the head of the pool where dissolved oxygen is highest and the flows are strongest. They like to hide behind the ‘bubble curtain’, the trail of bubbles resulting from the fall of water into the plunge pool. Suckers are likely to be near the bottom of the pool, in the deeper regions away from the margins. Pikeminnow are the most mobile and are likely to be seen in intermediate depths. By mid-summer rainbow trout are scarce in the Clavey and large pikeminnow have mostly moved back to the main river. As a result, small pikeminnows can occupy more and open flowing water.

The Clavey and Tuolumne Confluence

Confluence Hydrology

The confluence of the Clavey and Tuolumne Rivers is the meeting of an unregulated and a highly regulated river. Although the Tuolumne watershed is significantly larger above this point, a comparison of each river's characteristics can suggest what the Tuolumne might be doing without the reservoirs in its headwaters.

The relative impact of the dams decreases during wet years, when reservoirs are full and spilling water. However, if the reservoirs are low as they are following dry years, the Clavey could contribute enough water in a spring runoff event to more than double discharge in the mainstem.

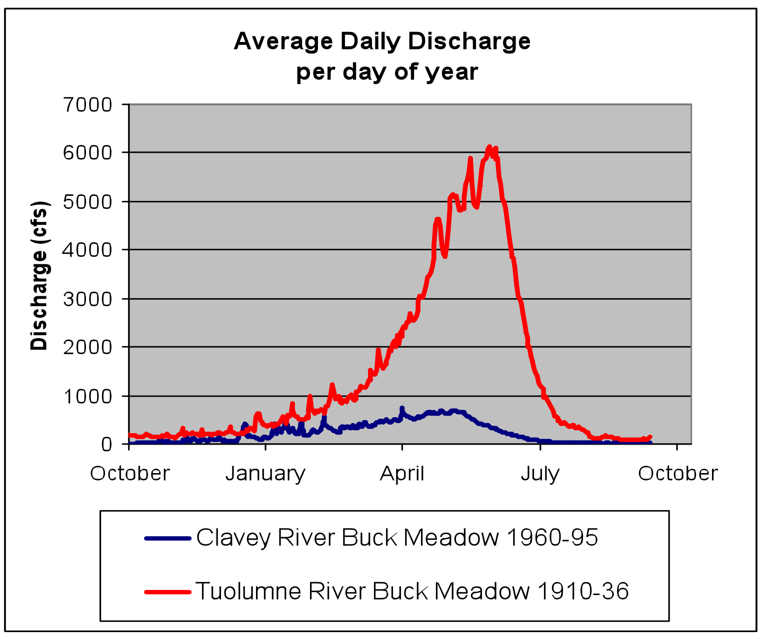


Figure 2.31 Daily average discharges from discontinued US Geologic Survey Gauges near the confluence. Although the O'Shaughnessy Dam was constructed on the Tuolumne during this period of time, the figure clearly shows the magnitude of difference between the two rivers.

Water quality

In general, rivers and streams of the Sierra Nevada have relatively good water quality. What does this mean? Water quality can be a hard term to define because so many different factors can positively or negatively affect it. Some of the main areas of concern are turbidity, dissolved oxygen, contaminents, and temperature.

Turbidity is a measure of the clarity of water. Electronic turbidity sensors work by sending light in the water and detecting how much light is reflected back. The more light that is reflected back, the more turbid the water is. Turbidity is generally caused by fine particles suspended in the water, but biological factors such as plankton or tannins from trees also contribute. During most of the year, the Clavey and the Tuolumne Rivers have very low turbidity, but various upstream factors might cause a turbid plume to flow downstream

Dissolved Oxygen (DO) is an especially inportant component of water quality for aquatic organisms. The Tuolumne River, with its clean water and aerating rapids maintains consistently healthy DO levels. Microorganisms, plants, bugs, and fish use dissolved oxygen for respiration. In places where primary productivity is very high, DO levels can fluctuate widely between day and night. Low DO levels can be threatening to fish, but is of no concern among rivers that keep DO levels high.

Focus On: *Giardia*

Do not drink the water! Even though you may be thirsty and the water looks cold and clean, there are non-visible contaminates. One such contaminate is Giardia Lamblia, which is a protozoa that can cause flu-like symptoms when you get home from your trip.

Giardia comes from humans and other mammals. It is a protozoan parasite deposited into the water through feces. You can get giardia if you drink untreated water, which makes water filters a vital tool for river rafters. Your rafting guides will be sure to filter all water before giving it to you.

However, if you do get giardia, the symptoms are loss of appetite, fatigue, weight loss, diarrhea,

Why would the Tuolumne River ever be turbid?

If you happen to see the Clavey or the Tuolumne become turbid, it might be the effect of one of the following causes:

- High flows carrying sand and sediment downstream
- Recent runoff from areas that have been in a fire (ash and other loose sediment can wash into the river)
- Landslides depositing high volumes of fine sediments.
- Can you think of others?

Although fine sediment is a natural component of the river, organisms adapted to live in the Tuolumne prefer clear water. Clear water benefits aquatic plants and algae by allowing light to penetrate deeper into the water, unclogs interstitial spaces along the bed for invertebrates, and allows visual fish to detect their food.

vomiting, abdominal cramps, and fever. You will not have symptoms until a few days after you ingest the cyst, but if you develop symptoms, go see a doctor who can prescribe medication to rid your system of these organisms.

Concept 1: *Temperature*

One of the most important water quality parameters is temperature. Almost all aquatic organisms have a specific temperature range that they require for survival. In general the Tuolumne is a cold river, so there is little harmful algal growth or other water quality problems. Clavey and mainstem Tuolumne temperature data show that the waters are at their warmest during the evening. This evening high temperature occurs because the heated water from the day continues to flow down the river during the evening. The Clavey is much warmer than the mainstem; dams regulating the mainstem Tuolumne discharge from the bottom of the reservoir, which keeps the river at a constant low temperature.

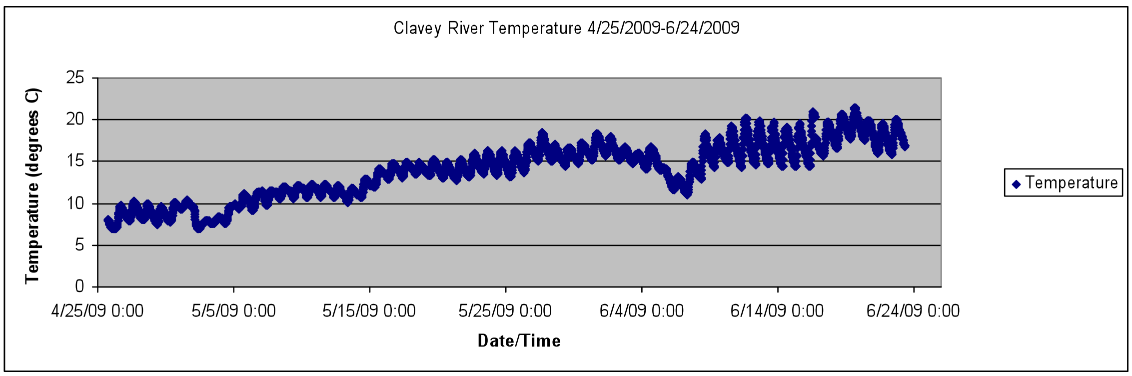


Figure 2.32 Clavey River temperatures between 4/25/2009-6/24/2009.

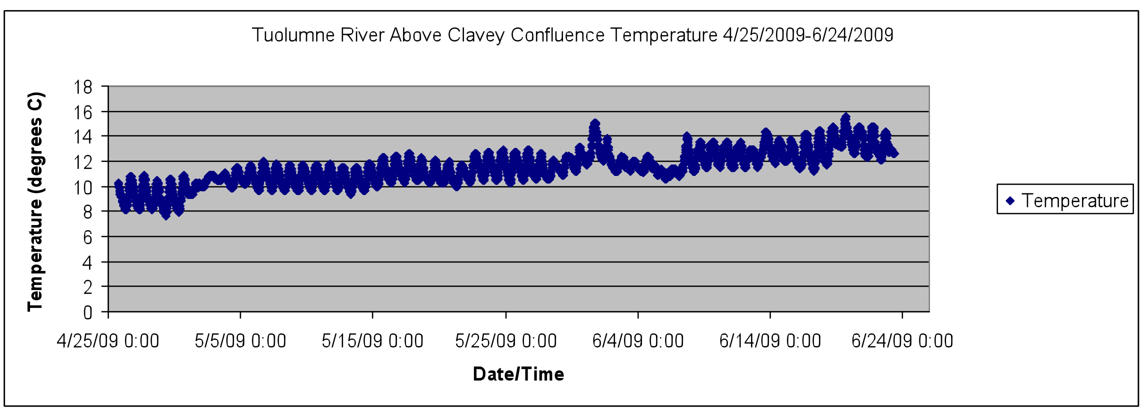


Figure 2.33 Mainstem Tuolumne River temperatures between 4/25/2009-6/24/2009. (Note the difference is scale on the left (y) axis

Both rivers are steadily increasing in temperature through the summer, but the mainstem increases less. Since there is more water in the mainstem, the large river is more resistant to temperature change. Higher and closer to the dams on the mainstem Tuolumne, there will be less temperature change, because the water is being discharged at almost a constant temperature regardless of season.

Confluence Geomorphology

Concept 1. *Hydraulic features*

Hydraulic features are water-forms that occur in the river and along its edges as a result of the interaction between the water's velocity and momentum and the river's physical form, such as boulders. Eddies, holes, and waves, which are classic hydraulic forms, are visible at the Clavey confluence and rapid. A brief discussion of the characteristics and functions of each will help develop an understanding of what is happening at this location and all along the river.

Hydraulic features are dynamic because they are interactions between flow volume, which changes daily, seasonally, and annually, and flow obstructions, which change very rarely. This means that at increasing water levels an eddy may become a hole as water begins to flow over the upstream obstruction that once caused the eddy. This can then become the trough of a wave as water levels continue to increase. Hydraulic forces at any particular location change over orders of magnitude, and depositional areas can turn to scouring ones and back again across large changes in discharge. As these physical features move and change, so does habitat.

Eddies are locations in the river where an obstruction causes water to flow back upstream behind it to fill in the space, creating a downstream pocket of slower water velocities.

As in the figure below, eddies often occur along the bank, but they also occur behind most large boulders or bedrock outcrops that are not submerged. Boaters and fish often use eddies as refuges from the fast-moving current.

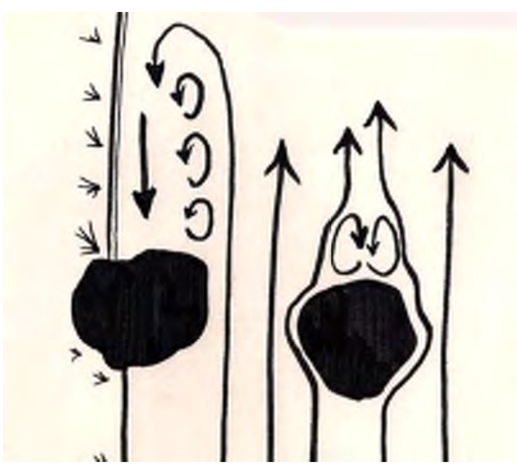


Figure 2.34 Eddy formation and water currents

Figure 2.35 Shoreline eddies. Photo: Patrick Hilton.

Eddies are examples of horizontally oriented flow separation. Figure 2.35 shows how these flow separation cells, or vorticies, can be oriented parallel or perpendicular to one another. Eddies are depositional zones because the water loses carrying capacity (energy to transport sediment) as velocity decreases. During flood flows eddies can accumulate cobbles and boulders but at rafting flows on the Tuolumne eddies are typically depositional zones for sands, fine sediment, and organic material.

Holes are standing waves created by submerged flow obstructions, which cause vertical flow separation. Holes have a wide range of characteristics as a function of water velocity, depth flowing over the rock, and depth behind the rock (Wyrick 08). Accordingly, these characteristics have a wide range of implications for boating and geomorphic scour. An important component of a hole is the hydraulic jump at the downstream end. As water flows over the rock or other obstruction, it's velocity and kinetic energy increases. When the water reaches the downstream end of that obstruction, it must suddenly fill in a much deeper channel while moving the same amount of flow past a given point per second. Because of momentum and inertial forces built up by shallow fast flow over the obstruction, the water keeps moving at the same shallow depth a small ways downstream before some of it separates and folds back to fill in the deeper cross section, converting kinetic energy to potential energy. Hydraulic jumps happen during this transition from fast, efficient flow over an obstruction to slower, less efficient flow in a downstream pool. An elevated pillow results at the crest of the recirculation. Clavey Rapid contains several examples of this phenomenon. Holes have tremendous scouring potential, because they direct the force of the water at the bed.

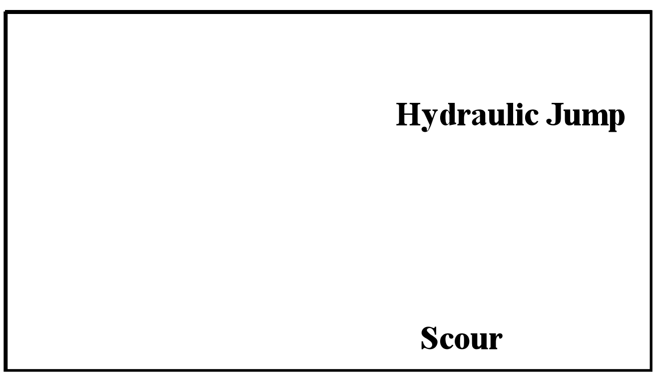


Figure 2.36 Diagram and photo of a "hole" on the Clavey River. Photo: Patrick Hilton.

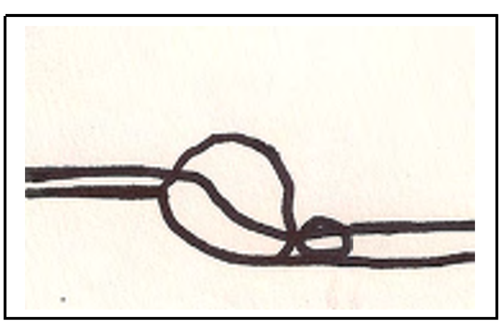


Figure 2.37 A hole becomes an eddy as flows drop, and a wave as flow increases.

As water levels continue to rise above flow obstructions, holes become waves**,** vortices disappear, and scouring zones transition back to depositional zones. The bar or riffle on river left above Clavey Falls is an expression of this deposition and scour pattern as a result of changing flows. At higher spring discharges the upstream bedrock flow obstruction along the river-left shore creates a large eddy where gravels and cobbles deposit closest to the main flow, and sand deposits closest to shore where eddy waters are slowest (and energy low). During daytime summer flows, these cobbles and gravels create a small riffle and eddy on river left. When flows drop because of dam operations at night, these deposits become a mid-channel bar. Winter flood flows also create a hole as water flows over the bedrock outcropping, scouring directly behind the rock and creating a deeper pool there. At very high flows this rock and the one upstream of it deflect the river's highest velocities towards the Clavey and river right.

Concept 2: *Comparing Clavey and Tuolumne Geomorphology*

If you hiked up the Clavey River you probably got a sense for the geomorphic differences between this river and the Tuolumne. Although the Tuolumne carries much more water annually, the Clavey, with its steeper gradient and different geology, delivers a significant amount of sediment, which has interesting implications here at the confluence and downstream.

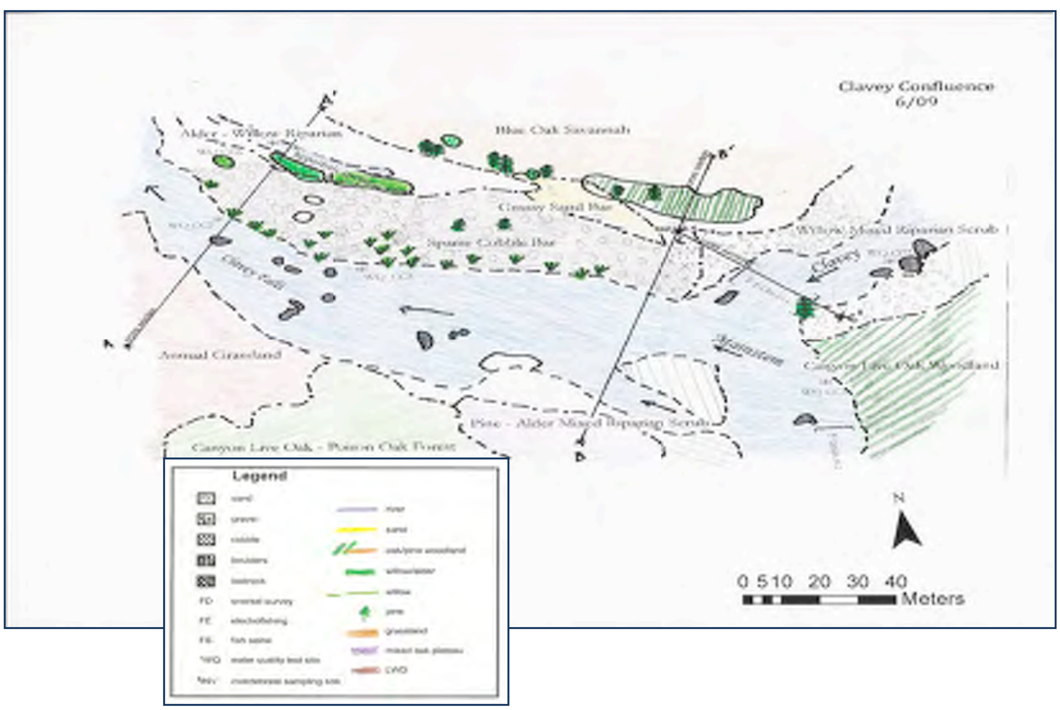


Figure 2.38. Map of Clavey confluence

The Confluence of Rivers and Orientation of Downstream Processes

A glance at the map of the confluence (Figure 2.38) illustrates how the direction of flow, sediment scour, and deposition can change when rivers converge at tributary confluences. Here, although the Tuolumne meets the Clavey at a gradual left bend, the downstream river channel is forced across the river to the opposite bank.

The Junction Bar at this confluence is a dominant geomorphic feature. The right bank downstream of the Clavey river mouth is a long, poorly sorted bar of coarse sediment because it becomes a depositional backwater when the river levels are at flood stage.

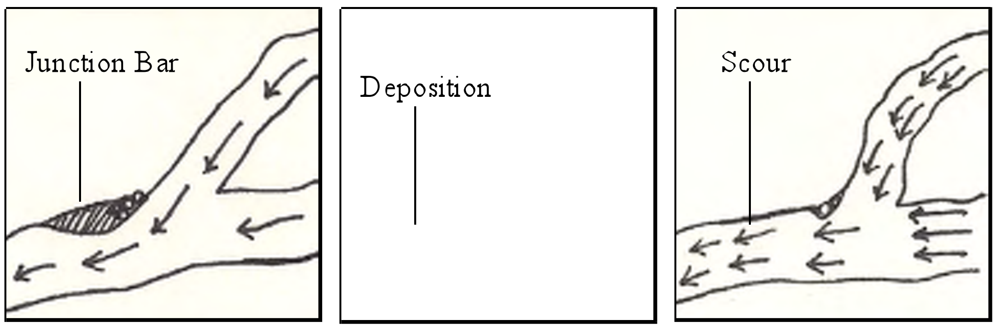


Figure 2.39 Tributary Junction Bar at 3 different water levels: intermediate, high, and flood stages, (from left to right) with different geomorphic properties

Notice where and what types of rock compose the highest deposits for clues about what geomorphic environment its represents at extremely high flows.

This deposit also has characteristics of a longitudinal bar, which are elongated depositional features either in the center or along the banks of rivers. The ridgeline down the center of this bar probably indicates scouring against the right bank at very high flows, maybe facilitated by a lower Clavey river and less forcing to river left.

Concept 3. *Forming a Rapid*

That the largest rapid on this stretch of river, Clavey Falls, occurs at the confluence with the largest tributary, should have you suspicious of a potential relationship between the two. Why would a tributary confluence cause a rapid downstream?

Sediment Deposition

One important factor is the sediment moved downstream by the Clavey during big storm or even landslide events, some of which deposits, backs up water and sediment behind it, and forms a pool upstream. Although the Tuolumne is a larger river, the Clavey must have on several occasions transported a sufficiently large volume and size make-up of rock to overwhelm the Tuolumne's ability to move all of it downstream.

Debris Flows

Debris Flows are masses of unconsolidated material that move rapidly downhill. With high densities and velocity, they are able to transport very large material. A large debris flow from the Clavey river within the last few hundred years could explain how the Clavey transported some of the largest material here, seen strewn across the entrance to Clavey Falls. Evidence of such a debris flow includes:

- The presence of very large boulders in Clavey Rapid and up on shore
- Scoured banks of the Clavey River
- Unsorted deposits including both smooth and angular rocks

Can you find other evidence of a historic debris flow?

Channel width

Figure 2.41 The mainstem of the Tuolumne River widens after the Clavey River confluence.

Channel width is an important factor in determining where sediment deposits. The cross-sectional area of the river directly downstream of the confluence is significantly wider than it is upstream, meaning that as the rivers rise to flood flow, downstream scour is not necessarily intensified because water can spread out laterally and deposit sediments that made it through and past Clavey Falls (Leopold, 1953).

Resistant Bedrock

Bedrock outcrops also determine the location of many rapids. Bands of erosionally resistant bedrock crossing the channel are visible throughout and below many rapids here on the Tuolumne. If you hike towards the middle or downstream of Clavey Rapid on river right and look across the rapid, you will see a resistant bedrock outcrop forming steep canyon walls across the river, with a large white dyke running across it. Bands of erosionally resistant bedrock like these contribute to the

Figure 2.42. Raft paddles by resistant bedrock in Clavey Falls

immobilization of large boulders, as you can see in the falls, which subsequently block more sediment upstream.

Focus On: *Hyporheic Flow*

Figure 2.43 Hyporheic flow at the Clavey confluence. Photo: Patrick Hilton.

Notice the large stand of vegetation downstream of the confluence on river right on the junction bar. There must be a significant amount of water reaching these trees and bushes to sustain them. Because porous material makes up the confluence bar, water from the Clavey goes underground and re-emerges in this spot. Water flowing underground in this fashion is known as hyporheic flow. This constant stream of water separate from the main streamflow creates a distinctive habitat.

The Clavey River is a dynamic system from which we can learn a tremendous amount. The undammed Clavey provides us an interesting model for considering the historical Tuolumne before it was harnessed, but its present state and confluence with the mainstem is just as fascinating. Although it is considered an oligotrophic system, it contains a tremendous variety of habitats that create a template for a complex terrestrial and aquatic food web.

III. Mainstem Tuolumne River: Indian Creek

Figure 3.1 - Indian Bar, viewed from upstream. Photo: Patrick Hilton.

Figure 3.2 - Trail to the Indian Mine. Photo: Adam Clause.

Indian Bar (Figure 3.1) is the most popular camping spot on the river. Every year, over 4000 people camp here, taking advantage of its sandy beach, camping spots, and high, shady terrace. Indian Bar is not only a unique site on the Tuolumne, it is a rarity among all rivers. It occurs along a stretch of river that has a relatively low gradient, resulting in a continuous flow with few large rapids. The channel is still almost entirely bedrock, but some alluvial features begin to appear as the river actually meanders back and forth within its constraining canyon walls.

At the Clavey River, you were able to explore and move around, but at Indian there are fewer places to go. Take the opportunity while here to think about various time scales, and use this guide to learn to observe a place's historical evolution by interpreting clues in the present environment. Not only are natural processes evident, but just across the river you can see a narrow single track trail (Figure 3.2) winding its way across the canyon wall. This trail was originally built to allow miners to haul equipment and food in and out of the canyon by mule. If you wish, you can cross the river by raft or kayak and explore the trail and the mine shaft just upstream from Indian Creek.

Hydrology

Concept 1. *Mainstem Hydrograph*

In the introduction, you saw what the hydrograph looks like on the main stem with ramping flows. This is an extremely unnatural occurrence for any river, and has many implications for organisms that live in and around the Tuolumne River. This dramatic flow change arises to generate power. The timing of this flow is specifically for rafters like you! During the summer, San Fransisco Public Utilities Commission (SFPUC) releases a pulse of water at 7:00 AM so that the river can be rafted. Try putting a stick in the sand and checking it periodically, to see how much of a difference about 900 CFS really is. The graph below (Figure 3.3) visibly demonstrates the magnitude of this ramping.

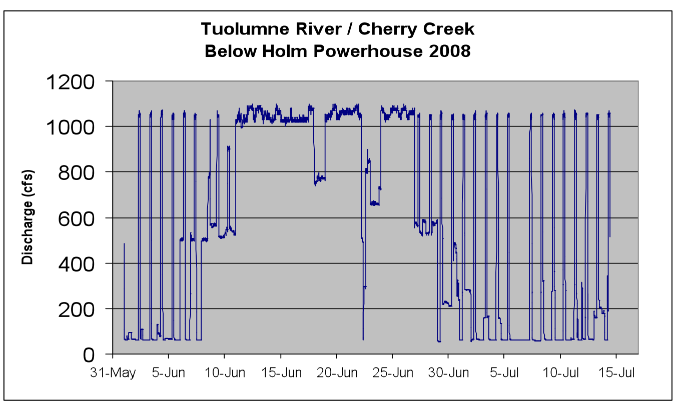


Figure 3.3 - This graph shows daily discharge of the Tuolumne River during periods of hydropower peaking.

Concept 2. *Features of Channel Hydrology*

1. Highest Velocity Flows

When you stand at the edge of the water can you see where the water is moving fastest? Try throwing a stick in the center of the channel and see where it

Different Velocity Flows

What is a thalweg?

The thalweg line essentially follows the deepest part of the river.

What is an alluvial river system?

An alluvial river system contains large amount of sediment that is constantly being transported and deposited along the stream or river.

What is a bedrock system?

A bedrock river system is typically confined by bedrock that restricts changes in the shape of the river due to its resistance to erosion and the resulting reduction in sediment movement.

Why do I care?

This is what helps shape the river. That "high velocity core" has the most sediment transport capacity and competence.

goes. It will most likely sit in the middle of the river at the upstream end of Indian bar, but as it goes around the bend it will get closer to the other side of the river before continuing downstream. Notice how it does not stay in the center of the channel the entire time. The stick was being carried by the water's high velocity core, following the thalweg (see sidebar). Higher velocity tends to occur at the outside of bends as water flowing there must "keep up" with water taking the shorter route on the inside of the curve.

The bedrock on the outer bend of the river (Figure 3.4) is preventing this meander from going any further. In a pure alluvial channel, higher velocity flows would continue to erode the outer bank and the river's meanders would continually migrate laterally and downstream. In bedrock influenced channels, however, the medium flows that you likely see now do not change the river much, and bedrock holds the river's meanders in a relatively static position over time. It takes very high flows to cause any significant changes to the river.

Figure 3.4 - Bedrock opposite Indian Bar. Photo: Denise DeCarion

2. River Meander

Here you begin to see river meanders. The river meanders above and below Indian campground as a result of upstream sediment contributions, decreased gradient, and bedrock outcroppings on either side of the river. The river has lost some of its stream power with a decrease in gradient below Clavey, and is eventually deflected by a bedrock outcropping on one side of the river. Slower velocities behind this erosion-resistant obstruction instigate deposition of accumulated sediment. The river is then deflected in the other direction, and the process continues until geologic channel confinement forces an increase in gradient and straightening of the river's channel a few miles downstream, with the onset of Grey's Grindstone and other rapids.

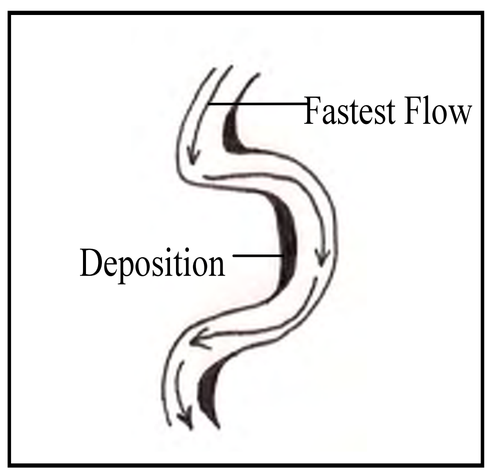


Figure 3.5 - Formation of a river meander

At Indian Bar, the high velocity core of the river is deflected by a bedrock outcropping at the upstream river-right end of the campground to the river-left outside of the bend, causing low velocity flows on the inside where material then settles out. This deposition of fine sediment is very important for creating plant and animal habitats (including rafter camping habitats).

3. Waves

As you raft down the river you will have most likely gone over a series of waves. One such grouping of waves is in the center of the channel next to Indian Bar. A common misconception exists that all waves in a river must be formed by a rock beneath the surface. This is not always the case, and a lot of waves are actually formed by a constricted channel where the water deflects off the sides and meets in the middle.

4. Superelevation

Superelevation of the water level can often happen in bedrock confined systems. As you read earlier, the highest velocity water stays to the outside and runs into and up on the bedrock. As a result, the water level is slightly higher on that side. To the left (Figure 3.6) is an exaggerated sketch of the phenomenon.

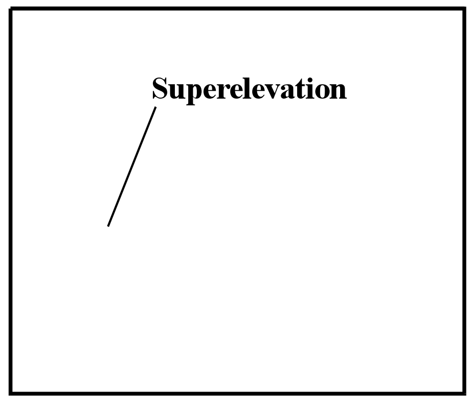


Figure 3.6 - Sketch of superelevation at Indian Bar

5. Eddies

It is of interest to note that there are very few true eddies located at Indian Bar. The large pool on the downstream side is not a true eddy, but rather a region of low velocity flow caused by the deflection of water off of the other side of the river. The sand located on that beach is a product of this drop in flow velocity. A true eddy can be seen at certain flows at the top of the bar behind the bedrock outcrop, and along the margin of the central portion of the bar.

6. Water temperature

Because the sun heats the Tuolumne's water as it travels through the hills, the water temperature at Indian Bar was found to be 1˚-2˚C (3˚-5˚F) higher than the mainstem at the Clavey confluence.

Geomorphology

Concept 1. *Hierarchies of Physical Form*

Hierarchies are a good construct to think about the physical forms we see on rivers, the processes that move the sediment, create rapids, and control the distribution and quality of biological habitat (Naiman 2005). If, for instance, we were interested in knowing why a particular distribution of gravel sizes occurs somewhere, we would look at numerous spatial (and temporal) scales to determine the sediment source and its driving, sorting, and depositional forces.

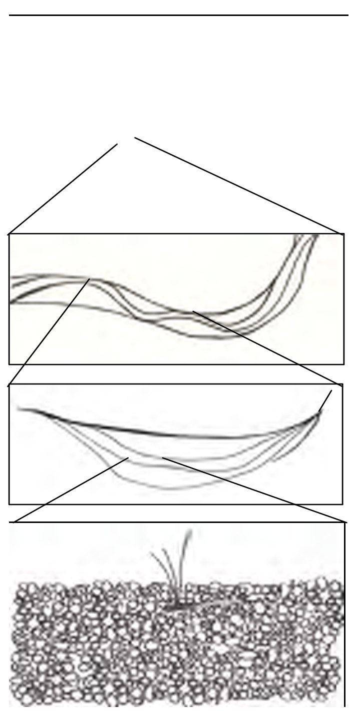


Figure 3.7 Hierarchies of physical from within a river.

The diagram to the right (Figure 3.7) graphically illustrates the various scales at which we can examine physical form. From the whole watershed (at the top), to a stretch of the river to microhabitat and hyporheic flow (at the bottom), this nested hierarchy of physical form provides a way to approach the analysis of physical scale.

Concept 2. *The Geomorphic Story of Indian Bar*

Figure 3.8 - Indian Point Bar.

To understand why Indian Bar exists and why it has its shape is to try to comprehend the spectrum of spatial and temporal time scales mentioned above. Indian Bar may have been here for thousands of years, which already tells us all kinds of information.

River Detective

First, try to identify the biggest form you can - maybe a bend in the river, or a long straight reach.

What controls this shape, and what are some subsequent features that occur because of it?

Now identify an intermediate sized geomorphic feature, such as a boulder, a sandbar, or a waterfall.

What created or controls it? Is its shape or location being forced by some larger feature? What are the timescales it might be evolving on?

Now look for a small sized unit, a patch of sand or a small pool or something, and ask the same questions.

Do the sizes of these units relate to the rates of time at which they evolve?

First, start with the fact that, as you approached Indian, you saw more and more point bars. Point bars form as a result of a river meandering (Figure 3.8). As mentioned earlier, slower velocity water on the inside of a bend deposits material forming bars that alternate as you go downstream. Below Indian you can see another point bar that is a result of Indian's existence.

Figure 3.9 - Indian is in the lower left with the river flowing downwards. From: RMC Water and Environment & McBain and Trush. Upper Tuolumne River: Description of river ecosystem and recommended monitoring actions. Final Report for SFPUC, 2007.

You can see how much more sediment is deposited in this reach (Figure 3.9). This is a direct effect of the gradient of the Tuolumne decreasing, allowing for more sediment to drop out.

You may be wondering why Figure 3.8 and the picture to the left do not match. Starting at the top of the photograph you can see a point bar on river left, then on river right, and Indian is also on river right. This is because Indian is actually a forced feature. The bedrock at the head of Indian and on the other side of the river force Indian to be permanent, meaning it stays there even at record flows (hence the reason it may have been there for a thousand years).

The aerial photo is a great comparison to the map provided on the next page (Figure 3.10) and will assist you on locating geomorphic features that will be described.

Figure 3.10 - Aerial Photo and Map of Indian Bar. Photo: McBain and Trush and SFPUC 2007

At the head of the bar you will notice a small sandy patch that is not consistent with any other sediment near you. This exists because of the large piece of bedrock that is protruding into the Tuolumne River. The bedrock creates a small eddy directly behind it that allows for this sand to deposit.

As you walk down the bar, you can **see a very distinct gradient in sediment size**, beginning with boulders then changing to cobble, gravel, and finally sand. At the upstream end of the bar, there is fast moving water, but as it wraps around the outside, the flow on the inside of the bend decreases in velocity and therefore gradually loses its ability to carry heavier sediment, depositing ever finer sediment.

You will also notice a difference in sediment size as you move laterally up the bar. Again it starts with larger sediment and decreases all the way to sand. Why would there be sand that high up the bar? Imagine extremely large flows that are around 100,000 CFS coming down the Tuolumne. This is when new material is deposited at the top of the bar. (Landslides can also deposit material high up). Below is a series of three diagrams showing the bar at different flows, and the water levels of each.

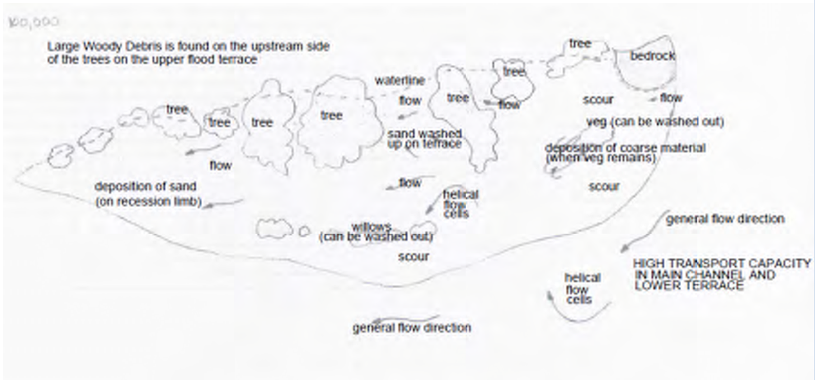


Figure 3.11 – Flow and waterline at Indian Bar during 100-year flood event.

In this case (Figure 3.11), the water would completely cover Indian Bar and be well over your head. Flows such as these are very rare, but they account for the presence of sand so high up the bar. One indicator that the flow was low velocity this high up the bar is the absence of exposed tree roots. At these high flows, if water were flowing fast around the trees, it would erode the soil around the roots.

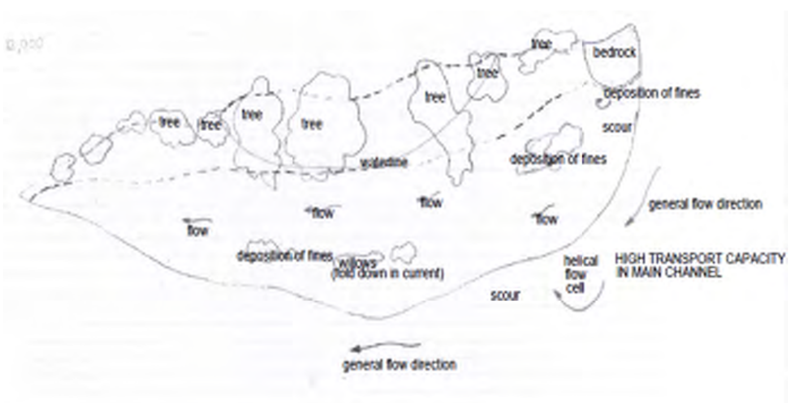


Figure 3.12 - Yearly flood event.

In Figure 3.12, you can see that the water line is about half way up the bar at 12000 CFS. Patterns in the sand lead us to this conclusion - you can see an abrupt slope change (or small dropoff) at the downstream side of the bar, indicating the point at which sand is redistributed by the yearly flood event.

River Detective: Determining Historical Flows

Do you notice anything unexpected in the flow diagrams?

There is only one eddy that really forms during the highest velocity flows. The presence of sand at the top of the bar should point to the idea that a large eddy is formed over the top of Indian during high flows due to the bedrock outcrop just upstream. Rather, only one small eddy is created just behind that outcrop. The rest is low velocity flows still moving in the downstream direction. In an eddy, woody debris will be flowing upstream and get caught on the downstream side of any trees. Look around and you will only see material trapped on the upstream side of trees, indicating that no eddy exists in that spot at high flows.

Figure 3.13 - Baseflow.

The minimum flow for the Tuolumne is about 200 CFS (Fig. 3.13) which is most likely what you will see during summer months. Here there is a minimum amount of bar formation or structural changes because the flows do not have the competence or capacity to cause change. These diagrams indicate how the bar forms over time. It was not formed by one big flood that happened a thousand years ago, but rather by a series of repeated events over the course of millenia.

Concept 3. *Bar Formation*

Longitudinal Bar

Just off the upstream side of Indian is a mid-channel bar, exposed at lower flow levels. This bar is characterized as a "longitudinal bar" (Fig. 3.14). Longitudinal bars are elongate and teardrop-shaped, with deposits typically decreasing in size in the downstream direction.

Figure 3.14 - Longitudinal Bar

This particular longitudinal bar is most likely caused by an increase in channel width. As water spreads out across this larger channel, velocities slow down and sediment that was carried by higher-energy flows upstream begin to drop out of the river's suspended load and settle instead on the river bottom. These new deposits then create an area of even slower velocities behind them, instigating the deposition of progressively smaller sediments in the tear-drop shape you can see now.

Imbricated Bars

Downstream of Indian is another point bar. This downstream point bar is imbricated, a term referring to the orientation and placement of cobbles on the bar: most are similar in size and leaning on one another. On the tail end of a high flow event (or flood), as velocity and stream power begin to decrease, a rock that was being pushed by the current will get stuck on another rock (Figure 3.15). All rocks of similar size rolling down behind it will then also get stuck leaning against the one in front in a sort of domino effect, resulting in the fairly neat arrangement of stones you can now see on river left, all leaning at the same angle (Figure 3.16).

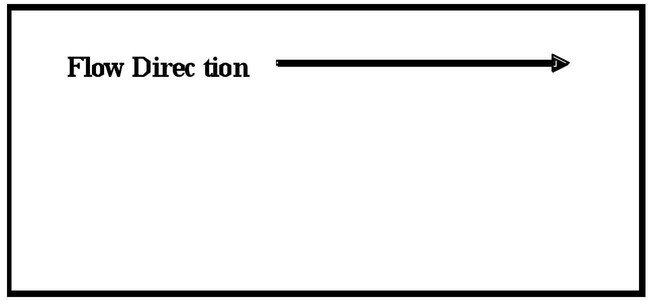


Figure 3.15 - Direction of flow on an imbricated bar

Figure 3.16 - Point bar indicating imbrications. Photo: Gerhard Epke.

Vegetation

Figure 3.17 – Plant species homogeneity along the main stem Tuolumne. Photo: Patrick Hilton

Concept 1*. Habitat Homogeneity*

The regulated hydrology of the main stem is reflected in the homogeneity of vegetation at Indian bar. This bar has relatively low species diversity and constant vegetative patterns. The bar contains relatively young willow recruits that have established since the last major flood event. At the top of the bar you will find old ponderosa pines and oaks that were able to survive the heavy scour of flood flows. Between the two woody bands, you will find only weedy grass species and herbaceous plants. The vegetation of Indian Creek campsite does not show the same vegetative layering complexity that is present in the tributaries.

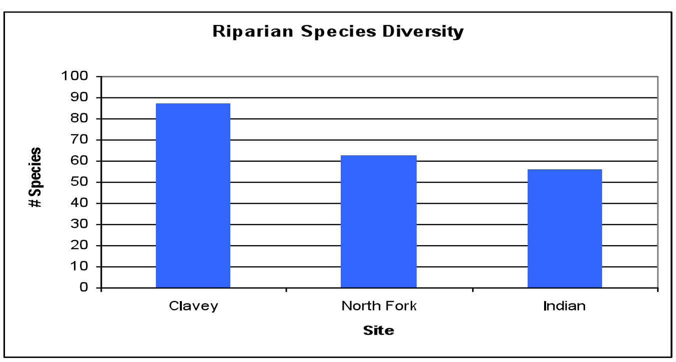


Figure 3.18 - Number of riparian plant species present along the Clavey River, the North Fork, and Indian Creek campsite.

Indian Creek campsite has the lowest number of riparian plant species of the three study areas (Figure 3.18). This low plant biodiversity stems from river regulation. Dams remove the natural hydrograph and prevent recruitment of plants that depend on natural flows. This system is not as natural as it appears.

Concept 2. ***Flooding the Riparian Zone***

After heavy rains or warm springs that quickly melt alpine snows, large amounts of water course through the river system. These high flows can overtop the banks of the river and flood the riparian ecosystem. Instead of completely scouring the banks as they do the bars, effects of floodwaters are reduced by riparian plants in a number of ways.

As water flows through the riparian vegetation, it encounters many well-rooted trees and shrubs, most of which can survive the occasional inundation. Some plants are specially adapted to these floods: willow and alder saplings are flexible enough to be bent over horizontally by flood waters, returning to vertical after flows have subsided. The leaves, stems, and roots of these and other riparian plants slow the movement of water over and through the soil, retaining moisture in the soil and reducing the extent of flooding.

Concept 3. ***Plants create structure for geomorphic features***

When plants establish along the water's edge in a low velocity part of the river, their roots act as sediment catchers. Roots not only serve as physical barriers to sediment, but also slow down the water so that the sediment suspended in the water column is more likely to settle out.

If this happens continuously over longer periods of time, plants can form entire sediment deposits around their root structures. If you get a chance to ferry over to the river-left bar below Indian (Figure 3.19), you'll see that the willows have accumulated enough sand at the downstream end to help form a sandy beach above the cobbles. This accumulation lead to the succession of different types of plants, as the community changed from a Dusky willow cobble bar to a Sandbar willow beach.

Fig. 3.19 - Alternate bar downstream and to river left of Indian Bar. Photo: Patrick Hilton.

Figure 3.20 - Upstream of Indian, view of contrasting south and north facing slopes. Photo: Patrick Hilton.

Figure 3.21 - South-facing slope above Indian Bar. Photo: Patrick Hilton.

Focus on: Aspect

As you look up in the hill slopes bordering the river, note that you can often see dense forest or woodland on one side, and savannah or grasslands on the other (Figure 3.20). These communities of plants are determined by a number of factors; including the amount of water available, the amount of sunlight they get, and the soils holding their roots.

Here in the northern hemisphere the sun never gets directly overhead. It instead carves an arc across the southern sky. Because of this, the south-facing hillsides (those on your right as you look downstream, Figure 3.21) often receive more sunlight during the day, making them much warmer than the shady north-facing slopes. Higher temperatures mean more evaporation, and the soils are thus much drier than those on the opposite slope.

Together, sunlight, high temperature, and drier soils affect the type of plants that can grow. The tall, broad-leaved black oaks you see on your left as you look downstream from Indian have trouble drawing up water and retaining it in these conditions. Thus, they can't persist as well as the small, hardy grasses and the evergreen live oaks you see on your right, with their small, thick, and hard leaves.

Concept 4. *Recruitment box, cottonwood, willow, and tamarisk*

Figure 3.22 - Fremont's Cottonwood (*Populus fremontii*)
Photo: Patrick Hilton.

If you are familiar with other California rivers, you may know some of the common shrubs and trees along the banks. In the vegetation guide you will see a variety of willows (Salix spp.), Fremont cottonwood (Populus fremontii, Fig. 3.22), and the introduced Tamarisk (Saltcedar). On the Tuolumne, however, you might notice that two of these are conspicuously absent: cottonwood and tamarisk. Why?

A number of factors inhibit the growth of cottonwood and tamarisk, including sediment deposition, flood patterns, and hydrology. Unlike some other California rivers, the Tuolumne's headwaters course through hard granite, which does not contribute much sediment to the river. In other rivers, this sediment would provide a nutrient-rich foundation for the seedlings of these trees to establish themselves. Along this stretch of the Tuolumne, minimal sediment contribution and minimal sand bar creation suggest a relative lack of

Why is there is a distinct band of willows growing along the edge of Indian Creek bar?

Willows produce white, fluffy seeds during the spring months that are dispersed by the wind. These seeds do not have a hard coating and do not live very long after dispersal; they have a relatively short window of time in which to establish.

Willows depend on spring flows to transport seeds into the proper substrate and provide saplings with water to grow. If flows get too high, the seedlings will be scoured away; if flows get too low, then the saplings will dry out. An optimal combination of spring flow timing, sediment type, and seed production is necessary.

These willows also serve an important ecological purpose.

Their presence creates a nice low velocity habitat for fish and other critters to live and hide in.

Changing one aspect of a river, can initiate a cascade of ecologically significant events. In this case, the Tuolumne's man-made flow regime allows vegetation to establish that then creates new habitat for other organisms.

fine-grain sediment deposition, resulting in a lack of habitat for seedlings to start growing.

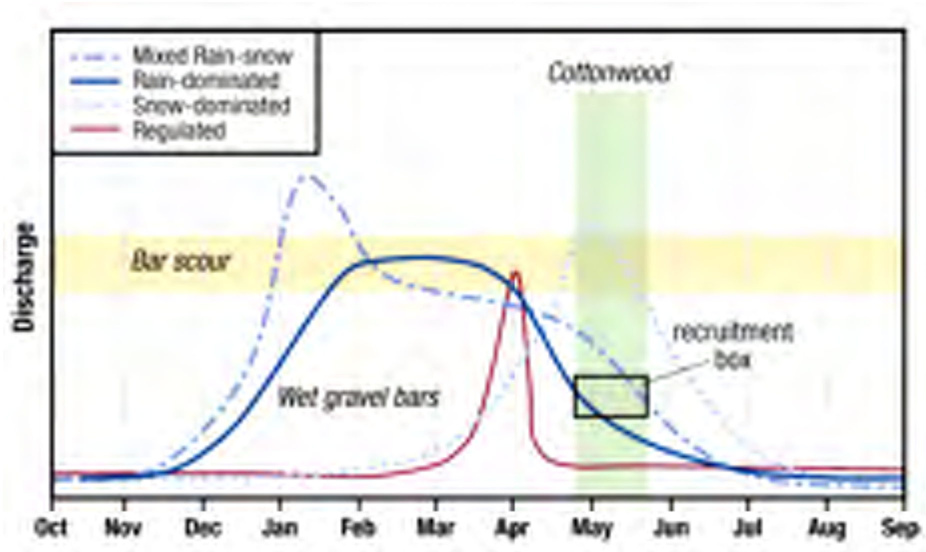


Figure 3.23 - Recruitment Box.
From: Yarnell S, Viers J and Mount J. Ecology and management of the spring-snowmelt recession. BioScience 2009

Another important factor in seedling establishment is the rate at which floodwaters decrease in the springtime (Figure 3.23). Cottonwood seeds are usually dispersed after the winter floods, floating through the air or water and landing on freshly scoured banks. As the floodwaters recede, the seedlings grow roots at up to 1 cm a day, following the water down into the soil. But on the Tuolumne, floodwaters recede more quickly, because the bedrock and coarse sediment doesn't retain the water as well.

Cottonwoods are rare on the Tuolumne, but you can see them occasionally in sandy spots downstream, where a lower gradient and accumulation of sediment from tributary input provides the necessary conditions to let them grow.

Aquatic Invertebrates

Although aquatic insects are found virtually everywhere that there is water, they are very specific in the type of habitat that they prefer. Some insects prefer to live in areas of swift-flowing, highly oxygenated water with a gravel substrate (for example the small riffles on the upstream edge of the gravel bar at Indian camp, Figure 3.24). Although these insects are common on the upstream edge of the gravel bar, they are virtually nonexistent on the downstream edge (Figure 3.25) where the finer sands and sediments occur.

Figure 3.24 - Upstream end of Indian Bar. Photo: Patrick Hilton

Figure 3.25 - Downstream end of Indian Bar. Photo: Patrick Hilton

Oxygen requirements dictate the location of many of these insects. Insects with high oxygen requirements are found in areas of colder water and in places where air and water are forcibly mixed, such as in a riffle. Insects with lower oxygen requirements flourish in microhabitats with lower available oxygen, such as slow-moving backwaters or warm streams.

Insect Respiration

Aquatic insects have developed a variety of adaptations to enable them to survive in conditions of differing dissolved oxygen levels. Many insects breathe cutaneously, that is they take oxygen in through spiracles in the exoskeleton. However, this strategy limits insects to remaining near the surface. Invertebrates which dwell on the substrate or in the water column tend to use other methods.

Many aquatic insects use gills to allow them to take advantage of oxygen that is already dissolved in the water. Without a high level of dissolved oxygen present in the water, the effectiveness of gills is improved through behavioral changes. Some species of insect larvae, when faced with low oxygen conditions, will wiggle their abdomen causing water to flow faster over the gill surfaces. This speeds up the rate of diffusion of oxygen into the gills.

Focus On: ***Caddisflies (Trichoptera)***

Left – Figure 3.26 - Caddisfly larvae, Family Limnephilidae (taken out of case).

Right – Figure 3.27. Caddisfly larvae cases. Photos: Adam Clause.

Caddisflies (Order Trichoptera), like many common aquatic insects, mostly prefer riffles. Larvae (Figure 3.26) are easily recognizable by their strategy of cementing sand grains, gravel, or even cast-off vegetative material into a case (Figure 3.27). This case provides physical protection for the larvae, as well as also providing camouflage. If the case isn't present, then you can recognize a caddisfly larvae by its long body and twin projections protruding from the end of the abdomen, each of which has two claws.

Figure 3.28 - Examples of caddisfly cases. Photo: Adam Clause.

Each family of caddisfly makes its case in a different way. Some don't make their case out of local material at all, but rather out of a substance they produce themselves, similar to a spider's silk. These 'net-spinning' caddisflies use this silky case as a means of filtering out small organic particles and organisms from the flowing water around them. Common materials utilized by other case-making caddisfiles include small pieces of discarded vegetative matter (pine needles, sticks, leaves), small pieces of gravel, and sand. Figure 3.28 shows examples of caddisfly cases constructed from those vegetative materials.

Exploring Habitats

Walk up to the upstream edge of the bar and take a look at the riffles. Imagine you are an insect living in a river, and you have chosen to live in one of these riffle habitats. Where in these habitats would you expect most of the insects to be?

The large gravels common in riffles provide a lot of available places for aquatic insects to avoid the rushing water and predators. Most of the insects will be underneath the rocks and a few will simply be hiding on the downstream sides.

Carefully pick up some of the larger rocks and see if any insects are visible attached to the underside. You may see several different types of insects underneath.

The life cycle of caddisflies (Figure 3.29) is also interesting. Most adults lay eggs under the water, which then hatch into larvae. These larvae undergo 5-14 *instars* (molts) before creating a fixed retreat/cocoon where they form a pupa. This is where the maturing insect undergoes metamorphosis. Once metamorphosis is complete, the mature adult emerges from the pupal case, and rises to the water surface to emerge. After it becomes airborne the adult will feed mostly on nectar. Adult males can form huge mating swarms after hatching.

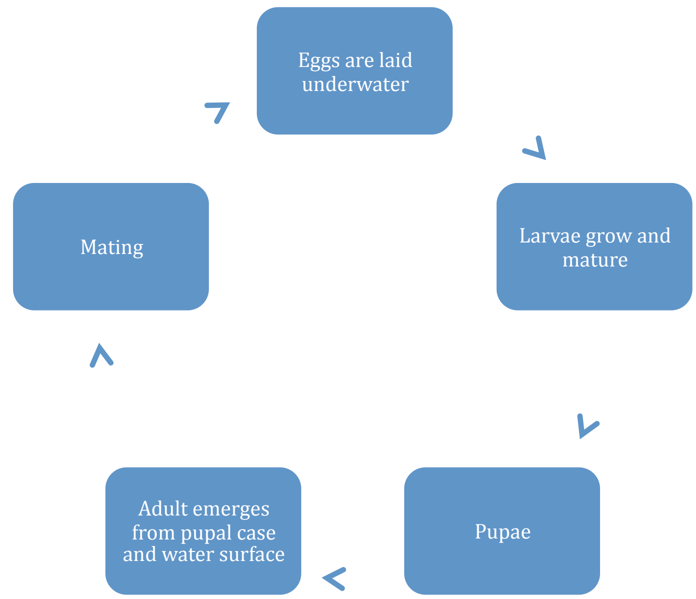


Figure 3.29 – Caddisfly Life Cycle

Concept 1. *Dam regulation affects aquatic insects*

Figure 3.30 – Indian Bar. Photo: Patrick Hilton

Having noted which microhabitats these insects are likely to be found in, think about what effect the daily tide of the regulated Tuolumne River will have on these insects. What will they do when the tide 'goes out'? Will they simply move to follow the water line, or will they perish?

This daily fluctuation has an extensive impact on this important link in the riverine ecosystem. Although overall water quality of the system is still high, encouraging the presence of sensitive species, these frequent disruptions presumably result in a marked decline in densities during periods of hydro-peaking.

Amphibians

Focus On: Sierra Newt ***(Taricha sierrae)***

Habitat: The Sierra newt frequents fast-moving rivers and

Figure 3.31 – Sierra newt in Indian Creek.
Photo: Denise De Carion.

streams in the Tuolumne River watershed. After the first fall rains, they become aquatic and begin breeding. Indian Creek is home to many breeding newts, which can easily be observed in slow-moving side pools from January to May.

Life Cycle: Sierra newt larvae are strictly aquatic, while juveniles are terrestrial, and adults utilize both environments. Breeding males can be identified by their bulbous vent. Females lay their eggs on the sides and underneath rocks in running water. It takes five to eight years before Sierra newts become sexually mature.

Distinguishing Features:

- Body size 2.75 – 3.5 inches
- Brownish on top, bright orange on belly
- Long, flattened body
- Long tail
- Skin just below the eye is the color of the belly
- Eyes bulge out from outline of head when viewed

Why are newts so visible and easy to handle?

Sierra newts produce a potent neurotoxin called tetrodotoxin (TTX). TTX binds to pores in sodium ion (Na+) channels in nerve cell membranes of predators and causes imminent mortality, except for some species of aquatic garter snakes.

Sierra newts and Sierra garter snakes are having a co-evolutionary arms race. Sierra garter snakes (*Thamnophis couchii*) have evolved a high resistance to TTX by preventing it from binding to their Na+ channels (Brodie, 2005). It is this mechanism of co-evolution that allows Sierra garter snakes to continue to utilize Sierra newts as a main food item.

Where do I find Sierra newts? When you are visiting the Indian Creek campsite, ask your river guide to row you across the river to the Mine site. Along the path to the mine, you will find moist, canopied side pools. These side pools act as refuges and as a breeding ground in late Spring.

from the top

Fun Fact: Adult Sierra newts have defense postures to deter competition from other newts and provide a warning signal to predators. These postures include standing high on their legs, wagging their tail, making loud clicking sounds, and the "Unken Reflex," a swaybacked position where the back is curved inward and the tail protrudes outward, exposing the brightly colored chest.

Fish

Due to dominant physical variables, different fish species are found at Indian than are found upstream at Meral's Pool. At Meral's Pool you will see an assemblage dominated primarily by rainbow/brown trout and Sacramento sucker, with both Sacramento pikeminnow and California roach present. Although the same species are present at Indian, the relative abundances shift.

Sacramento pikeminnow and hardhead are both large native minnows relatively common in the Clavey River, a tributary to the Tuolumne subject to seasonal high velocity flows. These flows push the adult minnows out of the tributary and flush them downstream, increasing the size of these populations downstream from the confluence of the Clavey and Tuolumne Rivers.

Focus On: ***Sacramento sucker*** (Catostomus occidentalis)

Figure 3.32 - Distinctive sucker mouth.

Figure 3.33 - Sacramento suckers near river bottom.

Photos: Peter Moyle

Suckers are one of the most versatile fish in California. They are commonly found in places where temperatures never exceed 15°C, but are also common in streams where temperature extremes reach up to 30°C. Thus, sucker habitat ranges from cool, clear mountain rivers (like the Tuolumne) to brackish estuary water (like the Suisun Marsh near San Francisco Bay).

These fish are easily recognizable by their mouth. The fleshy, papillose lips (Figure 3.32) work almost like fingers, probing the substrate (Figure 3.33) and picking up whatever happens to be there. Although suckers do not have a particularly powerful sense of sight, their senses of smell and hearing are quite acute. This is in part due to their substrate habitat, where turbidity is generally highest.

The Sacramento sucker is the vacuum cleaner of the Tuolumne. They consume anything and everything that they happen to come across on the substrate, but prefer small invertebrates and algae.

Historic Salmon Subsidy

The Tuolumne River was historically home to runs of Chinook salmon and steelhead. These large fish played an important role in the input of nutrients to the system. Salmon spawn in freshwater rivers, and after hatching gradually make their way downstream to the ocean. After spending two to three years eating and growing, they return to the rivers where they were born to spawn again, and then die. This mass migration and death of many fish provides a huge source of nutrients (marine-derived carbon, nitrogen, and phosphorous) for the entire river ecosystem. Salmon carcasses provide food for predators and scavengers, and the breakdown of this material provides essential nutrients for both riparian vegetation and for organisms within the river itself. The construction of dams downstream coupled with the alteration of Central Valley flow regimes has eliminated salmon from the Tuolumne River above LaGrange Dam

Where Have All the Sculpin Gone?

Riffle sculpin are common to most fast-flowing streams in California. Although found in many other Sierra Nevada streams, they are not found in the mainstem Tuolumne here at Indian Creek. Why? What is different here?

Riffle sculpin are small fish which live out their entire lives close to the substrate of fast-flowing water. Unlike most fish, sculpin lack a swim bladder (an air filled sac within the body cavity that provides buoyancy). This lack of buoyancy enables the sculpin to remain close to the bottom and not get swept away by the swift water. Larval sculpin are well-adapted as well. Many fish have what are known as pelagic (free-swimming) larvae. Instead, sculpin have benthic larvae. These larvae remain close to the substrate in order to avoid being swept away. These adaptations to benthic living unfortunately prevent riffle sculpin from being able to easily colonize new areas, or adapt quickly to changing conditions such as those caused by hydropower peaking.

Focus On: ***Brown and Brook Trout***

Figure 3.34 - Brown Trout. Photo: Nicholas Buckmaster.   Figure 3.35 - Brook Trout. Photo: Peter Moyle

Brown and brook trout are the only alien species on this reach of the main stem of the Tuolumne. These fish are similar in overall form to the rainbow trout, but are quite distinctive in patterning and color. Brown trout (Figure 3.34) have both black and red spots, and these spots are surrounded by a defined halo. Their body color tends to have a yellowish cast to it. Brook trout (Fig.ure 3.35) have a dark, olive green back with lighter-colored wavy lines, red spots on the sides with blue halos, and white leading edges on the pectoral, pelvic and anal fins. The caudal fin (tail fin) of brook trout is also less obviously forked than either the brown or rainbow trout.

Brook trout are similar to rainbow trout in most aspects of ecology and life cycle, but unlike rainbow trout they spawn in the fall. Brook trout are most distinguished by their tolerance of very cold water. They are able to actively forage when other trout are reduced to inactivity. Unfortunately for them, in the absence of extreme cold temperatures, brook trout are displaced by both brown and rainbow trout. The few brook trout present in the main stem have likely been pushed down from upper tributaries to both the Clavey and the Tuolumne Rivers, and are not a sustainable population.

Brown trout also have a very similar ecology and life cycle to rainbow trout. The thing which most distinctly separates the two species is the time of year in which they spawn. Brown trout spawn in the fall as temperatures plummet and more water courses down the river in the form of rain. On the other hand, Rainbow trout spawn in the spring as temperatures rise and water levels recede with the baseline and snowmelt recessions. This difference is crucial in explaining why brown trout can be found in the main stem but not in the tributaries.

The natural hydrograph of the tributaries shows large pulses of water during the crucial spawning months of brown and brook trout. These high flow events flush out any embryos buried in the gravel. Although the main stem is also subject to the same rainfall events, the dams help to regulate some of the flows and prevent the relative magnitude of the flows in the main stem from reaching that of the tributaries.

The life history strategies of many native fish are specifically adapted to deal with the distinctive hydrology related to a Mediterranean climate. Many native assemblages are characterized by fewer than seven species. The Tuolumne only has five species of native fish, almost all of which spawn in the spring in order to take advantage of spring snow runoff.

Many native species are characterized by relatively long life spans and high fecundity, which allow the fish to survive periods of adverse conditions and reproduce in large numbers during good conditions. Also, many species are behaviorally or physiologically adapted to avoid or survive extreme environmental conditions. Rainbow trout will leave a stream that warms over the summer, whereas California roach are specifically adapted to withstand extemely high temperatures and salinities. This suite of adaptations allow native fish to endure rapidly changing and severe environmental conditions.

Microcosm: Upstream End of Indian Bar

The upstream end of Indian bar (Figs. 3.24, 3.30) is a great place to observe fluvial interactions. You can see evidence of Native Americans who came up the river to fish annually if you look closely at the bedrock here. These grinding holes may be thousands of years old, and show a continuity of human impact on the Tuolumne River.

The patch of fine sediments found at the junction of the bar and bedrock wall occurs because of hydraulic forcing from the bedrock outcrop at higher flows. The bedrock outcrop at the upstream end of this longitudinal bar exhibits the same differential downstream forcing patterns that depend on discharge magnitudes, as we have seen elsewhere along the river. Decadal floods scour downstream of the outcrop because of the vertical hydraulics in this reach. However, during annual flood events an eddy forms here, which sorts and deposits medium to fine grained sediment. Looking at the pattern of sorting, it may be possible to piece together the hydrologic history of the bar. Also, depending on the time of year and day, you can see evidence of daily hydropower peaking from this location as well.

The fallen tree in the water in front of you is a great example of large wood that changes nearby flows and shelters aquatic species from predation, while slowly releasing nutrients into the river as it decomposes. Across the river, you'll see a small dip in the forest in front of you, which may appear much greener with different kinds of trees. This is Indian Creek. Indian Creek has a riparian plant community, unlike the surrounding upland community. Since this stand contains creekside habitat on a north-facing slope, there is subsequently more productivity. You will see riparian plants that are not seen anywhere else in the area, including spicebush, California bay laurel, red willow, and even peppermint! If you hike up to the mine, stop along the path and pick some... it's a non-native introduced plant! Overhanging trees in this riparian area provide shade to cool the slow-moving water, and provide protection from UV light to eggs of the Pacific tree frog and the Foothill yellow-legged frog. During summer, the lower reach of the creek dries up, but permanent pools may be present higher up the watershed.

The riffle at the upstream edge of the bar is typically good habitat for many species of aquatic insects, especially those sensitive species used for evaluating water quality (see Introduction). Here at Indian though, the densities of most taxa are unusually low, and the most sensitive species are most heavily impacted. This is a perfect example of the effect that hydropower peaking has on benthic organisms. The diel fluctuations cause drastic periodic reductions in habitat availability.

Most fish will avoid this region at the upstream end of the bar. The water is quite shallow and flowing rapidly. Young-of-year Sacramento suckers prefer to shelter among the willows along the margins of the bar, while larger fish can be found in deeper water. Large Sacramento suckers and trout are most likely to be found in the region between eddies and the faster current. Sacramento pikeminnow are present in low densities but are more likely to be found in slower runs and pools.

IV. The North Fork Tuolumne River

Introduction

One glance at the North Fork of the Tuolumne River will tell you that it behaves differently than the Clavey and Tuolumne. During summer months the channel is usually shallow, discharge is low velocity and warm, and trees and sedges grow across the mouth. Whereas the confluence of the Clavey River has a large pool, numerous gravel bars, and a major Class V rapid, it is easy to float past the North Fork of the Tuolumne without even noticing more than a small canyon.

If you get the chance, eddy out and spend some time looking around and thinking about the significance of some of the differences between these three rivers. People often hike up the North Fork to swim, explore and enjoy its lush riparian corridor.

Hydrology

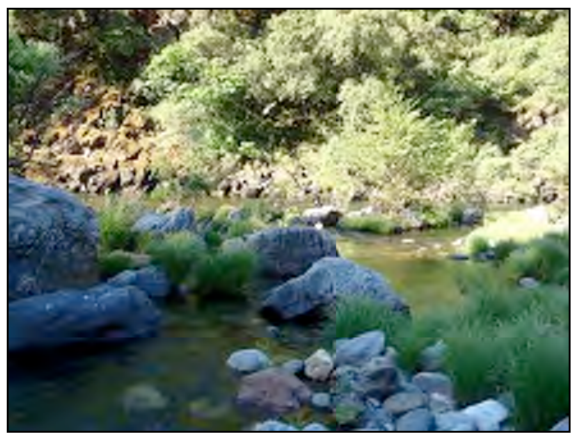
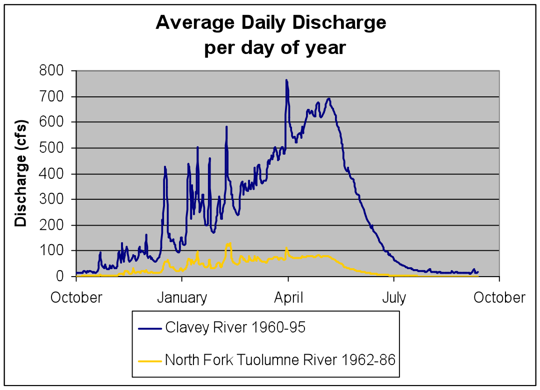


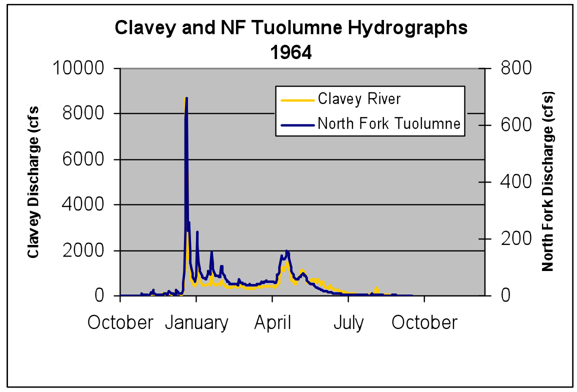
Figure 4.1 – North Fork confluence in April 2009 . **Figure 4.2 – North Fork confluence in June 2009**

Photos: Denise De Carion.

The photos above were taken from the same location, looking downstream from the North Fork Tuolumne River toward the confluence with the mainstem. The photo on the left (Figure 4.1) was taken in April and the photo on the right (Figure 4.2) was taken in June, note the same tree occupying the mid-channel gravel bar (more difficult to see in Figure 4.2). Although taken at different times of day, you can see the immense changes in discharge and vegetation.

Notice the volume and temperature of water the North Fork contributes to the mainstem, the size of the channel, the size and distribution of sediment and vegetation, and think about how these might all be reflections of a very different watershed than what you have previously seen.





Left: Figure 4.3. Average Daily Discharges from the North Fork Tuolumne and Clavey Rivers

Right: Figure 4.4. Comparison of North Fork and Clavey River hydrographs for one water year

Figure 4.3 shows average daily discharges from the two tributaries on the same vertical scale, while Figure 4.4 shows the hydrographs of the two tributaries. Be sure to note the differences in scale on Figure 4.4, with Clavey being multiple orders of magnitude higher than the North Fork. Both figures indicate that the North Fork and the Clavey River have similar hydrologic behavior, at different magnitudes.

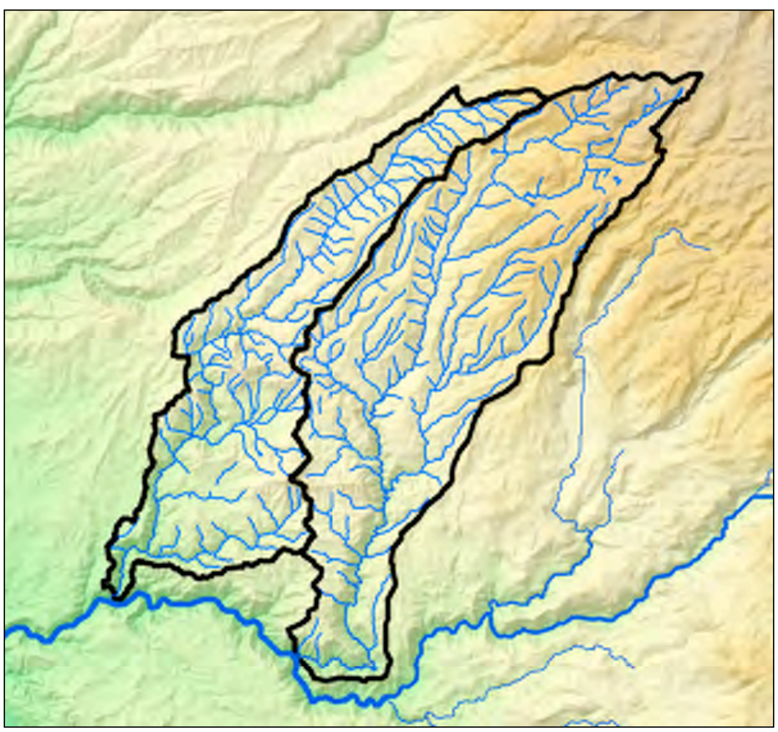


Figure 4.5. Map of the Clavey (right) and North Fork (left) watersheds.

The hydrograph comparison illustrates some very important points. Note the similar timing and proportion of storm runoff versus snowmelt.

Despite the order of magnitude difference between the discharges of the Clavey and the North Fork, the map to the left (Figure 4.5) demonstrates that the two watersheds are surprisingly similar. Both the North Fork and the Clavey are essentially undammed; they both receive some rain and some snow; they have very similar geologies, topographies, and channel slope; and they are neighbors, so they experience the same annual storm patterns. Although similar in hydrologic and geologic factors, the North Fork is about 2/3 as big and at a slightly lower elevation than the Clavey.

Hypsometric curves of the watersheds and slope profiles of the channels provide some insight into the differences between the two. Figure 4.6 is an example of a hypsometric curve. It shows the distribution of elevations within the two watersheds, and conveys the Clavey's higher elevations, by roughly one to two thousand feet. Figure 4.7 shows that the slopes of the two channels are almost identical.

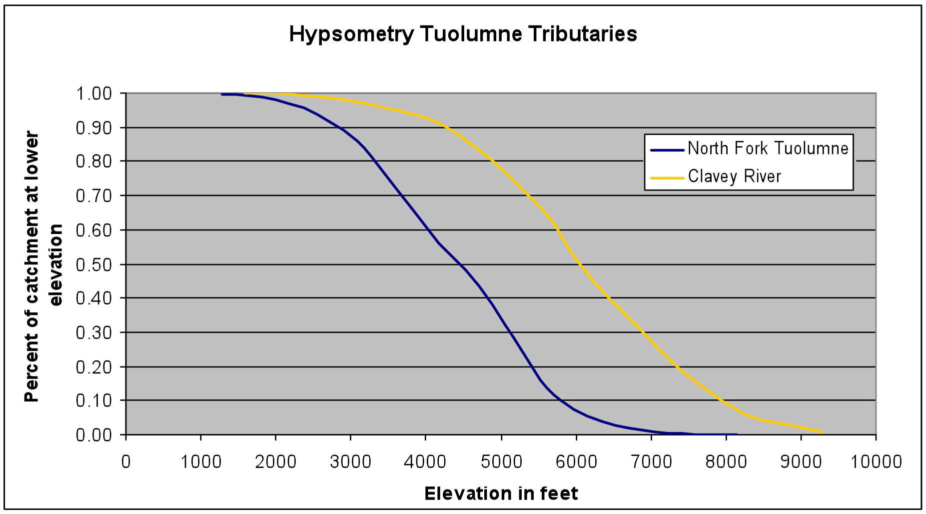


Figure 4.6 Hypsometry Curves for North Fork Tuolumne and Clavey Rivers.

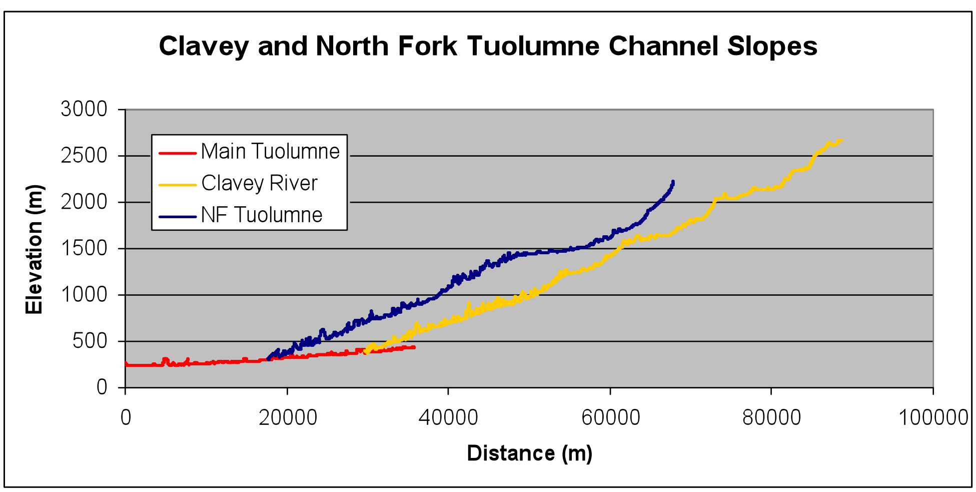


Figure 4.7 Slope profiles for both of the tributaries and the mainstem.

Concept 1. *Orographic Effect*

The orographic effect causes storms to release more precipitation at higher elevations (Mount 1995). This may account for the hydrologic difference between the watersheds. If so, it would seem that 200 feet of elevation gain translates to roughly ten times as much precipitation.

Vegetation is also an important factor in the hydrologic difference. Unlike the Clavey River, which is a scoured bedrock-boulder channel at its confluence, the North Fork has a lush riparian forest growing in and around the river. If this pattern continues up the length of the river, it would have a large effect on the hydrology. Lower elevations also tend to have higher temperatures and higher evaporation and transpiration rates.

Concept 2. *Tributary Contributions and Water Quality*

North Fork discharge might be as much as 100 times smaller than the Tuolumne at this confluence. This difference does not mean that the North Fork has no effect on the mainstem (Benda 04). Even with significantly smaller discharges, the North Fork can strongly affect the mainstem of the Tuolumne by altering water quality, both at the confluence and downstream. Water quality is an amalgam of water temperature, chemistry, and biological contributions.

Water temperature of the North Fork is usually much higher than the mainstem Tuolumne because it comes from lower elevations and because the temperature can equilibrate to the air temperature much faster due to lower flow volumes. As discussed previously, temperatures play a major role in dictating fish habitat. Warmer water temperatures reduce the amount of oxygen that can stay dissolved in water. At the confluence, thermal exchange between the two rivers is rapid.

The following graph (Figure 4.8) displays temperature data from four sites along the rafting reach: the mainstem above Clavey, Clavey River, mainstem below Indian Bar, and North Fork of the Tuolumne River. Notice how the mainstem water temperature increases much more slowly than the two tributaries. This is due to the mainstem's constant source of temperature (the bottom of Hetch Hetchy, Cherry, and Eleanor reservoirs) and larger flow volumes. The Clavey and North Fork are much more susceptible to changes relating to the ambient air temperature and you can see the correlation in air temperature spikes with tributary water temperature spikes. Because of this, the tributaries start out colder and end warmer than the mainstem.

If you stand where the North Fork and Tuolumne Rivers meet, stick your hand in the water. You will feel the mixing immediately as the temperature changes from cold to warm and back again.

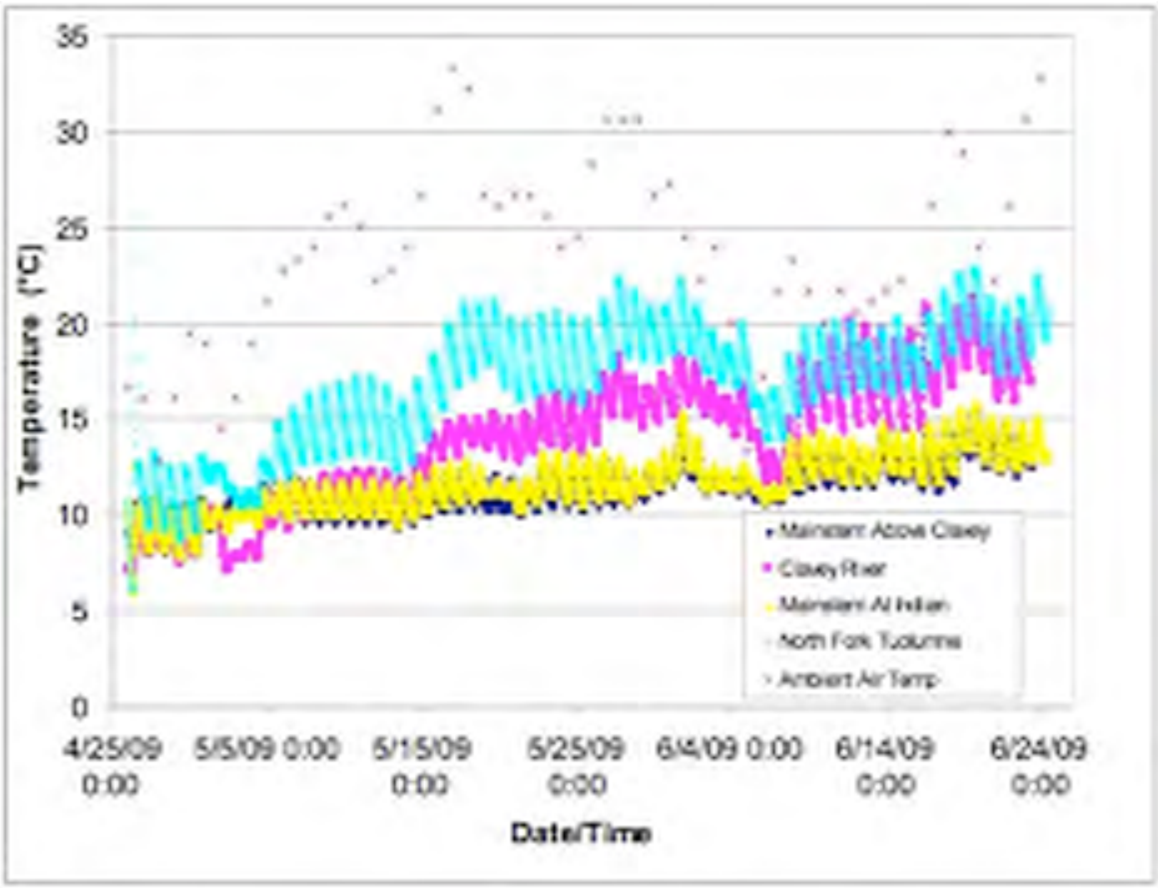


Figure 4.8 – Graph of water temperatures and ambient air temperatures.

Watershed properties and human land use determine the overall water chemistry of a river. Although the North Fork and mainstem Tuolumne Rivers have very similar water chemistries , some differences exist in terms of pH and electrical conductivity values.

The electrical conductivity of water is a measure used to assess the concentration of dissolved ions, or salts. Many ions dissolved in freshwater are inorganic nutrients necessary for primary production, so conductivity can be a rough proxy for nutrients concentration. In a more literal sense, conductivity just measures how much invisible 'stuff' is in the water. In natural systems, conductivity is dependent largely on the rocks and soils that are in contact with the water.

pH is a measure of how acidic or basic water is. It is another aspect of water quality which is largely dependent on geology, especially in natural systems. The North Fork and the Clavey River both have significantly more limestone in their watersheds than the mainstem Tuolumne River. As this limestone dissolves it turns the water basic and increases pH.

Concept 3. *Water quality and primary productivity*

Increased temperatures, nutrients, and pH in freshwater systems typically increase biological productivity. Primary production, which is the formation of organic compounds through photosynthesis, is the foundation of aquatic food webs. Once produced, much of this organic matter is washed downstream. On the North Fork Tuolumne organic matter may take the form of algae, invertebrate drift, or a fallen alder leaf.

At the confluence of the North Fork and the mainstem Tuolumne River all of these differences, subtle or not, are mixed and distributed. The mixing occurs at different rates for each quality and at different discharges, creating a zone of distributed water qualities directly below the confluence. Since native fishes thrive in heterogeneous habitats, confluences serve as excellent locations to support diverse fish populations.

Geomorphology

The geomorphic properties of the North Fork's channel are distinct from the Clavey or the mainstem of the Tuolumne River, despite similarities between their watersheds and hydrology.

Concept 1. *Geomorphic Scales and Vegetation*

Although the hydrology of the North Fork Tuolumne behaves like a miniaturized version of the Clavey River, with both being mixed bedrock/alluvial systems and with comparable channel slopes, the geomorphology of the two channels are quite different.

This issue of scaling is recurrent in watershed studies, particularly as humans try to maintain 'natural' and 'healthy' systems while diverting significant amounts of water. Although sediment transport and discharges scale to one another, vegetation is governed by varied life cycles and strategies, and different species will respond in unique ways to a change in discharge and other physical drivers. The confluence is bisected by a line of button bush, alder, and ash. That these trees managed to grow in the middle of the North Fork and mainstem Tuolumne River confluence is indicative of the flow regime. The geomorphic implications of these plant communities are twofold:

- Lower discharges are insufficient to scour many plants out of the channel
- These plants then take root which further immobilizes the sediment

Therefore, below a certain threshold of maximum discharges, vegetation is able to establish in the channel and entirely changes the character of a river. In order for these trees to have reached their current size, they must have been able to establish when the flow was at low levels. If the river was high, the seeds and sapling would have been scoured away. The most likely time for this establishment is during the summer, when both the mainstem Tuolumne and the North Fork exhibit their lowest flow levels. Smaller flows allow bigger plants to grow in the channel, until they become significant geomorphic units themselves.

Concept 2. *Differences between the North Fork Tuolumne and Clavey Rivers affect confluence characteristics*

This reach of the mainstem Tuolumne River is straight, low gradient, and flows uninterrupted past the North Fork whereas at the Clavey it flows around gravel bars and drops over Clavey Falls. Some of the differences between these confluences may be due to varied geologic features at the confluence, whereas others are due to the tributaries' size differences.

Potential Geologic Factors:

A large resistant layer does not dominate geology at the North Fork confluence as it does at the Clavey, where it may help to constrict deposition of large debris as they enter the mainstem during extreme events, as well as to necessitate faster water velocities in the mainstem. The absence of such a constriction may partially explain the absence of a significant rapid at the North Fork confluence, where water need not move as fast and debris flows have more room to spread out.

The Importance of Size:

The Clavey, with flows at orders of magnitude larger than the North Fork, has the ability to move both a greater volume and a larger size of sediment. It is more likely to overwhelm the Tuolumne's carrying capacity in flooding events, resulting in deposition of more cobbles and boulders of a larger size class than those being moved by the North Fork. The Tuolumne is forced to increase its gradient and thereby velocity, in order to move through these larger deposits.

A Geomorphic Mystery:

On the downstream end of the North Fork confluence, alluvial deposits form terraces of sorted gravels and cobbles, with elevations approximately 15 feet above the typical summertime shoreline. Regardless of whether this sediment came from the North Fork or the Tuolumne, it would take an extremely large event to build a deposit this high.

In the flood of 1997, for instance, Tuolumne River discharges in this reach are estimated to have reached 137,000cfs. Evidence of this high water line is still visible along the banks in some locations, but compare these high water lines to the height of this particular gravel bar.

One possible explanation for these terraces is that when the Tuolumne and the North Fork are both very high, the downstream shore becomes a large and very powerfully rotating eddy. These eddies might have been powerful enough to grab all passing cobbles and pebbles and hurl them into this corner, building up a pile of sediment which extended almost to the water's surface.

All natural historians are inevitably forced to make educated guesses at times. Not every feature of landscape or ecosystem has a readily apparent explanation, but we can use our understanding of physical processes and connections to construct several viable answers. Can you think of another explanation for the North Fork terraces?

Vegetation

Focus on: *Blackberry*

The North Fork Tuolumne River supports two species of blackberry common to California. The first is our own native California blackberry (*Rubus ursinus*) and the second is the nonnative Himalayan blackberry (*Rubus discolor*).

Figure 4.9. California blackberry (Left) and Himalayan blackberry (Right). Photo: Patrick Hilton.

Himalayan blackberry was introduced from Europe for its berry production, and has become a highly invasive riparian invader since. Himalayan blackberry shrubs grow to be very dense, which allows them to out-compete native understory vegetation and prevent the establishment of riparian trees along the river. The presence of this blackberry along the bank of the North Fork produces a homogenous system that reduces riparian habitat available for other native plants and insects to live.

There are some distinct differences between the two species of blackberry (Figure 4.10). Walk along the bank of the North fork and see if you can identify them. Notice the difference in understory species diversity with and without Himalayan blackberry.

	Himalayan blackberry	California blackberry
Leaves	Large, rounded to oblong, toothed leaflets, usually clustered in groups of 5, white underside	Small, leaves clustered in groups of three, green underside
Thorns	Arching, broad base	Straight, thin
Stems	Stout, arching, 5-angled stems with thick thorns	Rounded stems with fine thorns

Figure 4.10 Comparison chart of native and nonnative blackberry species (King County Noxious Weeds, SKCNP invasive nonnative plants).

Concept 2. *Invasive Plants of the North Fork Tuolumne River*

In general, vegetation along the Tuolumne River is surprisingly native for being so heavily altered. Invasive species thrive under disturbed conditions, of which the Tuolumne River system has plenty. Diel flows and dams alter the natural hydrograph, which give invasive plants a competitive edge over native species. Particularly in the North Fork, cattle grazing and logging operations have increased sediment runoff and eutrophication, providing disturbance for invasive plants to establish.

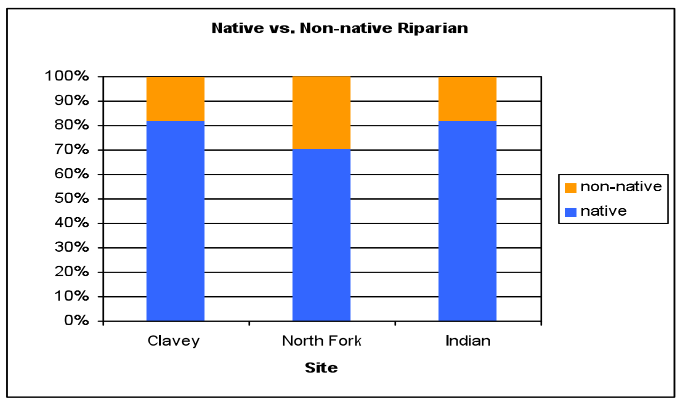


Figure 4.11 Ratio of native to nonnative riparian species along the Clavey River, North Fork, and Indian Creek.

Common, visible riparian invaders of California include giant reed, tamarisk, fig, pepperweed, Himalayan blackberry, and yellow star thistle. Although prevalent elsewhere in California, most of these species are completely absent from the entire system and only fig, blackberry, and yellow starthistle occur in very low densities along parts of the river.

North Fork contains the highest percentage of nonnative species, but the differences in nonnative species between rivers are not very high. North Fork has a higher chance of receiving nonnative species because its hill-slopes are at lower elevations and grazed by livestock.

Concept 3. *Fire plays a large role in plant ecology*

Look up at the upper cobble terrace and the grassy oak woodland above the North Fork confluence, and you'll see blackened scars on some of the trees from fires in years past. While flooding is the major source of disturbance in riparian plant communities, fire is the major controlling forces in the life cycle of upland plants.

Figure 4.12 Burned tree.
Photo: Patrick Hilton

Fire is an essential part of California's ecosystems, from the open prairie to the dense forest. The hot, arid Mediterranean climate of California dries out these plant communities, creating plenty of burnable fuel every summer. Most native and invasive plant species have thus evolved to adapt to fire of varying frequencies through different strategies. Annual grasses and forbs take advantage of the warm and wet spring to grow up, flower, and create seeds, which fall to the ground before fire can sweep through and burn the dead adults. Perennial grasses and forbs may also die out above ground, but they persist in the soils to resprout after a significant fire event.

The hillsides above the North Fork are no exception to this rule. Blackened shrubs, scars on the trees, or even charred ground are signs of the regenerating effect that fire has on the ecosystem. As it sweeps through a plant community, fire removes accumulated duff, or dead organic material, returning their nutrients to the soil and clearing the area for seeds or dormant roots to sprout. In some communities, this cycle is critical for the next generation to survive, since fire can remove native and invasive adult plants that usually shade and outcompete the new seedlings.

Some plants depend on fire to persist; many conifers are serotinous, meaning that they don't spread their seeds until after a fire melts their cones or kills the adults holding them. By retaining their seeds until a sufficiently large fire, these trees can ensure that the next generation has the best chance of surviving.

When fire burns the duff and dead plant matter, it releases stored nutrients and allows them to return to the soil. On the hillsides above the river, rain can wash these nutrients down into the riparian community and the river, supplementing the food chains in both ecosystems with necessary carbon, nitrogen, and phosphorus. When we suppress fires in California, we keep these regenerative and nutritious cycles from happening, and the entire ecosystem suffers.

Concept 4. *Grazing, runoff and eutrophication*

Human activities such as cattle grazing and fertilization of soils have a significant impact on the hillside, riparian, and aquatic ecosystems. If you look up in the hills above the upper North Fork Tuolumne River, you may see the occasional cow grazing away. The presence of cattle has altered the structure of the landscape by compacting the soil, removing vegetation, and consequently, accelerating erosion. These impacts have implications for not only plant communities, but also the rivers that receive all of the extra sediment and nutrients.

When cows graze grassland, they regularly produce and distribute a large amount of high-nutrient dung, which promotes the growth of bacteria and plants in the soils. When rain washes manure and other fertilizers down into the river, these nutrients enter the aquatic ecosystem, stimulating the growth of algae and phytoplankton. A large enough algal bloom can reduce the amount of light that penetrates the water and therefore prevent the establishment of aquatic vegetation. Algal blooms can be especially harmful to aquatic invertebrates that depend on aquatic vegetation for food and shelter. A reduction in aquatic insects can subsequently drive down the abundance of fish populations, thus affecting the whole ecosystem. The process of high nutrient loading is called eutrophication, and tends to occur in shallow, slower-moving waters because there is a higher incidence of photosynthetic production. You might not see the effects in the North Fork, but the human-introduced nutrients can flow across the landscape and into the watershed, eventually reaching the mainstem of the Tuolumne River and finally, New Don Pedro Reservoir.

Riparian plants play an important role in mitigating the effects of accelerated erosion by trapping sediment and nutrient runoff in the soils surrounding their roots. Willows and alders are especially crucial because their roots create microenvironments in the soil that are hospitable to specialized organisms that break down chemical pesticides.

Concept 5. *Water flow and vegetation*

The river can control the fate of trees growing along its channel. Think back on the difference between the water power and velocity of the Clavey River versus the water power and velocity of the North Fork. During the spring, the Clavey River flows at high levels and high velocity through its channel. The power that is in the water can scour the riverbanks and rip out vegetation. For this reason, there is not much large vegetation growing close to the waterline of the Clavey River. The North Fork is much smaller than the Clavey and does not receive the same quantity of water flowing through its channel, meaning that there is less scour. Thus, the riparian vegetation along the North Fork is able establish, grow, and persist due to hydrologic regime.

Shade

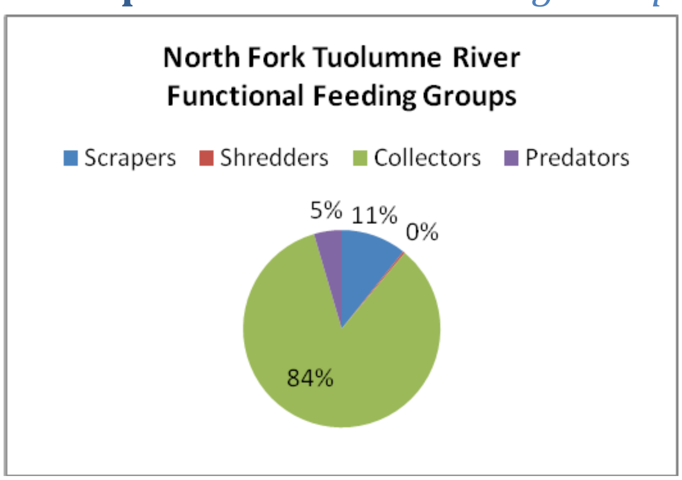
You'll notice as you walk up the North fork that there are more trees along the banks of the river than there are in the mainstem Tuolumne River. Many of these trees have canopies that extend over the water, creating shady areas below. Shade modulates water temperatures, which in turn, influences the plant and animal communities that inhabit areas below the riparian canopy (Naiman et al, 2005).

Take a look at the water in the shady parts of the stream, and you will see fish, amphibians, or bugs swimming around. They are taking advantage of the shade for a few reasons: the water temperature is slightly cooler, the shade provides camouflaging protection from predators in the water and overhead, and the tree canopy blocks the sun's UV light, which is harmful to developing eggs.

Aquatic Insects

The North Fork of the Tuolumne River differs substantially from both the Clavey River and the mainstem of the Tuolumne in terms of its dominant insect assemblage. Whereas the Clavey and Indian were both more or less dominated by members of the orders Ephemeroptera, Plecoptera and Trichoptera, the North Fork is dominated by a different set of orders: Odonata and Diptera.

Concept 1. *Functional Feeding Groups*



Data collected in riffle habitat demonstrates the abundance of collectors and the absence of shredders. These percentages match up with what we expect to find in rocky, high velocity habitat.

Figure 4.13 North Fork Tuolumne River Functional Feeding Groups.

Focus On: *Odonata*

Figure 4.14 Life cycle of odonates.

Figure 4.15 Dragonfly recently emerged from nymph form. Photo: Patrick Hilton.

Dragonflies and damselflies (Order Odonata) are some of the largest aquatic insects common in California. They are a predominately predatory group and flourish in warmer, more disturbed water bodies (Merritt & Cummins 2007).

The life cycle of the dragonflies and damselflies is dynamic. Eggs hatch into a larval stage known as a 'pronymph'. This immature stage is characterized by the inability to feed. Over the course of many molts (or *instars*), these immature forms develop wing pads and become increasingly predatory as they become nymphs. Once they reach their final nymph instar, they will crawl from the water and molt to a winged immature (or *teneral*) stage. They will then undergo one final molt to reach the fully mature winged adult stage. Once adult, they engage in elaborate courtship behavior subsequently followed by mating. Female Odonates typically deposit their eggs on or under the surface of the water using ovipositors located at the end of their abdomen.

Odonates are different from many other insects in that they don't have a pupal stage (similar to making a cocoon) or undergo a full metamorphosis. Instead, these insects are referred to as *hemimetabolous* (meaning that they undergo a partial metamorphosis). The picture above shows an Odonate which has just emerged from its nymph form.

Dragonfly nymphs can be differentiated from damselfly nymphs by the types of gills present on the abdomen. The pictures below depict a damselfly nymph on the left and a dragonfly nymph on the right. Damselflies have three leaf-shaped gill filaments extending from the end of their abdomen, while dragonflies have gills within their rectum. In fact, dragonfly nymphs are actually capable of expelling water from their rectum in order to move.

Figure 4.16 - Damselfly nymph (left), Family Coenagrionidae; Dragonfly nymph, Family Gomphidae (right). Photo: Adam Clause.

Focus On: Blepharicaridae

Net-Winged Midges

Figure 4.17 Midge Larvae. Photo: Adam Clause.

One very distinct group within the dipterans is the family Blepharicaridae, or net-winged midges. Their larvae are unique among flies in that they have suction cups at the end of each of their body segments. These segments allow them to stick to the rocks in areas of high flows. When they want to move, they release the suction cups from one end of their body, swing that end around, and then attach it in a new place. They then repeat with the end which was previously stationary.

Odonates utilize different habitats than many of the other taxa previously discussed. Adult forms will of course be conspicuously airborne, but larval forms are slightly more difficult to find. Many nymphs are still found under the occasional boulder or cobble in a riffle reach, but they are just as commonly found among emergent vegetation along the margins of large, slower-moving pools.

Odonate nymphs play an important role in the trophic interactions in the North Fork. Once predatory, nymphs consume large numbers of other aquatic insects and small crustaceans. Also,

Figure 4.18 Obtaining stomach contents from smallmouth bass. Photo: Peter Moyle.

they are a preferred food of many fish species, particularly smallmouth bass. The biomass of stomach samples from medium size (5-8 inches) North Fork smallmouth bass was overwhelmingly dominated by dragonfly and damselfly nymphs.

Odonates are more likely to be common on the North Fork Tuolumne River than either the Clavey or at Indian due to several reasons. First, the water here is warmer year round, and second, the watershed of the North Fork is highly disturbed by cattle grazing and logging operations that occur upstream.

Focus On: *Dipterans*

True flies, including your run-of-the-mill House Fly, belong to the order Diptera. True flies are characterized by only having one set of wings. If you look closely enough, you can actually see that those wings have tiny scales or hairs on them. Fly larvae are easy to distinguish because they will not have three pairs of true legs, unlike most other aquatic insects.

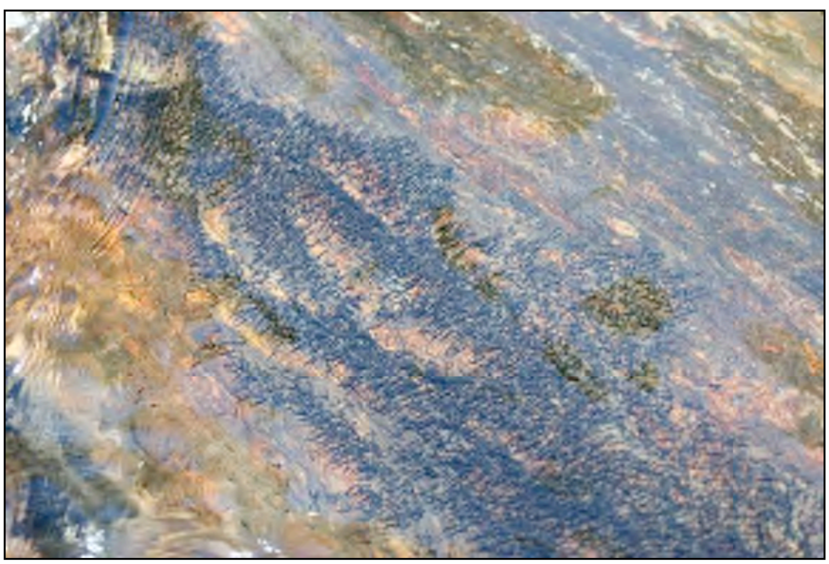


Figure 4.19 – Black fly larvae on bedrock. Photo: Adam Clause

Dipterans are an extremely varied group, but include such things as craneflies, mosquitoes, black flies, and midges. One family extremely common on the North Fork are the black flies, family Simuliidae. These fly larvae are identified by a small, relatively nondescript legless body with a distinct head capsule (Merritt & Cummins 2007). This head capsule has two brushy 'eyebrows' projecting from it which serve to collect food (fine particulate organic matter, or FPOM) from the water. They are typically found with their abdomen attached to the substrate and their head sticking up into the water. During certain times of the year you can see forests of these black flies on the bedrock substrate common to the North Fork (Figure 4.19).

Black fly larvae are ecologically important for several reasons. The first is simple; they exist in extremely large numbers and high densities. This provides a great deal of food for predatory insects and for fish. Also, not only are they abundant, but they are multivoltine, meaning that they can cycle through many generations in one year. This quick turnover combined with their abundance provides large numbers throughout the year. The second reason also deals with their abundance. By taking up large quantities of FPOM and converting it into biomass, black fly larvae play a huge role in transmitting primary productivity and riparian subsidy into higher trophic biomass.

Dipterans are an extremely tolerant group and are found in all sorts of different environments. However, they flourish in the absence of other insects in disturbed reaches despite the fact that competitive exclusion would prevent them from dominating diverse lotic habitats.

Amphibians

In general, finding amphibians is quite serendipitous. Luckily, you will have the best luck seeing frogs in the North Fork Tuolumne River because bullfrogs, a large and conspicuous invasive, are found in the side pools of this river. There are other amphibians present here, also, but none of them have such a great impact on the ecosystem as bullfrogs. Bullfrogs play a very important ecological role because they are voracious predators, much like the smallmouth bass, except that they can prey on both terrestrial and aquatic animals. The reason that bullfrogs are unique to this tributary in the Tuolumne River watershed is because they are a species that invades and thrives in disturbed areas. The effects of eutrophication, for example, are highly tolerable for the bullfrog; the chemical inputs from fertilizers and cow dung have less of an impact on this invasive than for other native species that are more sensitive. In addition, the bullfrog is one of the only frogs that can coexist with predatory fishes such as the smallmouth bass, because the tadpoles are unpalatable (Lannoo, 2005).

Invasive Frogs

The presence of invasive bullfrogs can lead to severely decreased diversity of native fishes and other amphibians.

The American bullfrog preys on small terrestrial animals as well as aquatic animals. This voracious predator will prey on any item that it can fit in its mouth including fish, frogs, crayfish and even mice. It can be extremely detrimental to native populations.

Figure 4.20 — Juvenile American bullfrog. Photo: Teejay O'Rear.

Focus on: American Bullfrog *(Lithobates catesbeiana)*

American bullfrogs prefer to inhabit quiet, slow-moving permanent waters filled with vegetation, such as ponds and small streams. They can withstand very high water temperatures, and they are generalists that thrive in disturbed areas, giving their population an advantage over other amphibians. They will spend a good portion of time in terrestrial habitats such as meadows, of which there are plenty near the upstream reaches of the North Fork.

While it was previously thought that bullfrogs would extirpate foothill yellow-legged frogs by preying on both tadpoles and adults, recent observations show that the two populations coexist on the North Fork in separate micro-habitats. These micro-habitats are distinguished by stream gradient, water velocity, substrate type, and canopy cover. While the bullfrogs could potentially out-compete the foothill yellow-legged frog, as they are known to do in many other river systems, there is enough variation in habitats available that allows them to coexist (Pers. comm., Yarnell, 2009).

Distinguishing Features:

- Olive, green or brown
- Banded and blotchy legs
- Spotted back
- Large body size 3.5 – 8 inches
- Deep-pitched bellow call

Bullfrog tadpoles occupy warm, shallow waters with sufficient vegetation, where they feed on algae, macrophytes and some aquatic insects, and avoid predation. Metamorphs move into shorelines dominated by riparian plants in order to conceal themselves. Adult bullfrogs frequent low velocity side pools. Females lay a large amount of eggs in sheet-like masses on the surface of the water. (Lannoo, 2005).

Fishes

Figure 4.21 – Smallmouth bass from North Fork.. **Photo:** Patrick Hilton

Figure 4.22 – Northern Crayfish (*Orconectes virilis)* from North Fork. **Photo:** Claire Stouthamer.

The North Fork of the Tuolumne River is a drastically different system from both the Clavey River and the main stem Tuolumne River. The same physical and hydrologic factors control the fish assemblage (temperature, velocity, and habitat complexity), but these factors have changed significantly in the North Fork.

The natural hydrologic regime is characterized by spring flows that are lower than higher elevation rivers such as the Clavey River, which receive a larger volume of water due to spring snowmelt from the tops of mountains. Low flows cause higher water temperatures in the spring and summer due primarily to high ambient air temperatures. Habitat complexity is increased due to in-stream hill-slope erosional deposits and increased marginal riparian vegetation.

Concept 1: *Biology driving fish assemblage and nonnative invaders*

The presence of invasive fish, such as the predatory smallmouth bass (Figure 4.21), is the primary biological driver of the fish assemblage in the North Fork. Smallmouth bass prey upon other fish, invertebrates, amphibians, and even small mammals. They have an enormous effect on native minnows, and juvenile fish of all taxa. In addition to smallmouth bass, there is also a species of invasive crayfish, *Orconectes verilis* (Figure 4.22), which is a major food of the smallmouth.

Figure 4.23 - Schematic cross section of the North Fork showing fish distributions within the river.

The above diagram illustrates the distribution of fish within a typical pool on the North Fork, although rainbow trout are probably not present in summer. The bedrock pools contain much more fine sediment, such as silt, sand, and gravel. High levels of sediment deposition and relatively few scouring events allow emergent vegetation to grow along the water's edge. Smallmouth bass are depicted on the right in the open water, juvenile Sacramento pikeminnow, California roach, and young of the year hide in the emergent vegetation, Sacramento suckers graze on the benthic substrate, and trout inhabit the higher velocity waters.

Moving up the North Fork, there are several fish barriers that exclude trout and smallmouth bass. In the absence of these predators, juvenile pikeminnow and hardhead find refuge while California roach populations thrive in large schools.

Concept 2. *Increased primary productivity increases biomass*

As mentioned before, the North Fork has higher productivity than the mainstem Tuolumne and Clavey Rivers, which increases the biomass of aquatic invertebrates. This increases the amount of food available for fishes inhabiting the North Fork, which in turn increases the biomass of fish. Increased productivity also increases the relative abundance of in-stream vegetation. Aquatic and emergent vegetation is important for

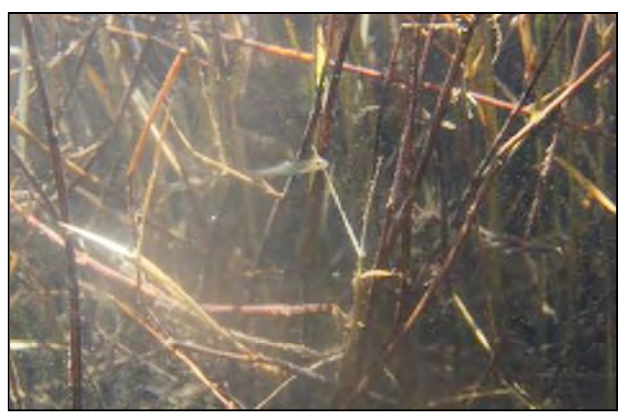


Figure 4.24 – Larval fish hiding**.** Photo: Patrick Hilton.

providing habitat for larval fish to hide from predators and forage (Figure 4.24).

Focus On: *Smallmouth Bass*

Figure 4.25–Smallmouth bass.
Photo: Claire Stouthamer

The North Fork is home to the most influential and nefarious invasive fish within the Tuolumne River watershed, the smallmouth bass. Bass are voracious predators and have been known to have huge impacts on native populations, particularly native minnows.

Smallmouth bass are easily identified by their dorsal fin that contains a rayed segment and a spiny segment. They have prominent banding on the side of the head below and behind the eye. Also, as the name suggests, they have a small mouth which doesn't extend beyond the eye, which is typically a disconcerting red color (Moyle, 2002).

Smallmouth are interesting not only because they are an ecologically important invasive but also because adults display territorial parental care behavior. Bass tend to spawn in late spring, and the eggs will hatch one to two weeks later. They are rare in that there is a period of time where newly hatched larvae are cared for by the adult male. This period of parental care can last up to four weeks. The picture to the left shows a smallmouth bass defending its nest. The large patch of sand directly below and behind the bass is the site of its nest.

Figure 4.26 – Smallmouth bass defending its nest.
Photo: Claire Stouthamer.

As smallmouth bass mature and grow in size, their prey preference shifts as well. This preference shift is tightly correlated with body size. As soon as a bass is physically able to fit a prey item in its mouth (and sometimes before), it will. California roach, juvenile hardhead, and juvenile Sacramento pikeminnow are typically completely eliminated by bass. Pikeminnow, if able to avoid the pressures of predation, are able to outgrow the ability of bass to prey upon them and are able to coexist and compete as adults.

Fish interact with each other in many ways. Conspecifics (members of the same species) compete for food, territory, and even mates. This intraspecific competition is taken to the extreme in the case of many predatory fish, notably invasive bass. Although noted for their nesting behavior and parental care, bass are known to exhibit cannibalistic behavior, with adults eating juveniles.

Concept 3. *Food Web Complexity*

The presence of smallmouth bass in the North Fork increases the number of species and the complexity of the trophic interactions within the food web (Figure 4.27). At the confluence, preliminary snorkel surveys established the dominance of smallmouth bass and invasive crayfish, and rainbow trout. Juvenile Sacramento pikeminnow, Sacramento sucker and California roach were present in limited numbers near the confluence as well.

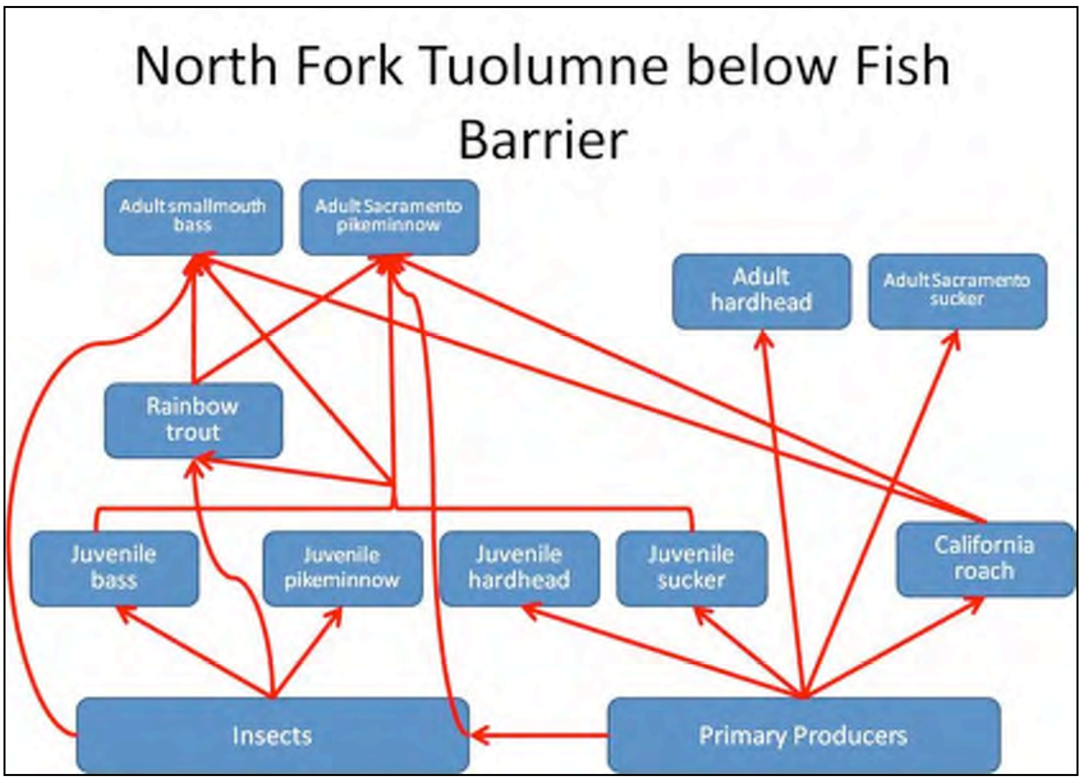


Figure 4.27 - Food web for fish assemblage below the fish barrier.

Moving upstream, the assemblage remains relatively static until the first of the large fish barriers is reached (Figure 4.28). Above this barrier, no bass or trout are present. Roach, pikeminnow, and sucker exist in larger numbers and hardhead are present. This lack of bass and trout above the fish barrier suggests that both species are moving up from the main stem, rather than being flushed down from further up in the system. The lack of bass is beneficial to native minnows and reduces predation pressure, allowing them to dominate.

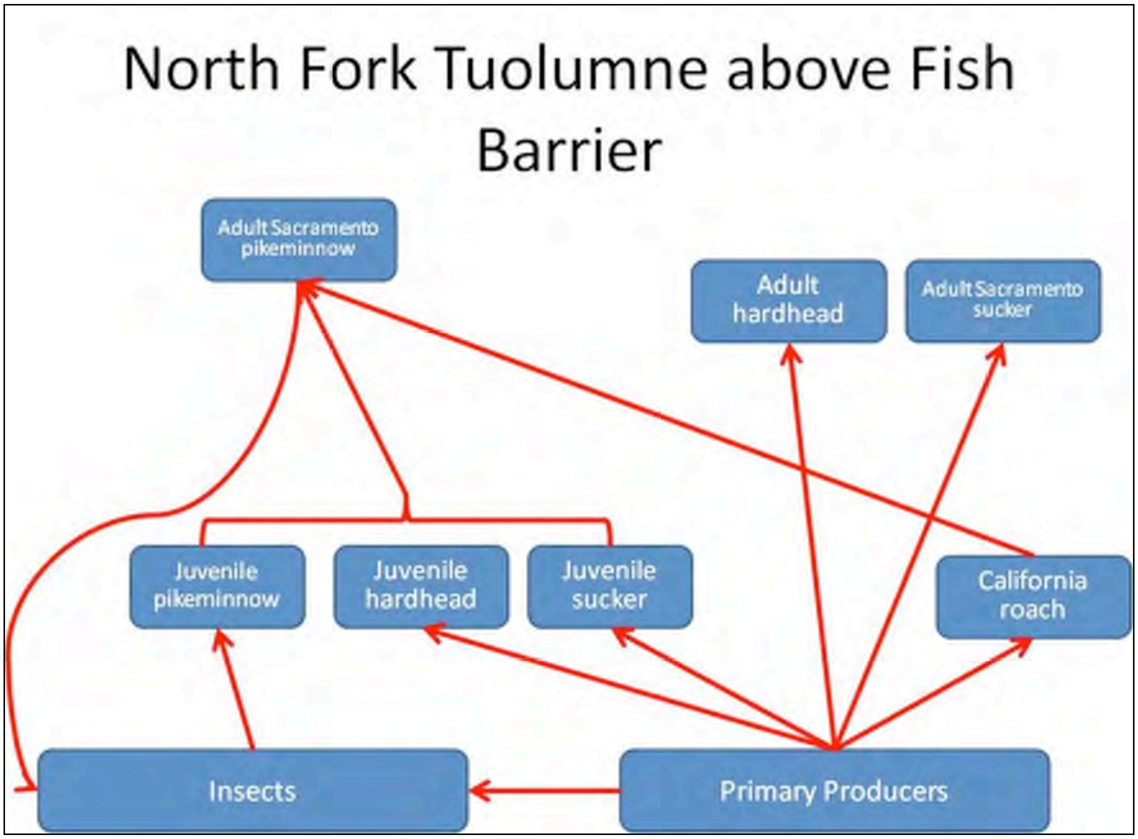


Figure 4.28 - Food web for fish assemblage above the fish barrier.

Concept 4. *Human Impacts: Grazing Disturbs Fish Habitat*

Grazing has a negative impact upon native fish assemblages. Cows and other large grazers destroy riparian vegetation, which decreases the amount of shade, cover, terrestrial insect food sources, and increases water temperatures. Loss of upslope vegetation also increases sedimentation and facilitates the addition of large amounts of sand and silt into the river. This increased sediment load alters spawning habitat, juvenile over-wintering habitat and aquatic invertebrate-producing substrates. Such high disturbance to aquatic systems makes it increasingly difficult for native fish to survive and increases the opportunity for invasive fish to establish themselves further (Forest Service).

Microcosm: Bedrock Chute

Figure 4.29 – Habitat Map for Microcosm Site

Upstream from the confluence of the North Fork Tuolumne River and the main stem Tuolumne River there is a large bedrock chute, at the top of which can be found a deeper pool (Figure 4.29). This chute is another popular swimming location, but there is also a great deal of information that can be gleaned from this one pool.

This location provides an excellent example of many geomorphic processes we have talked about throughout this volume. The channel is dominated by bedrock, but the inside curvature of the substratum is covered with alluvium and vegetation. This is because water velocities here are lower at high discharges. On the outside of the bend the bedrock has been worn smooth, but on the inside behind the riparian vegetation the bedrock is still coarse and fractured. If you look at the patterns of the bedrock where most of the flow is concentrated, you can see sculpted bedrock forms. Bedrock ripples, grooves, and potholes are created by the sediments that bounce along the bottom. Sediment sorting is visible as well, in the size of the rocks in the deepest part of the pool, along the edges, and deposited up on shore.

On the upstream end of river left on the bedrock pool there is a dense stand of aquatic grasses. These grasses accumulate and retain sediment, forming a sand bar on top of the bedrock that extends above the waterline, beginning the process of terrestrialization. While the river right side of the pool is mostly barren bedrock, the left side contains substrate that supports a diverse community of trees, shrubs, and herbaceous vegetation. The overhanging trees in this community shade the river left, and invasive blackberry dominates the understory shrubs. If you look at the water's edge below certain willows, you'll see pink aquatic roots, which are taking advantage of nutrients in the water, in addition to the plants' roots in the soil.

Take a look at the smooth bedrock lining the river channel on river right. These bedrock chutes and pools are covered in forests of black fly larvae during the warm spring and summer months. Although the bedrock is good for many Dipteran families, the lack of large cobbles and gravel limits the abundance of insects which prefer to live underneath them. Many of the taxa common in riffles at other sites are lacking here, due to the warm temperatures and habitat differences. If you look closely at the water you can observe many large, cased caddisflies dragging their cases over the substrate. An occasional American Dipper will prey upon the caddisfly, carefully pulling them out of their cases. The sandy substrate on the left supports a variety of different insects that prefer the cover provided by roots and emergent vegetation.

This cover also is used by young-of-year fish. Large schools of small fish can be seen flitting about and hiding amongst the roots and vegetation. Several species of larger fish are present in this pool, including Sacramento pikeminnow, smallmouth bass, and rainbow trout. The bass flourish in the low flows and they aren't heavily affected by the high temperatures. Although there are a large number of young fish, this pool itself isn't great for most native spawning efforts due to the silt and bedrock substrates.

Conclusion

This reach of the Tuolumne River ends in rather ignominious fashion. Only a short stretch of water separates the final tributary, the North Fork Tuolumne, from New Don Pedro Reservoir. This reservoir, the third largest in California in terms of storage capacity, effectively serves to isolate the upper Tuolumne from its lower reaches.

Despite being bounded by large (New Don Pedro) and controversial (O'Shaughnessy) dams, this reach of the river appears natural. The flow regime is quite drastically altered, but in broad ecological terms the system is healthy. The dams undoubtedly affect the overall productivity, but are not irrevocably abolishing the natural ecosystem in the way that many dams constructed in the Western United States have.

Although the Tuolumne River is a unique and beautiful watershed, the concepts driving its physical and biological components are more or less constant. Every terrestrial point on this planet belongs to a watershed of some sort, and understanding the driving concepts behind these universal constructs will help you to understand the relationships between these abstract ideas and the landscapes in which you live. Hydrological concepts which dictate channel morphologies here can be used to explain the shapes and patterns that define all other rivers. Similarly, trophic interactions between different species are a universal driver of ecosystem health and productivity.

It is useful to think of every different subject as being irrevocably intertwined as well. For the sake of simplicity this field guide has been divided into six broad categories: hydrology, geomorphology, vegetation, aquatic invertebrates, amphibians, and fish. We hope you can now see the depth of the relationship between each of these, and the effects that each has on each other.

Thank you for reading, and we hope that you leave the Tuolumne watershed with a greater appreciation for and understanding of the complexities and nuances of watershed science.

Suggested Reading List

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Yarnell S, Viers J, and Mount J. Ecology and management of the spring-snowmelt recession. BioScience 2009

Additional Field Guides

The University of California Press has a series of Natural History Guides that do an excellent job of summarizing both human and natural history in California and in the general Sierra Nevada. For those interested in Sierran natural history, some relevant guides to consider include:

A Natural History of California, by Allan Schoenherr

California Forests and Woodlands, by Verna Johnston

Field Guide to Freshwater Fishes of California, by Samuel McGinnis

Geology of the Sierra Nevada, by Mary Hill

Glaciers of California, by Bill Guyton

Introduction to California Mountain Wildflowers, by Philip Munz

Introduction to California Spring Wildflowers of the Foothills, Valleys and Coast, by Philip Munz

Introduction to Fire in California, by David Carle

Introduction to Water, by David Carle

Mammals of California, by E. W. Jameson, Jr., and Hans J. Peeters

Sierra Nevada Natural History, by Tracy Storer, Robert Usinger and David Lukas

The Natural World of the California Indians, by Robert Heizer and Albert Elsasser

All of these titles can be reviewed and purchased at:

http://www.ucpress.edu/books/cnhg/complete.php