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 River and the mainstem of the Tuolumne River. During most of the summer the channel is shallow, the discharge is low velocity and warm, and trees and sedges grow across its 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, to explore and to enjoy the lush riparian corridor.

Hydrology

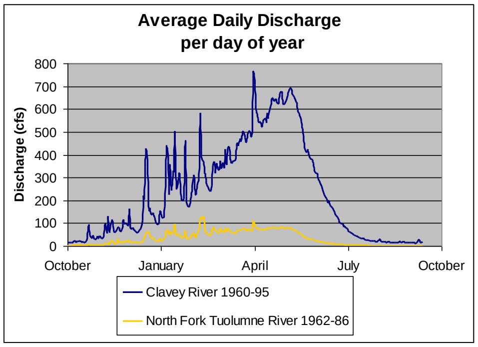

Figure 4.1 – North Fork confluence in April 2009 **Photo**: Denise De Carion.
Figure 4.2 – North Fork confluence in June 2009 **Photo**: Denise De Carion.

The photos above were taken from the same exact 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. Although taken at different times of day, you can see the immense changes in discharge and vegetation.

Notice the amount and temperature of water the North Fork is contributing 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.

Figure 4.3 - Average Daily Discharges from the North Fork Tuolumne and Clavey Rivers

Figure 4.4 - Comparison of North Fork and Clavey River hydrographs for one water year



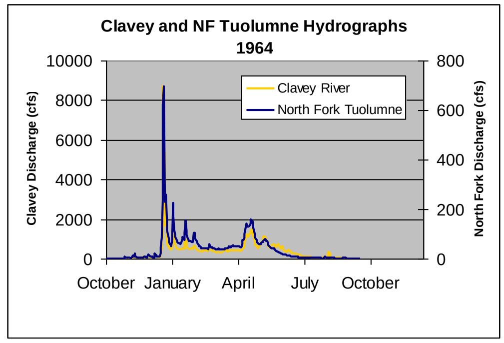


Figure 4.3 shows average daily discharges from the two tributaries on the same vertical scale, while Figure 4.4 shows the hydrographs of the two tributaries. Be sure to note the differences in scale on Figure 4.4, with Clavey being multiple orders of magnitude higher than the North Fork. Both figures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

The hydrograph comparison illustrates some very important points. The differences in scale allow you to see the similar timings and proportions of storm runoff and snowmelt.

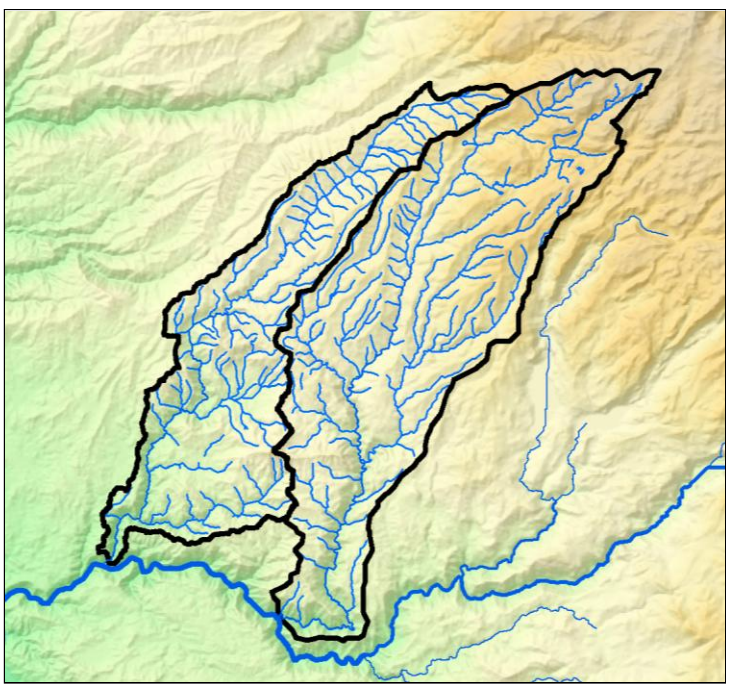


Figure 4.5 - Map of the Clavey (right) and North Fork Tuolumne (left) watersheds.

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 Rivers 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.

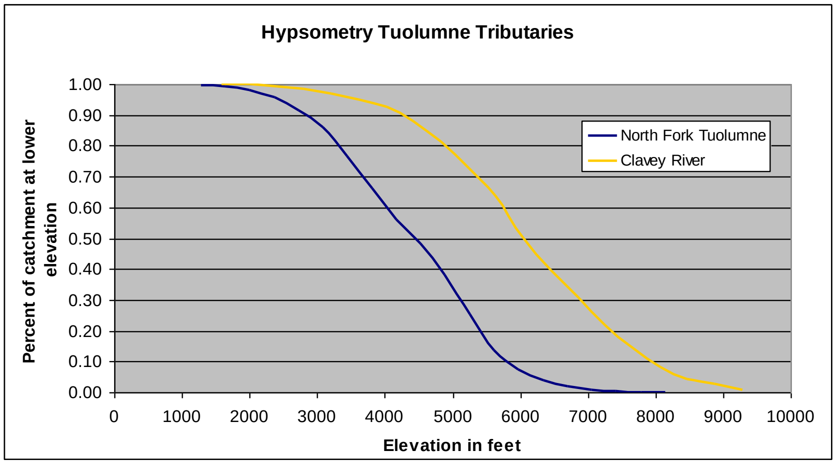


Figure 4.6 Hypsometry Curves for North Fork Tuolumne and Clavey Rivers.

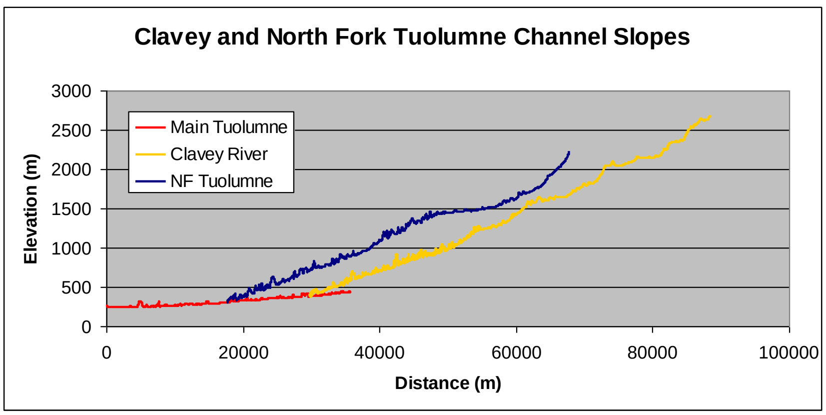


Figure 4.7 Slope profiles for both of the tributaries and the mainstem.

Concept 1. *Orographic Effect*

The orographic effect is an atmospheric phenomenon by which storms release more precipitation at higher elevations (Mount 1995). This concept could 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*

Discharges of the North Fork 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 the 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 the lower discharge. As we have discussed previously, temperatures play a major role in dictating fish habitat. Warmer water temperatures reduce the amount of oxygen which can stay dissolved in water. At the confluence thermal exchange between the two rivers is rapid.

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.

The following graph (Figure 4.8) displays the temperature data from four sites along the rafting reach. These sites are in the mainstem above Clavey, Clavey River, mainstem below Indian Bar, and North Fork of the Tuolumne River. Notice how the mainstem increases much more slowly than the two tributaries. This is due to the mainstem having a source of almost constant temperature (the bottom of Hetch Hetchy, Cherry, and Eleanor reservoirs) and due to the relatively large volume flowing through the mainstem. 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.

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, especially in terms of pH and electrical conductivity values.

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 geology that water is in contact with.

pH is a measure of how acidic or basic water is. It is another aspect of water quality which is largely dependent on the 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 dissolvesit turns the water basic and increases the pH.

Concept 3. *Primary productivity*

Increased temperatures, nutrients, and pH in freshwater systems typically increase biological productivity. Primary production, which is basically 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 of the 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. As one hikes from the confluence up through the North Fork, the geomorphic difference is visible in the character of the channel.

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 obviously is not miniaturized. 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 hydrologic flow regime. The geomorphic implications of these plant communities are twofold:

- Lower discharges are insufficient to scour certain 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 the confluence*

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 are due to different geologic features at the confluence, whereas other differences are because of the relative sizes of the tributaries.

Geology at the confluence of the North Fork is not dominated by the large resistant layer like at the Clavey, which traps boulders and sediment.

On the downstream end of the North Fork confluence the alluvial deposits form terraces of sorted gravels and cobbles, but the top of the bar is 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 get this high, let alone deposit sediment.

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.

Ask Yourself:

How did the rocks get up there?

One possible answer 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.

Vegetation

Focus on: *Blackberry*

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

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*) (Calflora).

Himalayan blackberry was introduced from Europe for its berry production, and has become a highly invasive and noxious riparian invader since. Himalayan blackberry shrubs grow to be very dense, which allows them to outcompete 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 more 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 that have increased sediment runoff and eutrophication provide suitable disturbance for invasive plants to establish.

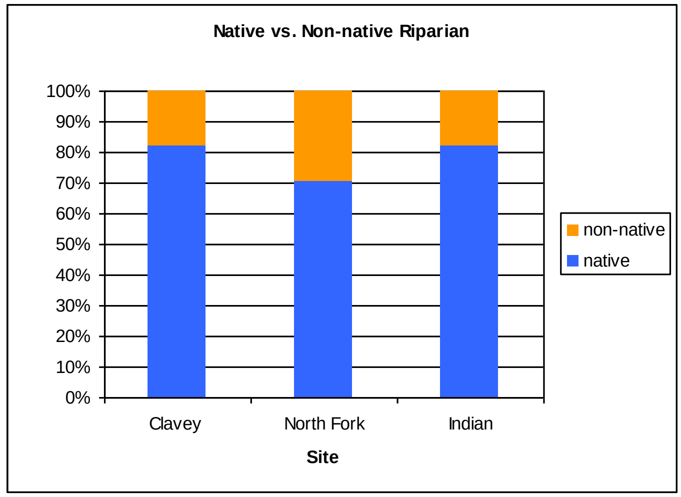


Figure 4.11 Ratio of native to nonnative riparian species along the Clavey River, North Fork, and Indian Creek.

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 different. North Fork has a higher chance of receiving nonnative species because its hill-slopes are grazed by cattle.

Concept 3. *Fire 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.

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

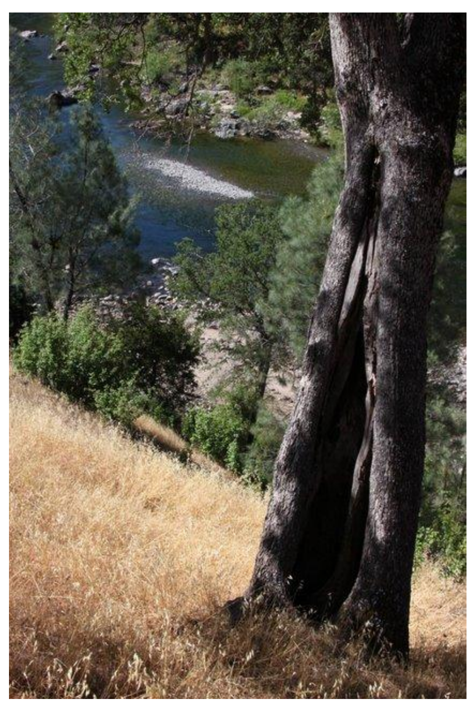


Figure 4.12 Burned tree. Photo: Patrick Hilton

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 had another 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

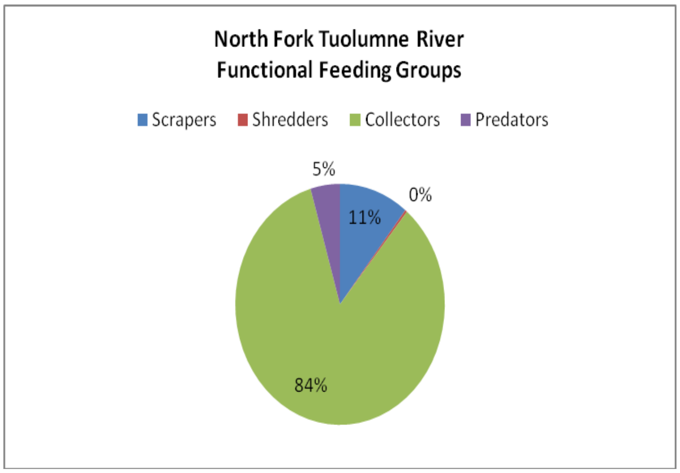
You'll notice as you walk up the North fork that there are more trees along the banks of the river than there are in the mainstem Tuolumne River. Many of these trees have canopies that extend over the water, creating shady areas below. Shade modulates water temperatures, which in turn, influences the 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

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).

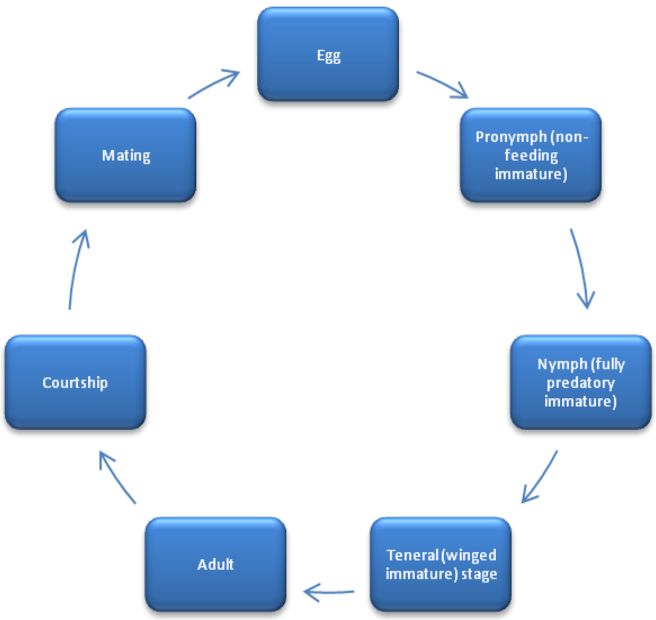


Figure 4.14 Life cycle of odonates.

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

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 uder 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 to the left 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 (Pers. Comm.. Sharon Lawler).

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

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.

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

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, 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.

Focus On: Blephyaricaridae

Net-Winged Midges

Figure 4.17 Midge Larvae. Photo: Adam Clause.

One very distinct group within the dipterans is the family Blephyaricaridae, 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 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.

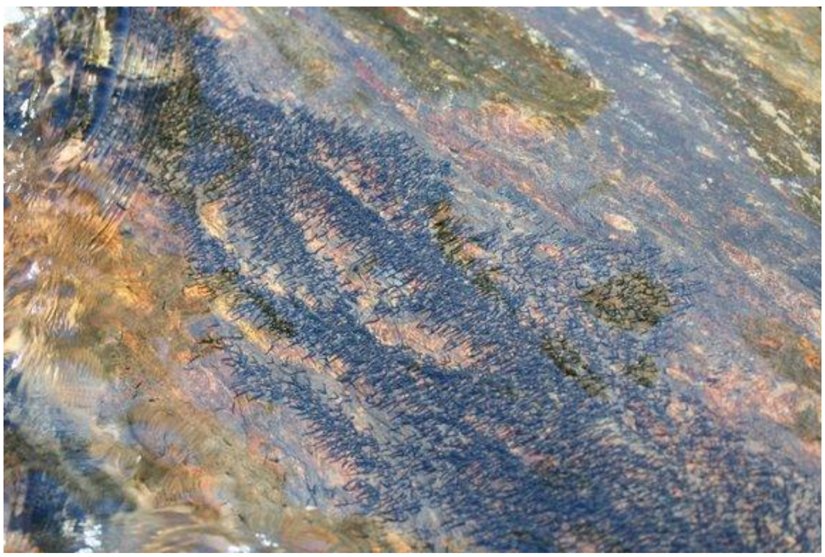


Figure 4.19 – Black fly larvae on bedrock. Photo: Adam Clause

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).

Focus on: American Bullfrog *(Rana catesbeiana)*

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

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).

Concept 1. 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.

Fishes


Figure 4.21 – Smallmouth bass from North Fork. **Photo:** Patrick Hilton.
Figure 4.22 – Verile's Crayfish (*Orconectus verile)* from North Fork. **Photo credits:** 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, *Orconectus verile* (Figure 4.22), which can be found in the North Fork of the Tuolumne.

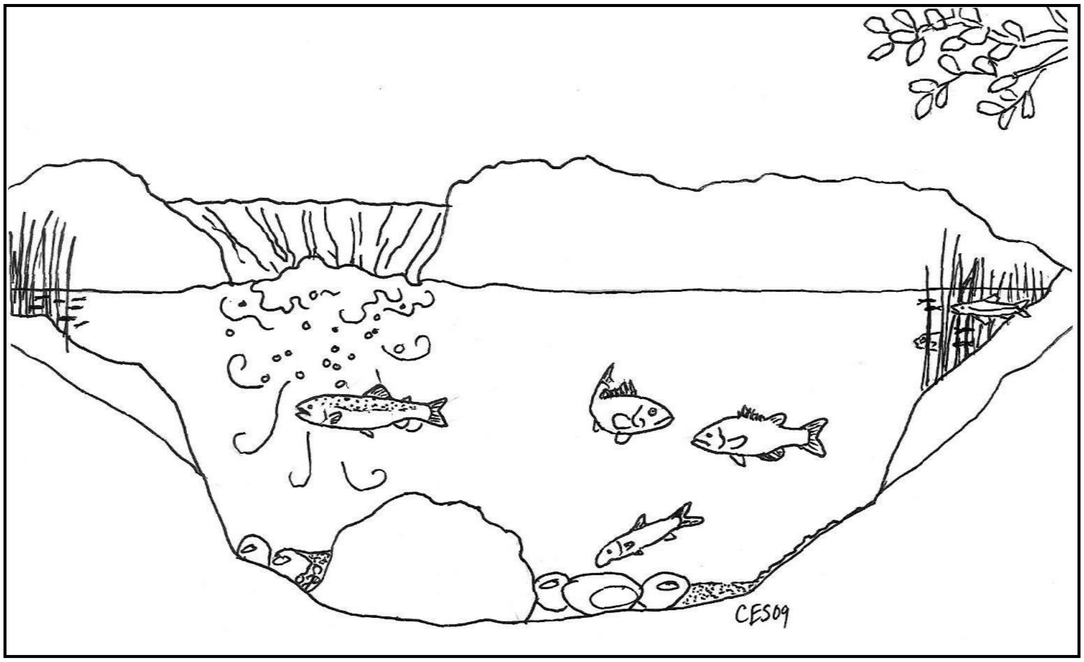


Figure 4.23 - Schematic cross section of the North Fork showing fish distributions within the river.

The above diagram illustrates the distribution of fish within a typical pool on the North Fork. 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*

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

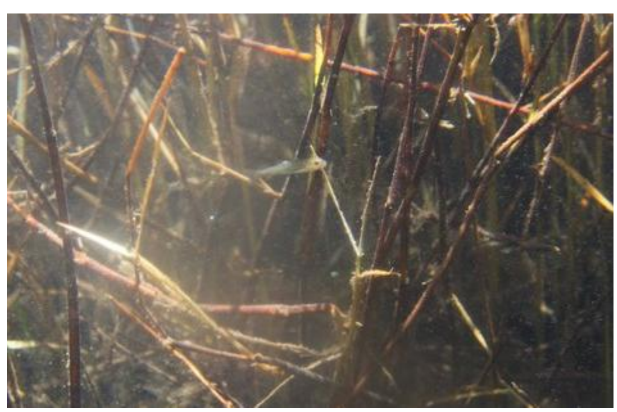


Figure 4.24 – Larval fish hiding.
Photo: Patrick Hilton.

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

Focus On: *Smallmouth Bass*

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.

Figure 4.25 – Smallmouth bass **Photo:** Claire Stouthamer

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).

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

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.

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.

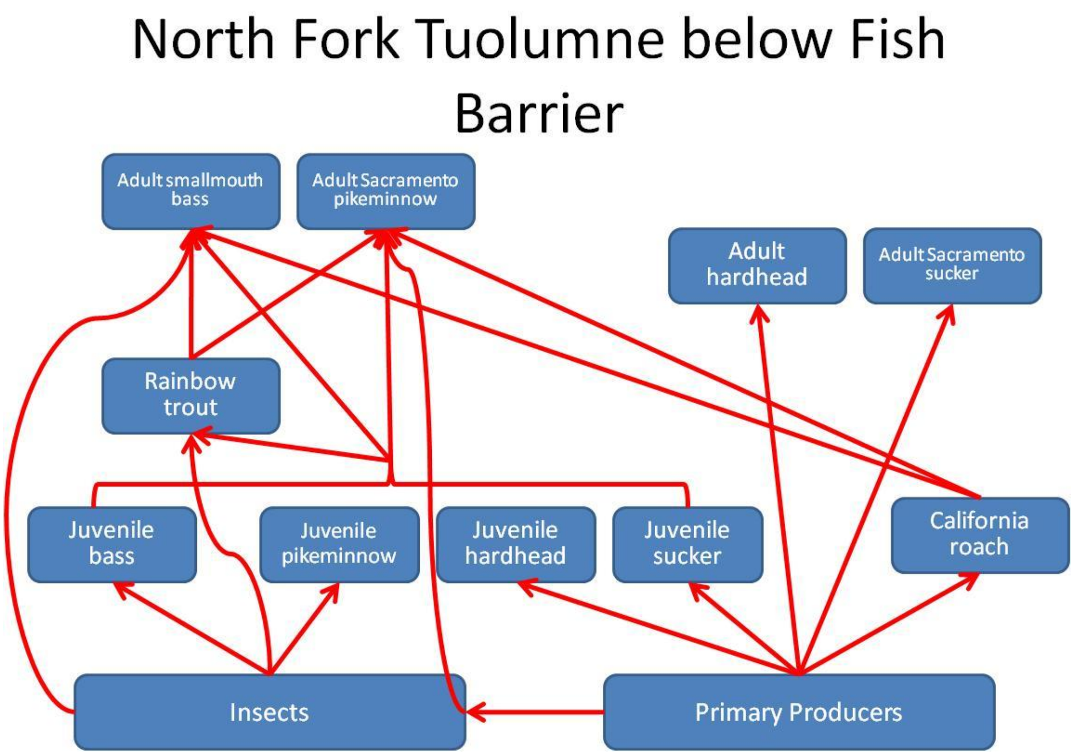


Figure 4.27 - Food web for fish assemblage below the fish barrier.

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 competitive pressures, allowing them to dominate.

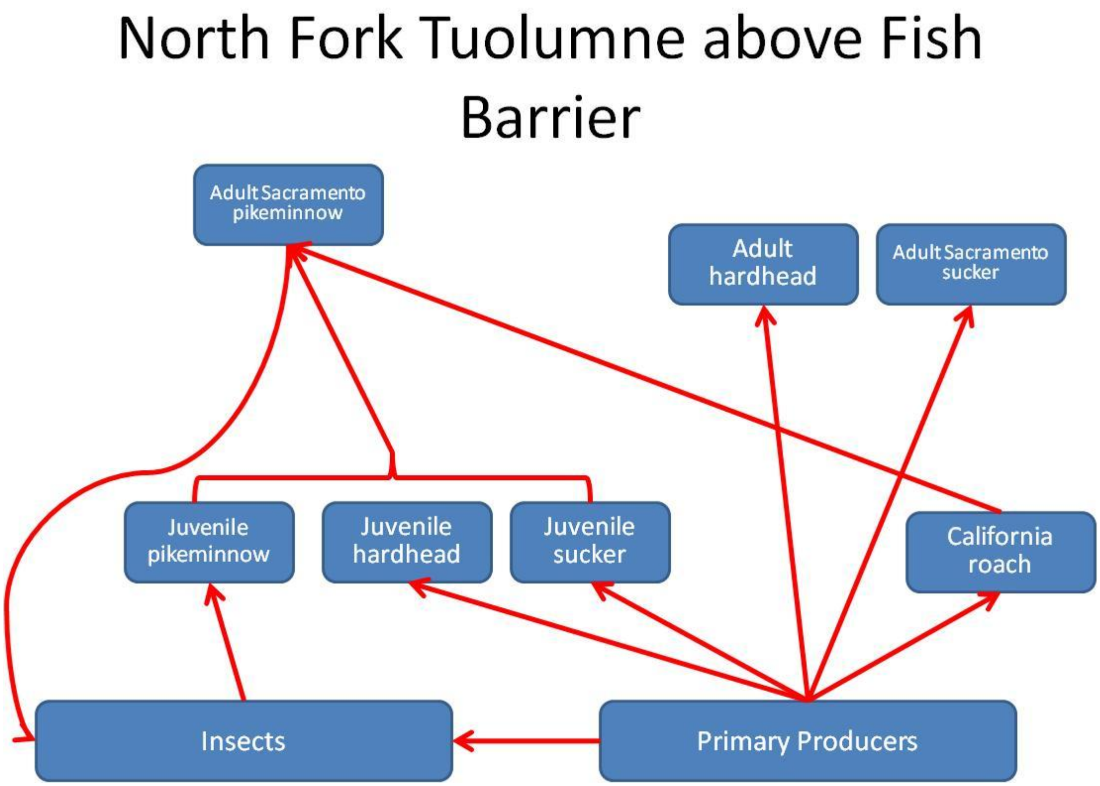


Figure 4.28 - Food web for fish assemblage above the fish barrier.

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 Tuolumne from its lowest extent.

Despite being bounded by large (New Don Pedro) and controversial (O'Shaughnessy) dams, this reach of the river is strikingly 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 previously 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. Hopefully 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.