Freshwater Mussel Abundance and Habitat in the Klamath River of Northern California

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Preface

As a Biology-Environmental Studies major, my senior thesis represents both aspects of my major. My thesis has two main parts: one part that is a nature essay describing my experience in the Klamath River Watershed and the other that is a biological research paper on freshwater mussels. The nature essay gives a broad narrative of my senior research and how it connects to a wide range of people. The research paper includes some environmental aspects, but also has results and an interpretation of these findings.

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Pikyávish

The first step into the arctic water of the Salmon River numbed my vulnerable toes wrapped in wool socks and tightly tied in felt-bottom boots. Snowmelt feeds the Salmon an everlasting coldness, barely reaching 65 degrees in the summer as the water rolls down the valley to enter the Klamath River. As I plunged myself into the Salmon, the water trickled into the small openings of my neoprene layer that protected me from hypothermia and injury in swift rapids. Through the snorkel mask suctioned to my soiled face, I stared at pebbles sitting more than ten meters away at the bottom of the river. This Wednesday, I was privileged to get a day off work to spend time with Karuk tribal members counting fish that had returned to the Salmon River, *Masuhsava* in Karuk traditional language, from the Pacific Ocean.

After such a clear environment in the Salmon River, returning to the murky waters of the Klamath River, *Ishkêesh*, to continue my summer thesis research would be a marked contrast. Most days I spent snorkeling with Karuk tribal members, researching freshwater mussels of the Klamath River in western Siskiyou County. If lucky, in the Klamath River I could squint through the floating silt and algae to see bedrock a few meters away. These conditions make it difficult to survey. Wetlands, marshes, and lakes in the high mountain desert of southeastern Oregon feed the Klamath, which runs over 260 miles to the Pacific Ocean. As the river twists through agricultural land, the water heats to almost 80 degrees during the summer months. After swimming down the cooler Salmon River, I saw how warm and turbid the Klamath was to conduct research.

Diving headfirst down the North Fork, just over four miles upriver from the small town of Forks of Salmon, my group set off in search of Chinook salmon and steelhead that would be swimming upriver to their spawning ground. Our rubber flippers directed us downstream, in the opposite direction, in order to cross their path only once for an appropriate count. However, we found no Chinook immediately.

Every few feet, I dove down into the clear depths of the mystifying river to examine behind boulders, in hidden waters untouched by the sun's rays, seeking out the hiding Chinook. The boulders were interspersed among the sand-cobble substrate mix at the bottom of the river. With my routine of snorkeling every day in the Klamath River, even when my eyes were closed I still saw water. Images of the river seeped into my mind every night as I attempted to sleep after each day of surveying. It was as though I never took any time off from my swimming. Not only did substrate infuse my river dreams, but also freshwater mussels, the key organism for my thesis research. But where were the freshwater mussels, *axthah*, in the Salmon River?

I could not stop myself from searching in bedrock cracks, behind boulders in sand pockets, and in cobble-sand substrate mixes for mussels; there was a clear difference in the substrates inhabited by mussels and not inhabited. After a couple weeks, I had finally learned how to decipher a mussel from an old piece of cobble, while Karuk tribal members easily found them after years of swimming in the river. Subconsciously, I demanded my eyes search for mussels as they had been doing for months. As a cultural resource to the Karuk Tribe, the freshwater mussels need to be preserved as a part of the natural ecosystem and their traditional practices. Without the fish we were supposed to be counting, freshwater mussels cannot exist. They cannot breed without them.

The mussels need the fish to grow. A glochidium, the fertilized larval stage of mussel reproduction, is expelled into the water from the female mussel siphons; the mussel's opening into the world. By looking like fish food, the glochidium deceives fish into attempting to consume it. Brushing over the gills, the larva latches on and acquires nutrients until it can support itself. The five-millimeter-long mussel then releases its grip from the gills, dropping into the surging waters. Vulnerable, the organism works its way into the river substrate that is likely to be its home for the rest of its life.

Swimming on a "fish-count" as it was called, was my break from surveying for freshwater mussels. I wiped my thoughts to focus on fish and peered out of the water. Ahead, the surface of the river was no longer smooth. Oxygenated water swirled just downriver, causing a ripple wave train on the surface. The water did not slow to swerve around the bedrock protruding from the water. I paused for only seconds to allow one of my group members to walk around the rapid and slide back into the pool below. He was there to count any fish that came out of the crashing waters as I swam through it. Proceeding face-first through the rapid to count fish swimming up the rapid, I made sure to keep my knees up and my hands in front of me; so not to slam my face or gouge my knee open on a boulder.

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Swirling clear waters flowed from the mouth of frigid Dillon Creek, intermixing with the algae water of the Klamath River. As with the Salmon River, the cold deposits from the tributary were a refuge to defenseless fish. The Klamath waters warm to a temperature that is almost lethal to the growing fish. The cold sanctuary of Dillon Creek provided a habitat that anglers know to harbor hundreds of fish. The Klamath River was once one of the most productive salmon streams in North America and now includes many of the longest free-flowing stretches of rivers in California.

I jumped off the Karuk tribal raft and dragged it onto the cobble bar at the mouth of the creek. Binx, a member of the Karuk Tribal Fisheries, stuck his mask onto his face and dipped his head into the icy water. He shot back out, telling us about the tremendous quantity of fish that hovered in the water at this sacred tribal fishing ground.

With the large amount of fish in this one location, I was bound to catch the first fish of my life. The fishing pole I had just learned to cast while slowly floating along the river was my weapon. Walking along the uneven pebbles, I looked over my right shoulder to make sure there was nobody to hook. With a big swing from my right arm, I cast the line out into the oxygen-rich current. Quickly, I began to reel in the lure as something pulled, hard, on the line.

Out shot the hook, smothered in algae. I picked it off and tried again. Each time, it returned with more algae. Of all the fish that were apparently swimming right where I was casting my line, why would none of them bite?

Almost ready to surrender, I finally tricked a fish. In the clear water, the fish chased diligently after my lure. It lunged forward and closed its mouth, which caused it to become trapped and tangled. I swiftly reeled in the lure, knowing that a fish was waiting at the end. Whipping out of the water, the fish squirmed back and forth, just as I did.

The rainbow trout ran no more than ten inches. I looked the fish in the eye and grasped my pole firmly, unaware of what I had to do next. Binx grasped the slimy fish and gently removed the hook from its lip, pitching it back into the mixing waters so it could continue to grow. Compared to historical records, the Klamath River has a massive decline in fish runs today. The river can use all the fish it can get.

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Partway through the Salmon River rapid, without any warning, an ancient creature hovered only inches away from my face. His black lips pulsed. The churning waters of the Salmon did not give me any warning. The four-foot-long Chinook stared into my eyes. I dug my left knee into a boulder, placed my left arm straight against the same one, and hung onto another with my right hand. It took every effort to not be swept away by the turbulent current as I lay out like a starfish.

His curved jaws gaped open. My eyes wandered to the fish's back to observe the packing-peanut-shaped black spots halfway down his body. I needed to complete an identification of the tail before I could properly classify him. The caudal fin was not a straightedge as a steelhead's would be, but created a slight "C" shape—a Chinook salmon.

I heard a faint mumble as I continued to stare in awe at the size of this fish. I had never experienced anything like him before. I wanted to reach out and touch him as I floated, wedged, into the rapid. Suddenly, I realized a team member upriver yelling at me to get out of the way. He had no way off stopping himself from running into me. I returned to look at the Chinook and proceeded to release my grip from each of my surrounding boulders.

The bubble curtain gushed past my face and I could no longer see. Speckles of quartz and feldspar minerals of a granite boulder slammed into the clear plastic of my face mask. My snorkel shoved further into my mouth. I knew I had to get out of the rapid and into the shadowed pool below to avoid being crushed by my fellow fish counter behind me. I allowed the rapid to swallow me, knowing I had my neoprene for protection and hoping no new boulder would plaster to my face.

Once into the clear pool below, I ripped off my snorkel and mask, declaring that I encountered the hugest salmon ever. Only one person glanced at him before I did, and nobody behind me was fortunate enough to see him. It was almost as though he was non-existent.

That was one of four Chinook we saw in our five-mile stretch of the North Fork of the Salmon River. A sign of the dwindling salmon population. The Chinook is listed as endangered.

It is the largest of all Pacific salmon, growing to over 100 pounds. It spends between one to eight years in the ocean and then return to the rivers to spawn. Their eggs are laid in deep waters with large gravel due to their large size, allowing for cool, flowing water to rush past them.

In the thousands of years the Salmon River cut away the canyon, the river reach had eroded over twenty pools below oxygenated rapids, which is where the fish are normally found. Along the Salmon, spring Chinook runs have declined tremendously, leaving fewer than one hundred fish to count, less than eight percent of the historical abundance. Something is changing, causing fewer salmon to return to the Klamath River and its tributaries. The river morphology remains relatively constant over the centuries, as well as the physiology of the archaic fish that return, but the numbers decrease. *Pikyávish*, meaning "to fix the world" in Karuk, is necessary for the health to be restored. Not only for the health of the fish, but for other cultural and natural resources as well.

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One of our freshwater mussel survey days on the Klamath River, we drove more than two hours to reach the site. The site we surveyed had a huge bed of freshwater mussels, so many we had to count a subset and extrapolate the actual number. It was not unusual to find a bed of mussels in the 40 sites that we surveyed, but this was one of the largest. Though the mussels seem to be found in overwhelming numbers in the Klamath River, there is still the need for the study of their age structure for relative health.

As we took our lunch break, Binx got out an old jelly jar packed with salmon flesh.

Summer is an opportune time for the tribe to catch Chinook returning upriver. Chinook spring salmon, called *áama* by the Karuk, is an important food source for them, just as freshwater mussels used to be until the river got too toxic. The Klamath was dammed in the mid-20th century, and with no fish ladder on Irongate Dam, the lowest dam, the salmon runs have since dwindled. The river warms and becomes poisoned with toxic blue-green algae overflowing from Irongate Dam, causing many Karuk traditions to diminish or be lost in the absence of the fish and other cultural resources. As my summer research on the Klamath River continued, I was fortunate to see and learn some to the traditions and beliefs of the Karuk.

I reached into the jam jar and grabbed a four-inch-long stick of dried salmon that Binx had packed that morning. The fish oils seeped out of the muscle and sat an inch thick at the bottom of the jar. The salmon melted on my tongue; I hardly bit into it before it fell apart. Smoke seeped into my taste buds and an umami flavor overwhelmed my senses.
Binx interrupted the flavors by asking, “What does the skin taste like?”

At home, I have always seen my parents remove the skin from cooked fish, so I did the same with the dried salmon. I could not answer him. Emily, the research team leader, took another piece, eating the entire stick, skin and all.

“It tastes fishy, but with a rubber feel, not like the actual fish texture,” Emily quickly responded. “Have you never had fish skin before?”

In Karuk tradition, the tribal dancers are not supposed to eat the *amvámaan*, salmon skin; a tradition that has been passed on through countless generations, just as the practices of land management has been preserved. Most men in the tribe are dancers and therefore have never eaten the skin. In their ceremonies, they dance for the health of their people as well as the land off which they live. Two other regional tribes—Hoopa and Yurok—and the Karuk gather in August to collect fish, trade, feast and also dance. Their ceremony is called *pikyávish*, to renew resources to feed their people and continue traditions.

Hopefully, as more fish return to the rivers, Karuk traditions can continue through the generations. At sacred Ishi Pishi Falls, the Indians hope to continue their fishing traditions. I have only glimpsed it from afar on the side of the winding, two-lane Highway 96. They use long-handled dipnets at these sacred falls to fish for food as well as glory. It is a practice passed among tribal fishermen. When they no longer see the leaping salmon that were so abundant in the past, the anglers feel as though they are letting their entire tribe down. It is their duty to supply this nourishment to their family, and if the river is unhealthy and fish are not returning, it cannot be done.

Even though I swam through rivers in the historic Karuk traditional lands for only a month and a half, I feel adopted into the family of those who have enduring relationships with the Klamath and Salmon Rivers. While cultural taboos prevent it, I still hope to go to Ishi Pishi Falls and see an overwhelming number of jumping Chinook, just as Karuk wish. *Pikyávish* is necessary, not only to renew resources for the Karuk, but to mend the deteriorating rivers. As the geology of the river and the structure of its organisms remain stable over time, there is still a change. Numbers decline over the years as impacts continue to rise. With each organism connected to the next, we all need a change. Just as the Karuk are tied to the rivers with their traditions, the fish, the freshwater mussels, and I require vigorous river resources for survival, recreation, pride, and even healing.

Abstract

Mussels play a vital role in freshwater ecosystems. They have also been an integral part of the diets and culture of the indigenous peoples in North America. Due to mussels' imperiled status and sensitivity to environmental changes, it is important to continue studies of the taxon, especially since there is a lack of knowledge of mussels west of the continental divide. This study examines freshwater mussel distribution and habitat use in the Klamath River of Northern California. We snorkel surveyed forty sites for the presence of freshwater mussels and recorded three mussel genera (*Gonidea, Margaritifera,* and *Anodonta*), with *Gonidea* being most abundant, *Margaritifera* present in low numbers, and *Anodonta* present at a few sites at the upper end of our study area. Mussels were recorded primarily in areas of high stability, and were found to populate low slope riffles and stable bank edges more often than expected. *Gonidea* are located in boulder and cobble and *Margaritifera* in bedrock substrate more often than expected if they were distributed randomly.

Introduction

Mussels in Freshwater Ecosystems

Mussels play an important role in freshwater ecosystems through purifying water, enhancing soil fertility, and supporting other organisms such as crayfish (Abramovitz 1996). With a long life span and complicated reproduction, mussels provide insight into watershed changes like water quality (Cuffey 2002). Freshwater mussels burrow into river substrate and face their siphons into the water current, allowing them to filter a liter of water per hour. They are usually the greatest biomass in most freshwater ecosystems and help create habitat for other organisms (Nedeau et al. 2005). Unfortunately, freshwater mussels are difficult to study due to survey methods and are therefore studied less than other organisms (Lydeard et al. 2004). Due to this lack of attention, they are rarely considered during conservation efforts.

As sessile organisms, freshwater mussels are unlikely to move to a different habitat if their current location is disrupted. They are extremely sensitive to pollutants, fluctuating temperatures, host population dynamics, and disturbance of substrate. Increased impoundments on rivers have been a major factor in the decline of mussels (Vaughn and Taylor 1999). In the United States and Canada, there are 297 freshwater mussel species, with over 70 percent listed as endangered, threatened, or of special concern (Williams et al. 1993).

Freshwater mussels reproduce sexually by releasing sperm into the water, which are then filtered in by another mussel. The resulting larval form of the mussel, known as glochidium, is ejected and taken in through a host fish's mouth. The glochidium attaches to the fish gills to receive nutrients for growth (Davis 2008). More research should be conducted to learn the host fish for the mussel species in the Klamath River, especially *Gonidea angulata*. Given the decline of the ecological conditions in the Klamath, there is a concern of the loss of host fish populations, thus making it difficult for mussels to continue reproducing.

The Pacific and Klamath River Freshwater Mussels

Compared to the eastern United States, watersheds west of the continental divide have few species of freshwater mussels (Abell 2000, Nedeau et al. 2005). The two families of mussels present are Unionidae and Margaritiferidae (Bauer and Wachtler 2001). The three genera found west of the continental divide include *Gonidea*, *Margaritifera*, and *Anodonta* (Nedeau et al. 2005). *Margaritifera* live longer lives in rivers when away from dams and agriculture and tend to inhabit stable areas of large boulders (Nedeau et al. 2005). *Gonidea* are rarely found in lakes and reservoirs, are absent in unstable substrates, and do not often inhabit high-elevation headwaters. *Anodonta* are more tolerant of low-oxygenated waters than the other two species and tend to live in low-gradient rivers (Nedeau et al. 2005).

Most freshwater mussels prefer well-oxygenated water and a constant flow of shallow water (COSWIC 2003, Strayer et al. 2004). After a river impoundment, there is typically a gradual increase in mussel species richness and abundance when moving downriver (Vaughn and Taylor 1999). Mussels are less abundant in channelized or mined locations, as opposed to parts with little modification (Brim Box et al. 2006). The Klamath River had been mined for gold until recently to review the impacts of suction dredging on fish. Logging in forests surrounding the river caused sedimentation and erosion. Mussels inhabit areas with low shear stress from the current (Cuffey 2002, Sietman et al. 1999). Flow refuges, such as boulders and bedrock outcroppings are used by mussels for protection from fast flowing currents, but allow water flow for nutrients (Vannote and Minshall 1982, Nedeau et al. 2005).

Basic surveys of the west are minimal, but are necessary to better understand the life history and distribution of freshwater mussels (Brim Box et al. 2006). Few studies on freshwater mussels have been conducted in the Klamath River of Northern California. The environment has extreme seasons that make living conditions and research difficult (Wallace 2003). One study was conducted in the 1860s and the second study was done in 2007 by Emily Davis and Aaron David of Whitman College (Davis 2008, David 2008). With so few surveys on the Klamath River, it is important to conduct additional surveys to understand how the system is changing, especially with Klamath River dams slated for removal in 2020. Once the dams are removed, the data collected will be important to see the mussel abundance differences.

Cultural Importance of Freshwater Mussels in the Klamath Basin

Three main tribes live along the Klamath and Trinity River: the Hoopa, Yurok, and Karuk. The Karuk gained federal recognition in 1979, but have no reservation land. The ancestral territory of the Karuk is situated in northern California along the mid-Klamath River where our research was conducted. Freshwater mussels, *axthah* in the Karuk language, are an important cultural resource to tribal people. Freshwater mussel shells were traditionally used as tools, scrapers, spoons, jewelry, and toys (Harling 2006). Historically, the Karuk harvested freshwater mussels as a traditional food source, passed on over centuries. Mussels are important to the Karuk Tribe of Northern California and have also been consumed by other Pacific Northwest tribes, including many along the Columbia River (Brim Box et al. 2006).

There are dams along the Klamath River which block salmon and steelhead passage. The Klamath watershed was historically the third largest salmon producing watershed on the Pacific coast, following behind the Columbia and Sacramento Rivers. Salmon are extremely important to the Karuk diets and also to freshwater mussels. The salmon runs are depleted today, which is a potential problem for mussel reproduction because of their need for a host fish. Salmonids are the known host fish for *Margaritifera falcata*, while *Gonidea angulata* requires more research. Not only do dams block fish passage, but they also create reservoirs behind the dams. This stagnant water in the reservoirs, heated by solar energy, is released into the Lower Klamath River causing high temperatures in the river. The reservoirs also are a good environment for toxic blue-green algae to grow and thrive, which is then released below the dams (Tucker 2006).

Project Goals and Objectives

Freshwater mussel research on the abundance and habitat preference of freshwater mussels was conducted in the summer of 2009 as an extension of research in 2007. We collected baseline data on the distribution and abundance of freshwater mussels in the Klamath River. In 2007, Emily Davis and Aaron David (Davis 2008, David 2008) found mussels were protected from rushing currents and scouring flows. Mussels tend to live in stable substrates that they can wedge and not wash away by the current (Davis 2008, David 2008). Many factors may influence the habitat of freshwater mussels in the complex Klamath River (Rempel et al. 2000). For example, both the mesohabitat and microhabitat impact mussel distribution.

Our project seeks to answer how freshwater mussels are distributed in the river. We looked to answer these questions: Are sites below tributaries more likely to have an abundance of freshwater mussels? Are sections of the river with slower moving water more likely to have a large abundance? How abundant are the different mussel species? Is there a substrate that the different species of freshwater mussels prefer? The 2009 freshwater mussel research examined microhabitat, mesohabitat, and macrohabitat characteristics of freshwater mussels. We focused on the substrate (microhabitat), bank edges (macrohabitat), and type of run (mesohabitat) of the Klamath River. We expected to find mussels along stable bank edges in stable substrates into which they can burrow   Mussels were expected in flowing currents rather than stagnant waters, such as pools, and behind boulders and outcroppings for protection. We expected to find *Margaritifera* downriver from the tributaries because of their need for cleaner water, while *Anodonta* will likely be the more abundant mussel by the dam because it can tolerate slow moving water. Based on earlier work by Davis and David, the mussels were expected in substrates that allow them to wedge with less surface area exposed to the current and to have protection.

Materials and Methods

Survey Area

We surveyed the mid-Klamath River in the Klamath Basin of Northern California. All study sites were between Irongate Dam, the lowest dam on the Klamath River, and the town of Weitchpec, California (Photo 1). Most sites were within Karuk ancestral territory which extends along approximately 140 river miles from Seiad Valley on its northern border to Aikens Creek on its southern border. We sampled 40 sites and repeated a survey of 5 of those sites at the end of the study. These surveys were conducted over a month and a half survey period.

We selected study sites using a previously conducted US Fish and Wildlife Service mesohabitat mapping project. The USFWS project divided the Klamath River, from Irongate Dam to the mouth of the river, into reaches of differing length and assigned each reach a mesohabitat. The mesohabitat types included glide, pool, run, low slope riffle, medium slope riffle, and steep slope riffle using gradient to determine. We used this information, global positioning system (GPS) coordinates for each reach, and aerial photos from the US Fish and Wildlife Service project to find the site locations which we accessed by hiking or rafting. A “site” was a 50-meter stretch of the river within the mesohabitat reach.

Of the possible 900 sites, we randomly selected 40 sites using Excel's "randomize" function. Some sites were discarded and replaced with other randomly selected sites in order to distribute sites evenly among different mesohabitats. If any of the sites were determined to be unsafe to survey or impossible to access, they were discarded and replaced randomly.

Survey Protocol

Once at a reach, we laid a 50-m survey tape along the bank of the river. We recorded GPS coordinates at the river and took photos of the site from the upstream and downstream ends.

We conducted a survey by snorkeling at each site. Surveyors covered as much of the site as safely possible. A surveyor began at the bottom of the site and surveyed in a zigzag pattern upstream. The same method was conducted on both sides of the river. Surveyors continued as far out into the middle river channel as safe. We often excluded the middle from detailed survey due to swiftness and depth. Therefore, different areas across the river channel were surveyed from site to site. We did not expect to find mussels in the fast-flowing, unprotected middle channel current. Mussel count, side of the river, species, and substrate (silt, sand, gravel, cobble, boulder, bedrock) were recorded.

A "bed" of mussels was identified by dense amounts of mussels. Individually counting an entire bed would be excessively time consuming. Alternatively, beds were sample counted using quadrats. To be considered a bed, an average density of 40 mussels needed to be present in the quadrats. Quadrats are $0.25m^2$ PVC pipe squares placed in different parts of the bed. We calculated the dimensions of the bed to get an area and then calculated how many quadrats we needed to record 10% of the mussels. For example, a bed 1m wide and 20m long required 8 quadrat measurements to meet the 10% area requirement. We spaced the quadrats evenly throughout the bed, both on the inside and outside of the bed. If we use the previous dimensions as an example, quadrats would be spaced out 2.5m between one another. Within each quadrat, we recorded the total number of mussels per species and substrate. Post-survey, we extrapolated the total number of mussels in the bed.

Once we completed the snorkel survey, we drew a site map, marked general locations of mussels, noted important hydrological features, described important markers on the sides of the river, and labeled the mesohabitat upriver and downriver of the site. We chose the two river edges as a bank (steep, stable edge) or river bar (low slope, unstable edge). We took site notes for access and any other conditions that made it difficult to survey the site (e.g. excessive amount of algae, turbidity, etc.).

Following the snorkel survey, we visually estimated total percentages of each substrate within a 50-m stretch in order to evaluate the expected number of mussels in each substrate based on availability if mussels were randomly distributed. Substrate categories included silt, sand, gravel, cobble, boulder, and bedrock, as defined by Brim Box et al. (2006) in their survey of mussels in the Umatilla River system. Mixed substrates are those that have more than one substrate and the two dominate substrates were recorded. Mixed substrates of silt/sand, silt/gravel, silt/cobble, silt/boulder, silt/bedrock, sand/gravel, sand/cobble, sand/boulder, sand/bedrock, gravel/cobble, gravel/boulder, gravel/bedrock, cobble/boulder, cobble/bedrock, and boulder/bedrock were also included in the Klamath survey. These were condensed into substrates defined by Brim Box et al. (2006) by changing substrates of smaller grains into the larger component (i.e. bedrock/sand to bedrock). This increased the value of repeatability.

Data Analysis

To assess mussel abundance over different substrate types, we used G-tests to determine if *G. angulata* and *M. falcata* occupied substrates according to the proportional availability. For each substrate, we compared total mussels in one substrate to mussels in all the other substrates combined. *Anodonta sp.* were found at few sites and not statistically analyzed. A Generalized Linear Mixed Model, with Poisson error and the site as a random effect, looked at the effect of bank type and mesohabitat on the distribution of freshwater mussels. We surveyed five sites twice to determine repeatability of substrate estimates and mussel counts of our protocol for future research and to see the quality of our data.

Results

In the Klamath River, we identified three species of mussels: *Gonidea angulata*, *Margaritifera falcata* and *Anodonta sp*. We found *G. angulata* at 36 sites, *M. falcata* at 7 sites, and *Anodonta* at 3 sites. *G. angulata* was the most abundant species and most widely distributed (Fig. 1). Of the 40 sites that were surveyed, 37 sites had at least one mussel. The site with the highest abundance contained 27,087 mussels. We estimated a total of 202,606 mussels of all three species at the 40 sites.

At each of our sites, we labeled it as one of four mesohabitat categories: steep slope riffle, medium slope riffle, low slope riffle, and pool. There was 1 steep slope riffle, 8 medium slope riffles, 17 low slope riffles, and 14 pools. A Generalized Linear Mixed Model found no significant differences between the abundance of *G. angulata* ($F = 0.66$, d.f. = 36, $p = 0.58$) and *M. falcata* ($F = 0.45$, d.f. = 36, $p = 0.7198$) in the different mesohabitats (Fig. 2, Fig. 3).

We found 54 bank edges and 26 bar edges at the 40 sites we surveyed. Using the Generalized Linear Mixed Model (GLMM), more mussels were found on bank edges than on bar edges (Fig. 4) for *G. angulata* ($F = 18.48$, d.f. = 39, $p = 0.0001$) and *M. falcata* ($F = 5.22$, d.f. = 39, $p = 0.028$).

G-tests showed that the observed abundance across substrates for both *G. angulata* and *M. falcata* differed from the expected abundance of mussels based on the mean percentages of substrates across 40 sites (Fig. 5; Fig 6). We used G-test analysis because the results did not converge using the GLMM. We observed more *G. angulata* on boulder and cobble than expected by chance and found fewer than expected in bedrock, gravel, sand, and silt (Table 1). Bedrock and gravel contained more *M. falcata* than expected by chance and we found fewer mussels than expected in boulder, cobble, sand, and silt (Table 2).

After considering how substrate affected the total number of mussels at the sites, we also used a G-test to evaluate the location of beds at the 40 sites (Fig. 7). This analysis did not reveal a significant difference for the observed number of mussels beds compared to the expected number of mussel beds at the different mesohabitats ($G = 5.118$, d.f. = 3, $p = 0.163$).

Repeatability of *G. angulata* counts was 0.92 ($F = 22.769$, d.f. = 4,5, $p = 0.002$) and of *M. falcata* was 0.31 ($F = 1.915$, d.f. = 4,5, $p = 0.246$). Repeatability of lumped substrate percentage estimates (Fig. 8) was 0.86 ($F = 14.056$, d.f. = 24,25, $p < 0.0001$). Perfect repeatabilty (identical counts or estimates on repeated visits) equals 1. We originally had many categories that included the dominant and sub-dominant substrates. Due to a lower repeatability value, we clumped the smaller substrates into the larger substrates, which increased repeatablity (ie. sand/bedrock became bedrock).

Qualitatively, we observed mussels in areas protected from the current, but still had water flow to feed. We found mussels directly behind boulders and in bedrock cracks and sand pockets. We rarely found mussels any of the three species in the middle of the river, with the exception of a few mussels at one site. We did not analyze any of these observations statistically.

Discussion

General Distribution of Freshwater Mussels

All three previously identified mussel species of identified mussels from the 1860s were present in our 2009 surveys (USDA Forest Service 2004, David 2008, Davis 2008). *G. angulata* were the most abundant and widely distributed mussels throughout the mid-Klamath River, while *M. falcata* and *Anodonta sp.* were found in drastically lower numbers. *M. falcata* were scattered below the tributaries running into the Klamath River and *Anodonta* were at a few upriver sites. Our work compares to a study on the Middle Fork John Day River in eastern Oregon conducted by Brim Box (2006) that found *M. falcata* less abundant in stretches of the river altered by channelization or mining. This is a possible explanation for the small numbers of *M. falcata* we found in the Klamath.

Many factors may contribute to a greater abundance of *G. angulata* than *M. falcata* in the Klamath. Due to the presence of dams on the Klamath River, water temperatures increase dramatically to be warmer during the summer than if dams were not present. *G. angulata* tolerate a wide range of temperatures, while *M. falcata* do not. *M. falcata* are found downriver of creeks feeding into the Klamath River due to the lower water temperatures and less sediment buildup. The decline in host fish populations may also lead to a drop in the numbers of mussels in the Klamath River. Without a host fish, the glochidium does not have a source of nutrients to develop into a juvenile mussel.

We identified a bed of *Anodonta* below Iron Gate Dam. Very few sites downriver of the dam contained *Anodonta*. *Anodonta* are likely found below the dam because they are able to tolerate and prefer lentic systems. The mid-Klamath River has seasonal variation in its flow, thus the dam is able to regulate the upper area, making it more suitable for *Anodonta* to live. *G.*

angulata and *M. falcata* are not found by the dam due to stagnant water. With more differences in flow at the mid-Klamath that are not regulated by the dam, *Anodonta* are unable to survive while the other species are able to do so.

A study of the South Fork Eel River of Northern California, found a large number of *M. falcata*, a moderate number of *A. californiensis*, and no *G. angulata* (Cuffey 2002). Interestingly, this distribution is the opposite of the Klamath River distribution. A possible explanation for this difference is the sedimentation throughout the Klamath. Vannote (1982) found the mussel composition of the Salmon River Canyon, Idaho to be changing its relative abundance from *M. falcata* to *G. angulata* due to sediment influx. The Klamath may have had this switch occur in the past and now is an ideal environment for *G. angulata*.

Mesohabitat Distribution of Freshwater Mussels

Though there was no significant difference in the effect of mesohabitat on both *G. angulata* and *M. falcata* distribution, there were more mussels of both species in low slope riffles probably due to a continuous flow for nutrients to flow past the mussel siphons. A pool has limited movement and steep slope riffle may move too fast for optimal food intake and stability (Vannote 1982). The mussels will not suffocate from sediment build up with a constantly moving current. When the flow is not strong enough, this build up can occur and decimate mussel populations. Cuffey (2002) found *M. falcata* inhabiting areas of low velocity, which could explain my observation of mussels in low slope riffles and pools, rather than medium slope riffles and steep slope riffles. These mesohabitats are the most stable for *M. falcata* to live over one hundred years due to decreased water flow.

Bank Type Distribution of Freshwater Mussels

Bank edges are more stable habitats that do not change as readily as bar edges. Bar edge substrates can be washed away and scoured. A Committee on the Status of Endangered Wildlife in Canada (2003) assessment found *G. angulata* avoid shifting substrates, leading them to live in stable bank areas as found on the Klamath. Skinner et al. (2003) state that *M. falcata* do not inhabit the inner curves of river channels due to instability. Mussels establish themselves in stable substrates to remain there throughout their lifetime. In an unstable environment (i.e. bar edge), the mussels could be crushed or suffocated by the shifting substrate or possibly do not have enough energy to wedge into the substrate again (Skinner et al. 2003).

Microhabitat Distribution of Freshwater Mussels

G. angulata and *M. falcata* were not randomly distributed in the substrates nor did they preferentially inhabit the same substrates. *G. angulata* were found behind and underneath boulders due to the boulder stability (Skinner et al. 2003). With flooding, it is most likely boulder and cobble that will remain in place. However, it is not just boulders or cobble, but a mix of a more stable substrate and a fine substrate for *G. angulata* to bury. COSEWIC (2003) states that the presence of at least some fine material is required for *G. angulata* to wedge. The larger substrates create stability, but it is the finer substrate that allows the mussel to hold itself in for protection. Sietman et al. (1998) found mussels accumulate on bedrock in the presence of a smaller substrate, such as gravel or sand. Though bedrock is thought to be an unsuitable habitat for freshwater mussels, if finer sediments accumulate on top and are relatively undisturbed, then mussels can colonize there.

We observed more *M. falcata* on bedrock than expected. Bedrock, like boulder and cobble, is a stable substrate. Patches of sand stabilized among large stones and boulders can be a popular microhabitat for *M. falcata*. By living on bedrock, there is little to no bank erosion and scouring to harm the mussels that live over one hundred years. Not only do the larger substrates provide stability, but they are also a sign of stronger currents and less sedimentation for mussels to filter more water (Skinner et al. 2003).

Vannote et al. (1982) found a decline in *M. falcata* populations in the Salmon River of Idaho due to increased sedimentation from logging, mining and grazing. The Klamath River watershed had much logging in the past, as well as, until recently, mining. With *G. angulata's* incurrent and excurrent siphons, they are better adapted to high sedimentation than *M. falcata* (Vannote et al 1982). A history of logging and mining therefore may account for the greater abundance of *G. angulata* than *M. falcata*.

Conclusion

Freshwater mussel research needs to be continued on the Klamath River. The data collection is essential baseline data that can be used in the future once the Klamath dams are removed to see how the mussel populations change. Mussel's ability to filter water, cycle nutrients, and provide habitat for invertebrates is necessary for the survival of the watershed. Not only must fish populations be researched and protected, but freshwater mussels must as well.

Steps are being taken to look into the human impacts on the Klamath River. Recently, suction dredge mining has been put to a halt in the Klamath River until further research on the effects of mining on fish populations is conducted. Though the research will mostly be on fish populations, realistically the return of different fish species will lead to increased health of freshwater mussel populations. The State of California should review the effects of suction dredge mining on freshwater mussel populations. In a study of suction dredge mining on the Similkameen River in Washington, Krueger et al. (2007) found little effect on mussels that were passed through a suction dredge. Though they are able to reestablish in substrate, it may not be the most stable area to live and if they are completely buried, it may be too difficult to escape. Stopping suction dredge mining or eliminating it in areas that contain mussels would be beneficial to their survival. Mussels will no longer be suffocated when tailings are placed on top of them and will not be stressed from trying to reestablish (Krueger et al. 2007).

Currently, the four lowers dams on the Klamath River are slated for removal in 2020. In February of 2010, there was the signing the Klamath Basin Hydroelectric Agreement between federal, state, utility and tribal officials for dam removal (Greenson 2009). Although removal is not guaranteed, it is a step in the correct direction after years of work advocating for their removal. This dam removal would help restore salmon and steelhead populations to the Klamath River, which the freshwater mussels rely on for reproduction. It is important to continue research looking at the affects of dam removal on the freshwater mussel populations. *Anodonta* that live directly below Iron Gate Dam and tolerate lentic waters may not survive a dam removal.

Future Research

Repeatability was high with the combined substrate estimates, though *M. falcata* needs to be interpreted cautiously because of the lack of significance. Before starting to survey, an orientation should be conducted to learn to correctly identify substrates for consistency throughout the survey period. It is difficult to get an exact count of mussels without disturbing their habitat. Decreasing the number of substrate categories is also necessary.

The protocol should be altered so that the same distance between the river edge and the middle of the river is measured for each site. This is difficult because each site is very different from one another, so one site is safer to go further into the middle of the river than another. There needs to be a standard distance that will lead to improved results. Keeping the surveyors consistent is important as well for the sites because it will allow for the best repeatability with more practice snorkel surveying.

Future research needs to continue to look at the habitat locations of the different species of freshwater mussels in the Klamath River. The tributaries in the Klamath Watershed should also be studied to see distribution throughout the watershed, not just the large Klamath River. Looking at the slope of the river may be important for mussel distribution to see if different gradients may be better for filter feeding and stability. Cristine Tennant of Whitman College has conducted a study on the population age structure of the freshwater mussels of the Klamath River (Tennant, 2010). There is a need for a larger sample size for this study to understand whether the mussel populations are reproducing successfully. Further study into the host fish species of *G. angulata* is necessary. All these questions are worthwhile for further research.

Figures, Graphs, and Tables

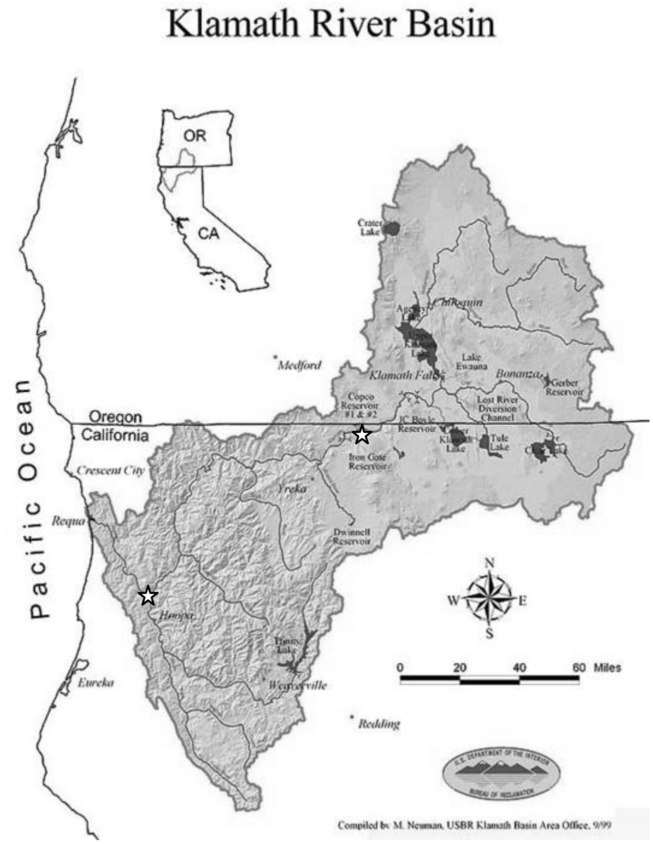

Photo 1. Klamath River Basin and research area.

Table 1. G-Test results comparing *G. angulata* distribution in different substrates.

Substrate	**G**	**d.f.**	**p-value**
Bedrock	-3784.02042	1	< 0.0001
Boulder	6817.04636	1	< 0.0001
Cobble	7006.57216	1	< 0.0001
Gravel	-389.887974	1	< 0.0001
Sand	-2949.82790	1	< 0.0001
Silt	-513.166910	1	< 0.0001

Table 2. G-Test results comparing *M. falcata* distribution in different substrates.

Substrate	G	d.f.	p-value
Bedrock	579.3858876	1	< 0.0001
Boulder	-64.38907453	1	< 0.0001
Cobble	-47.59266767	1	< 0.0001
Gravel	14.03285348	1	< 0.0001
Sand	-13.38306794	1	< 0.0001
Silt	-2.480015845	1	< 0.0001

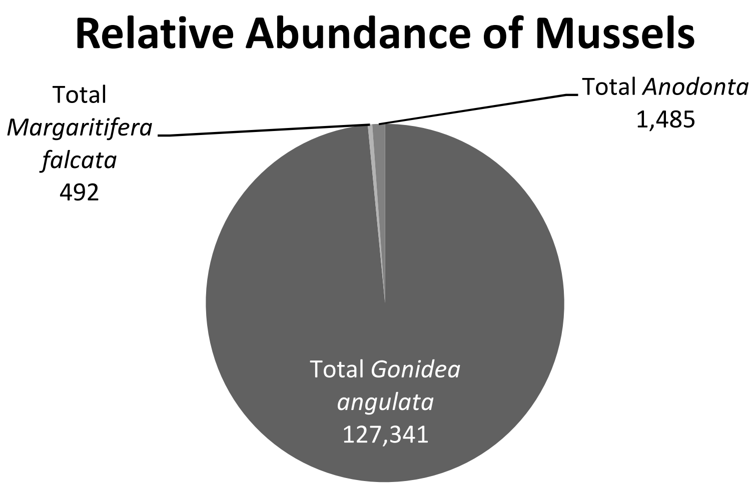

Figure 1. Total estimated *G. angulata, M. falcata,* and *Anodonta sp.* at the Klamath survey sites.

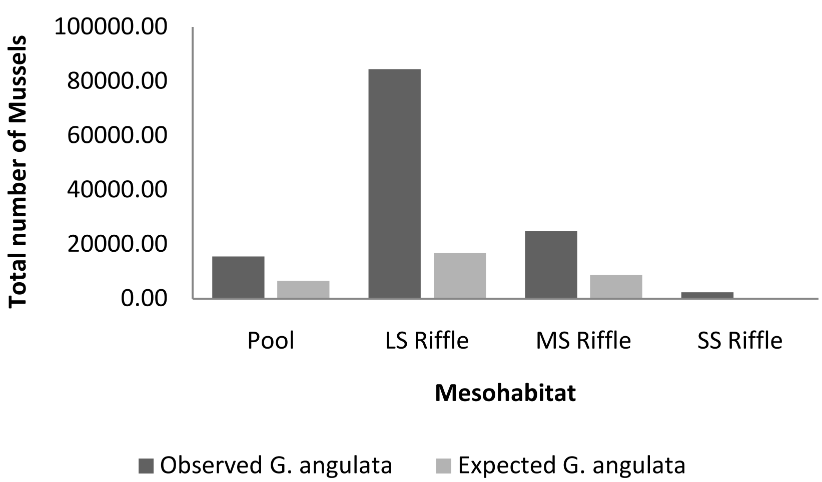

Figure 2. Total number observed and expected (based on mesohabitat abundance) *G. angulata* in each mesohabitat that include pool, low slope riffle (LS Riffle), medium slope riffle (MS Riffle), and steep slope riffle (SS Riffle).

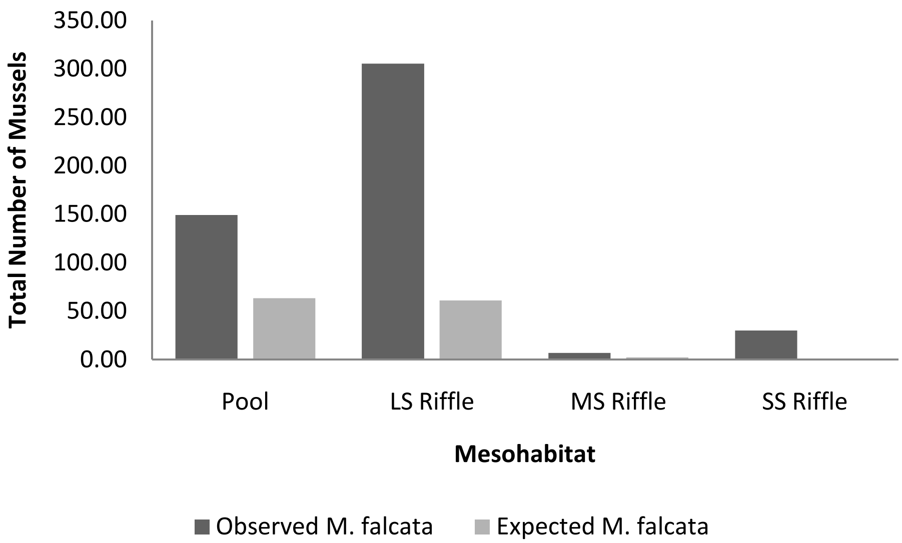

Figure 3. Total number observed and expected (based on mesohabitat abundance) *M. falcata* in each mesohabitat that include pool, low slope riffle (LS Riffle), medium slope riffle (MS Riffle), and steep slope riffle (SS Riffle).

Figure 4. Total number of observed *G. angulata, M. falcata,* and *Anodonta* on river edges

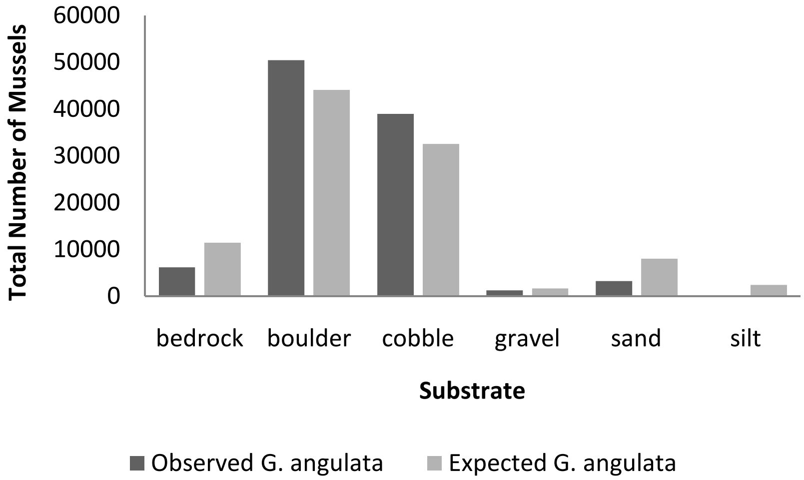

Figure 5. Actual (observed) versus expected numbers of *G. angulata* based on mean substrate percent cover across 40 sites.

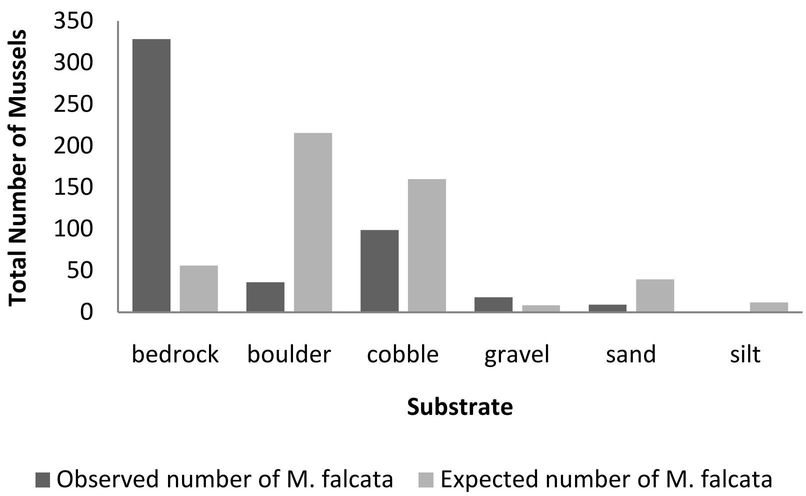

Figure 6. Actual (observed) versus expected numbers of *M. falcata* based on mean substrate percentages across 40 sites.

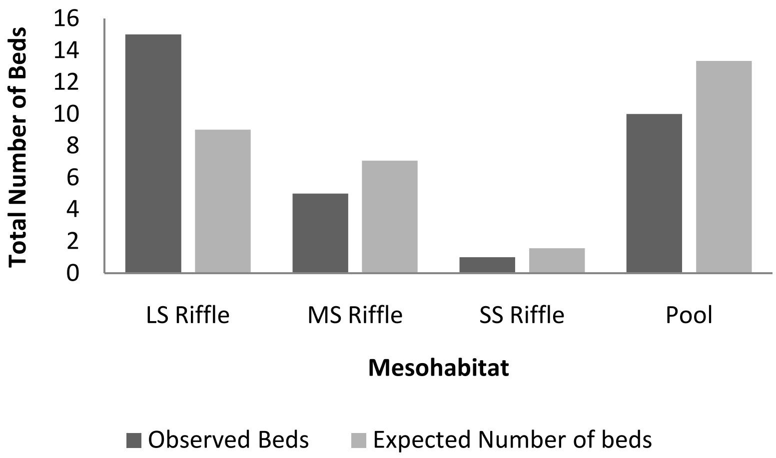

Figure 7. Actual (observed) and expected numbers of beds for mesohabitat categories.

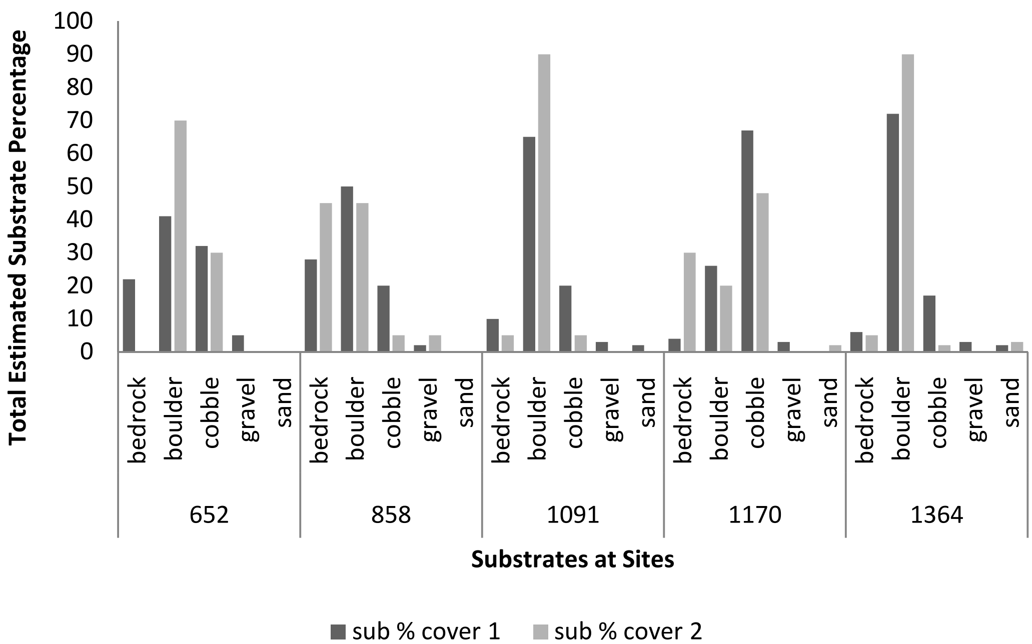

Figure 8. Percent substrate estimates for the first survey and the second survey of the 5 repeated sites.

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