Trout Habitat Assessment of Upper Codornices Creek for Steelhead Spawning

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Abstract In March of 2000, steelhead trout (*Oncorhynchus mykiss*) were discovered in the lower reaches of Codornices Creek, located in Berkeley, CA. The following year, Kier Associates evaluated the potential trout habitat throughout the stream. Kier concluded that the existing habitat in the upper reaches had the potential to sustain a large steelhead trout population. Kier also concluded that migration to the upper reaches was restricted by an impermanent fish barrier. This study consists of an in-depth assessment of the suitability of four sites in the upper reaches as potential trout spawning habitat, with the goal of localizing the optimal site. In this study, habitat was assessed weekly, and measurements of dissolved oxygen, water temperature, water velocity, and pool depth were analyzed. The study was conducted over a period of ten weeks during the winter of 2005, since steelhead trout spawning typically lasts from December until May. Results reveal that all four sites had pool depth below two feet, the minimum depth for primary pools. In addition, the temperature of the four sites went above optimal spawning conditions (10-13°C) after test week seven. Site 3 was determined to be slightly superior, although further research is mandatory before restoration efforts begin. Future studies to assess pool depth and temperature of existing trout habitat, comparison studies between existing trout habitat and potential habitat, embryo survival rates studies, and location of erosion sites are recommended before restoration begins.

Introduction

Codornices Creek, located in Berkeley, CA is one of the numerous urban creeks in the San Francisco Bay Area (Friends of Five Creeks 2004, Berkeley Creeks 2004). From the headwaters, Codornices Creek runs through various urban environments, including residential neighborhoods, recreational parks, a small industrial area, and a marital housing unit owned by the University of California, Berkeley. In comparison to other Bay Area creeks, Codornices Creek is notable due to its low percentage of culverted area, and therefore high percentage of exposed potential habitat capable of supporting aquatic species (Friends of Five Creeks 2004). In March of 2000, Codornices was found to be capable of supporting aquatic species when steelhead trout (*Oncorhynchus mykiss*) were found in the lower reaches of the stream (LOCCNA 2003). However, the steelhead trout were not able to migrate and establish habitats in the upper reaches of the stream due to the presence of culverts (large pipes used to direct steams underground), and other fish barriers. Efforts are currently underway by local non-profit organizations, including the Friends of Five Creeks and Urban Creeks Council, to dig up and expose the parts of the creek that run underground, a process referred to as "daylighting" (Friends of Five Creeks 2004). Daylighting, as well as barrier removal, will return the creek to a more natural configuration, thus allowing fish populations to migrate upstream and establish habitats.

In the year following the discovery of the steelhead in Codornices, the Urban Creeks Council hired Kier Associates, a consulting firm, to assess the both the upper and lower reaches of Codornices for its potential to support steelhead trout populations (LOCCNA 2003). The Kier study evaluated the amount and quality of trout stream habitat, and produced a report that noted fish presence, fish barriers, water quality, and potential spawning pools. The study also tested for many common urban pollutants, and took two water samples that tested for heavy metals, hardness, toxicity, and sewage leaks (LOCCNA 2003).

My research focused on the upper reaches of the creek, in the region of the stream where the steelhead have been unable to migrate due to the presence of culverts and other fish barriers. This study analyzed the potential spawning pools located by the Kier study in greater detail, by retesting dissolved oxygen and temperature parameters, and collecting a new set of data not analyzed by the Kier study, including stream dimensions and water velocity. The importance of retesting some of the parameters from the Kier study was to account for the possibility of significant changes in the creek since the completion of Kier study, which could lead to the data from the study now having become inaccurate. Samples were taken at a time of year prior to the Kier study testing period, in the late winter and early spring months when California steelhead spawn, as a means of further testing Codornices' habitat capabilities (NCRCD 2004). Steelhead spawning is the process by which females select pools with aerated substrate, digs nests called redds, and deposit their eggs. The eggs are then fertilized by male trout, covered with substrate, and allowed to hatch (NCRCD 2004). The data collected from my study will compliment the Kier data to form a more complete record of the capability of Codornices to support fish populations.

The three goals of my study were to: first, determine if the upper reaches were suitable for trout populations; second, determine which area had the highest quality habitat and showed the most consistent characteristics, and third; make specific recommendations for the restoration and/or reintroduction of trout into the upper reaches of the creek. Suitability of the creek was determined both from observational data from this study, as well as reference to US EPA standards and comprehensive review of relevant scientific literature. The healthiest region is important to locate in that it will be the region where the steelhead will have the greatest chance of survival, and therefore restoration should be carried out to promote fish migration to the area. Inconsistent water quality can have negative impacts on trout populations, as frequent changes in quality will lead to excesses in stress on the fish populations, and decreases in survival rates by increasing susceptibility to disease (NCRCD 2004). Stream restoration takes careful planning and can be quite expensive, and will need to be carried out in numerous steps, as the entire creek cannot be restored and trout populations introduced all at once. One of the goals of this study was to produce data that will help guide restoration efforts by locating the highest quality habitat in the upper reaches, and therefore the area where much of the restoration efforts should be focused.

As is the case with many of the creeks throughout the Bay Area, a limited amount of water quality data has been collected on Codornices Creek. Water quality testing is necessary in evaluating the health and the potential of a water source to support aquatic life. The additional testing and data that this study has produced will help direct restoration actions in ways that will eventually lead to both increases in trout survival rates and population size (US EPA 2004).

Methods

The study regions were located in the upper reaches of Codornices Creek. The upper border for the study region was the Berkeley Rose Garden, which contains a culvert that is impassible for fish due to its steepness, and therefore considered to be a permanent fish barrier (LOCCNA 2003). The lower border for the study area was the area where the creek intersects Albina Ave. At this location, downcutting, a process where high water flow creates separations in stream bed levels, has prevented fish from ascending the creek. The barrier at Albina Ave. is not permanent and can be removed (LOCCNA 2003). Preliminary data were collected to determine the number of pools that could be assessed adequately given the constraints of the study. The results of preliminary testing were not reflected in the final data, as the data were collected at random sites throughout the creek for timing purposes, and lead to the conclusion that four study sites could be adequately analyzed. The study region was divided into four study sites (Fig. 1), from which samples were from January 2005 until April 2005. The study sites were located near street

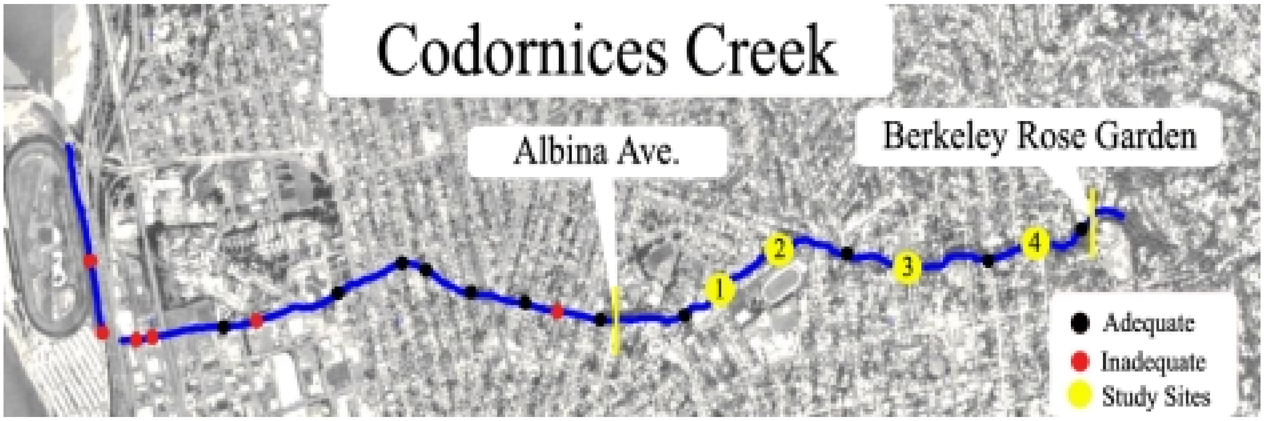

Figure 1. Location of study Sites 1, 2, 3 and 4.

intersections of Colusa Ave., Milvia St., Shattuck Ave., and Oxford St. and Codornices Creek (Fig. 1). The data collection for this study included 10 weekly samples, in order to gather enough samples to do an accurate statistical analysis, and due to the time restrictions of the ES 196 course (Latto 2004, pers. comm.).

Sampling sites were selected from areas of Codornices that the Kier study determined to have adequate spawning substrate, and from within the region of Codornices between Albina

Ave. and the Berkeley Rose Garden (LOCCNA 2003). Within these areas, four sampling pools were selected by visual inspection for size, depth, canopy cover, with limitations imposed by private property restrictions. Permission to enter private property was given for study Sites 1 and 2 by property owners. The four pools were chosen because they contain the great potential habitat, and are within the area the Kier study determined to have the potential of supporting a large population of steelhead (LOCCNA 2003). These four pools were not chosen to be representative of all the pools within each of the four sampling areas. The number of sampling sites was chosen to be four due to restrictions in availability of testing resources and equipment provided by the UC Berkeley Environmental Sciences Teaching Program (ESTP).

Water quality data was collected using a colorimeter and a multimeter. At each site, a multimeter was used to measure pH, dissolved oxygen, turbidity, water temperature, salinity, and electrical conductivity. A colorimeter was used to measure nitrates, phosphates, and chlorine levels. Each of the measured parameters has set ranges necessary for healthy fish environments, and whether the measurements lie within the set ranges is important in determining the capability of the creek to support fish populations (US EPA 2004). These parameters can affect various steelhead activities and characteristics, including spawning, feeding behavior, and body size (Dunham *et al*. 2004). Acceptable levels and guidelines for each measurement were determined through review US EPA guidelines, and a comprehensive review of relevant scientific literature (US EPA 2004).

In addition to water quality testing, a habitat assessment, which entailed measuring water velocity, pool depth, pool width, general pool shape, and noting qualitative aspects of the habitat, was used to determine the spawning area(s) in the upper reaches of the creek which are the healthiest and demonstrated the greatest consistency in water quality.

Of the parameters tested, water temperature, dissolved oxygen, and stream depth and velocity were the focus of the data analysis for the reason that they produced results that when combined with the data from the Kier study led to specific recommendations for trout restoration of Codornices, and are important characteristics in determining adequate trout habitat (Scarnecchia and Spangler 2001). Water temperature is important to trout spawning in that it dictates the length of time the eggs take to hatch. In temperatures that are below optimal, embryos have less of a chance of hatching, and in temperatures that are above optimal, embryos can hatch too soon, and have lower survival rates (NCRCD 2004). In addition, warm water temperature lead to lower levels of dissolved oxygen. Dissolved oxygen is the amount of oxygen suspended in the water, and is important for fish respiration. Stream depth can affect temperature in that deeper pools usually display cooler temperatures. Water velocity determines the amount of dissolved oxygen reaching the eggs during the spawning period. Velocities that are below optimal do not allow adequate amounts of oxygen to reach eggs, and velocities that are above optimal can lead to fatigue and death of juvenile trout.

Once the data was collected from the four sampling areas, a statistical analysis of the water quality combined with habitat assessment data were used to explore the three goals of the study. An analysis of the effect of precipitation on the measured parameters using linear regression statistics was carried out to determine the correct statistical analysis needed to note correlations between parameters. An analysis of variance test (ANOVA) was used to analyze the correlation between parameters. A linear regression test was used to determine the average and standard error for each measured parameter for each of the four sites. The data was then checked to verify if the measurements were within ranges acceptable for trout habitat. The sites with smaller standard errors were considered to show greater consistency. The consistency data combined with quantitative and qualitative data from the habitat assessment were used to determine the most favorable site for trout populations, and specific recommendations for restoration.

Results

The potential of correlation between each parameter and precipitation measurements from 24, 48 and 72 hour periods prior to the day of testing was assessed for each of the four study sites. Precipitation data was obtained from the University of California Agriculture and Natural Resources Integrated Pest Management website (UC IPM 2005). A linear regression analysis revealed that pH, electrical conductivity, dissolved oxygen, water temperature, salinity, stream depth, and nitrate parameters could not be correlated with precipitation (R^2 less than 0.25). The 24-hour and 48-hour precipitation for Site 1 was correlated with turbidity (24-hr: $R^2 = 0.66$, $P = 0.007$; 48-hr: $R^2 = 0.79$, $P = 0.001$), and the 72-hour precipitation with velocity measurements ($R^2 = 0.57$, $P = 0.02$). Water temperature and dissolved oxygen could not be correlated for any of the four study sites ($R^2 = 0.38$, $P = 0.001$).

Time series data for stream temperature (Fig. 2), depth (Fig. 3), velocity (Fig. 4), and dissolved oxygen (Fig 5.)—dissolved oxygen data for test week seven was not collected because the testing equipment was out for service and not available for use:

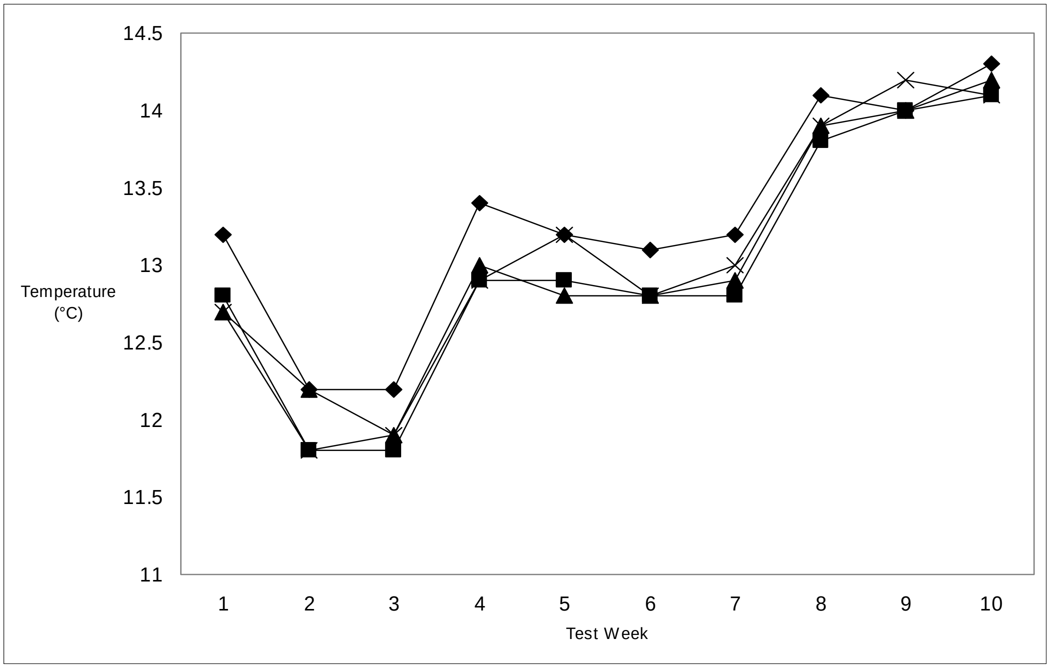

Figure 2. Temperature time series. Site 1: ◆. Site 2: ■. Site 3: ▲. Site 4: ✕.

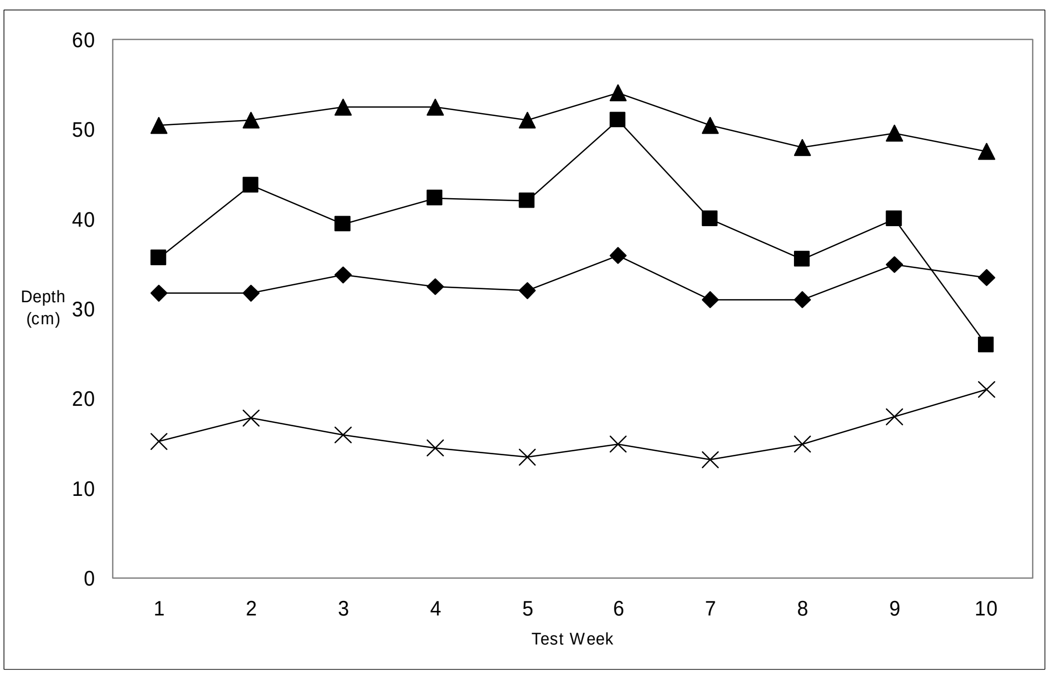

Figure 3. Depth time series. Site 1: ◆. Site 2: ■. Site 3: ▲. Site 4: ✕.

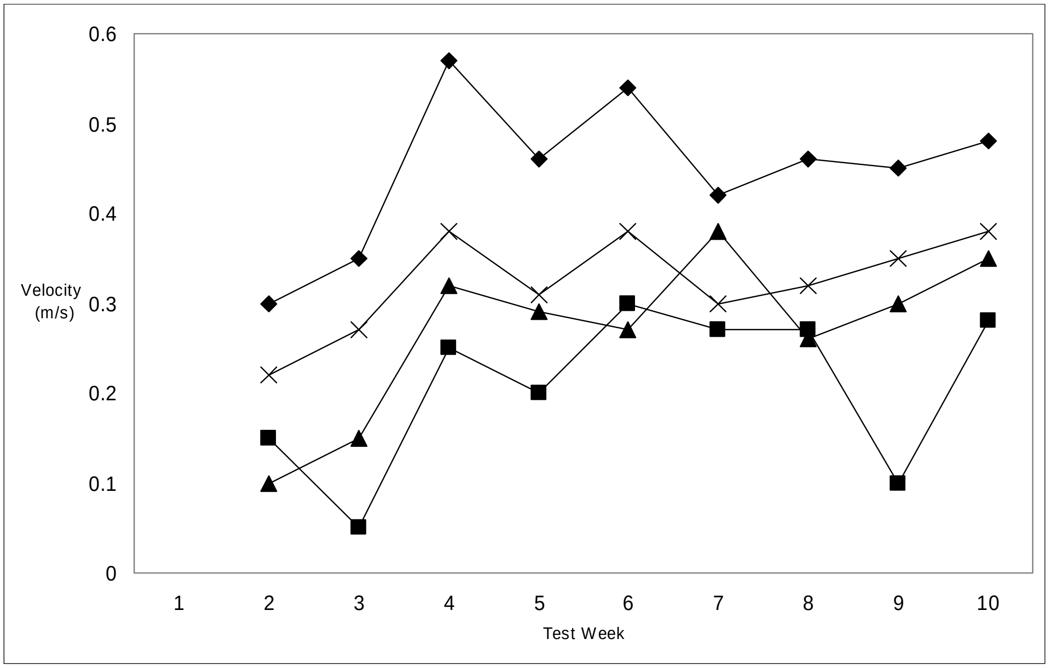

Figure 4. Velocity time series. Site 1: ◆. Site 2: ■. Site 3: ▲. Site 4: ✕.

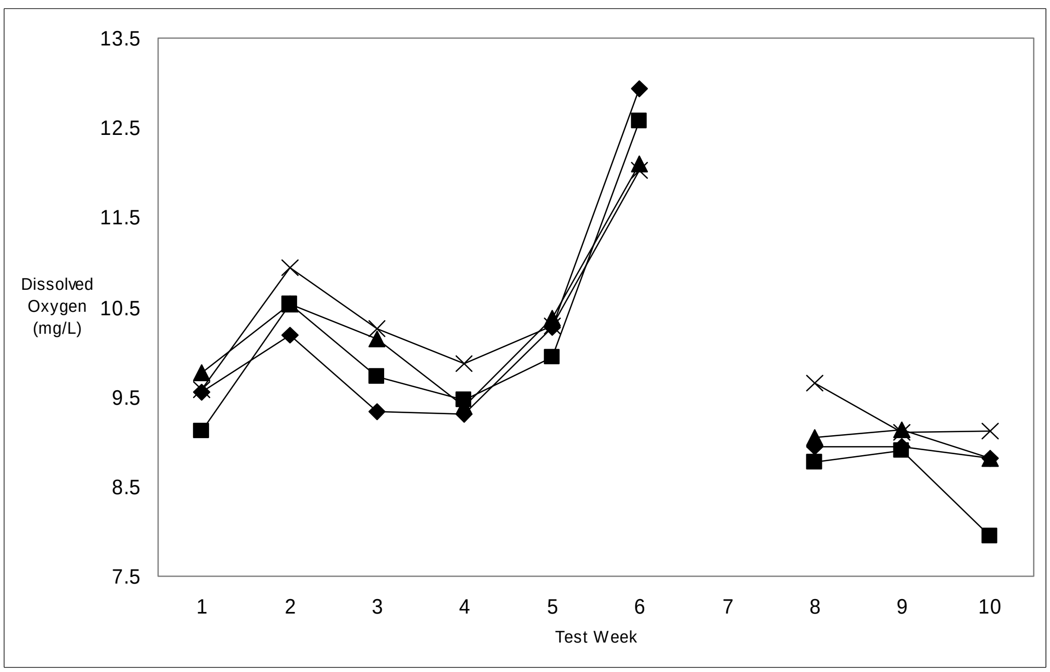

Figure 5. Dissolved oxygen time series. Site 1: ◆. Site 2: ■. Site 3: ▲. Site 4: ✕.

Site 1 showed the greatest consistency in temperature (SE 1.9%), and stream depth (SE 1.6%). Site 2 had the most consistent nitrate readings (SE 25%), and the least consistent dissolved oxygen readings (SE 4.6%) (Fig. 9), and stream depth (SE 5.2%) (Fig. 2). Site 3 didn't show superior consistency for any of the measured parameters, and had the least consistent stream velocity (SE 11.2%) (Fig. 8). Site 4 demonstrated the greatest consistency in dissolved oxygen (SE 3.1%) (Fig. 9), and stream velocity (SE 5.7%) (Fig. 3), but the least consistency in turbidity (SE 21%), and temperature (SE 3.1%) (Fig. 6).

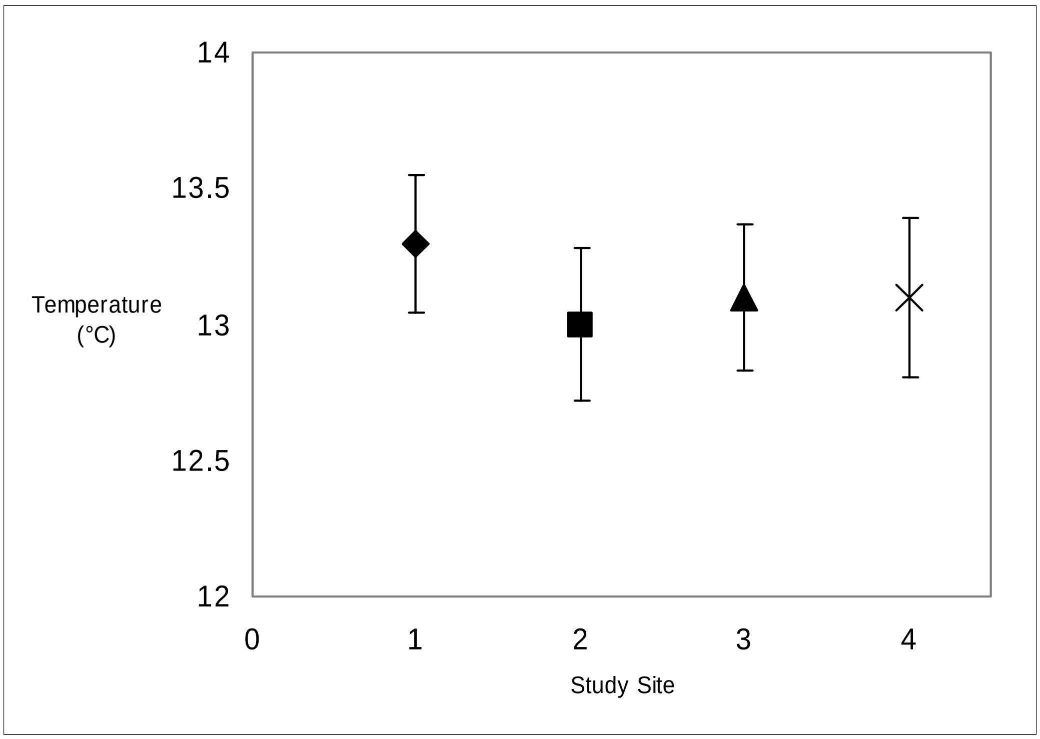

Figure 6. Average temperature. Error bars indicate +/- 1 SE.

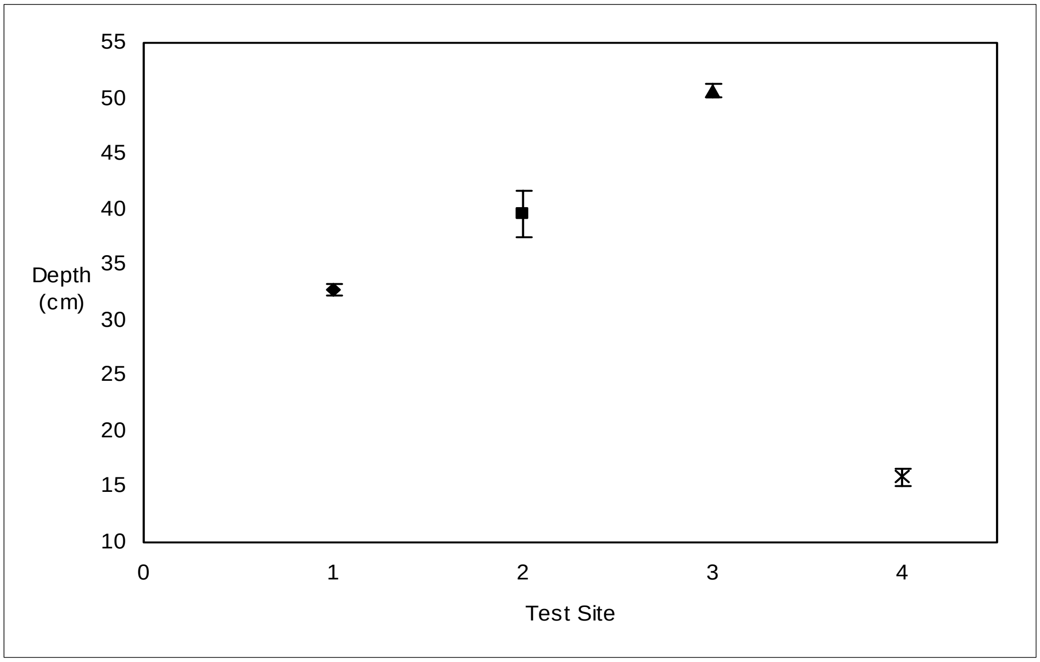

Figure 7. Average depth. Error bars indicate +/- 1 SE.

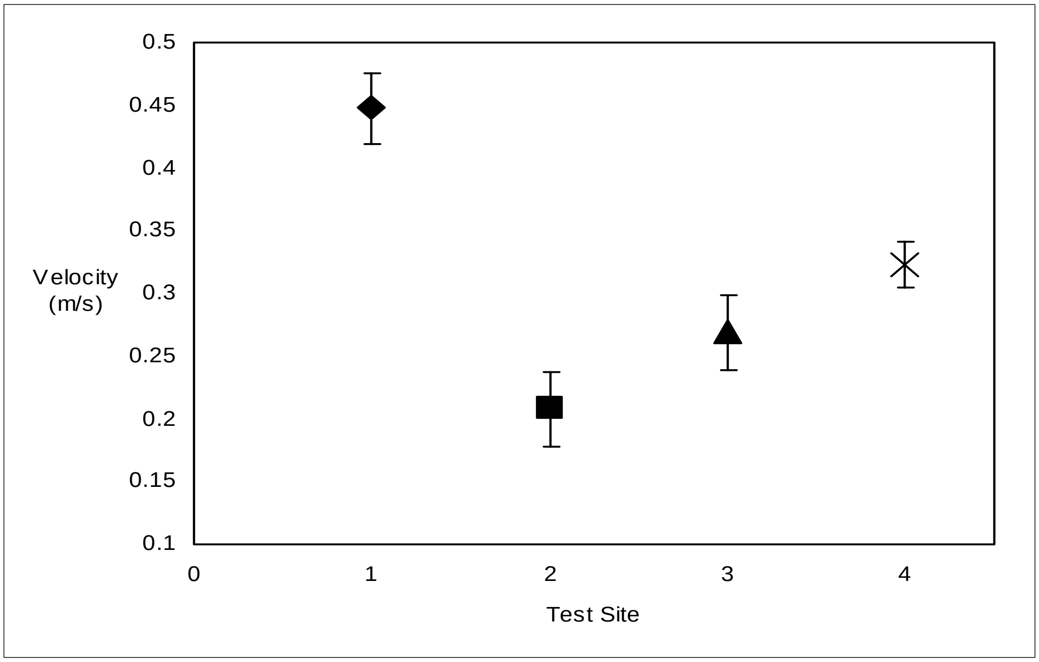

Figure 8. Average velocity. Error bars indicate +/- 1 SE.

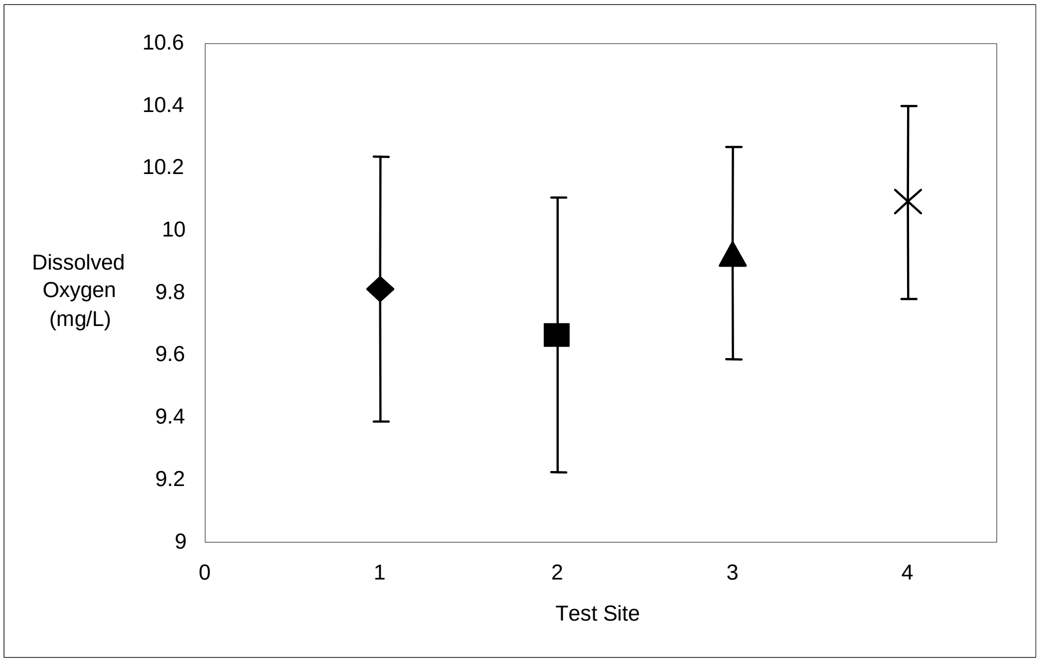

Figure 9. Average dissolved oxygen. Error bars indicate +/- 1 SE.

Discussion

Temperature As the season evolved from winter to spring (January to April), all four test sites appeared to follow the general climatic temperature trend of the area, by showing a gradual increase in water temperature (Fig. 2). This warming trend agreed with the data from the Kier study, where water temperature was reported to increase throughout the summer months, until reaching a maximum temperature of close to 18°C in October of 2003 (LOCCNA 2004). Water temperatures reaching 13°C and above during periods of trout spawning can reduce fertilization and decrease embryo survival rates, therefore reducing the potential for steelhead populations to develop (Kolmes and Richter 2005). Optimal spawning water temperatures range within 10°C and 13°C (US EPA, 2004, Kolmes and Richter 2005). Figure 2 shows the water temperature of Site 1 to increase beyond the upper limit of 13°C beginning on test week four, and continuing to increase throughout the rest of the testing period. Site 4 rose above 13°C on test week five, and then again from test week seven onward. Test sites 2 and 3 both rose above the optimal range during test week 8, and continued to increase throughout the testing period.

In California, steelhead trout spawning typically lasts from December to May, and eggs take an average of 30 days to hatch after fertilization given optimal conditions (NCRCD 2004). According to the temperature data from this study, current spawning that takes place during the beginning of the spawning season (approximately December to early January) will be in water temperature conditions that are favorable for embryonic growth and early development (between 10 and 13°C). The remainder and majority of the spawning season (from mid January until May), conditions will be above 13°C and unfavorable for spawning. According to the data from the Kier study, water temperatures during the mid summer months will exceed the 16.7°C lethal limit for developing embryos (Cech and Myrick 2004, LOCCNA 2004).

Comparing the optimal and lethal limits from the literature to the measurements of water temperature from Codornices would lead to the conclusion that Codornices is unfit to support trout spawning for the majority of the trout spawning season. However, trout populations still exist throughout the lower reaches of the creek. The contradiction between expected low survival with temperature measurements from this study, and the current presence of steelhead in the creek can only be resolved through further research of Codornices. The data from both this study and the Kier study provide important information for the restoration of trout in the upper reaches, yet further research that considers all the results from both studies is necessary.

Depth The pool depths of all four study sites are below the minimum depth of two feet (60.96 cm) that the Kier study reported (in accordance of California Department of Fish and Game recommendations) to be adequate for the primary pools throughout Codornices (LOCCNA 2004). Despite having the smallest average depth throughout the study period (Fig. 7), Site 4 showed a similar warming trend in water temperature as in the other three, deeper test sites. This was not expected, as shallow pools with smaller volumes of water tend to show less buffering capability against rises in air temperature, and therefore show greater increases in water temperature in comparison to deeper pools. Differences in canopy cover could be a possible explanation for the discrepancy in water temperatures, although this study did not collect data to justify the water temperature at Site 4.

Sites 1, 3 and 4 maintain consistent depths throughout the study period (Fig. 3). Site 2 showed the greatest variation in depth (Fig. 7), possibly due to a storm event between test weeks nine and ten, causing a drastic increase in sedimentation in the area. The depth of Site 2 decreased nearly to 40% (Fig. 3), and such drastic changes in habitat conditions are not favorable for spawning. The sedimentation of the study sites decreases the capability of the area as spawning habitat, as the additional sediment would greatly decrease (if not complete eliminate) the amount of oxygenated water reaching developing embryos in the stream bed. Changes in stream bed height as in Site 2 are usually due to stream bank erosion sites upstream of the site of sedimentation, although this study did not locate the cause of the change. In addition, increases in fine sediment from bank erosion can lead to other undesirable changes, such as decreases in growth rates of juveniles, decreases in food availability, and increases in activity (Levine *et al*. 2003). The data from Site 2 does stresses the importance of locating current and potential erosion sites throughout Codornices. The Kier report did note various erosion sites, however, the report the study produced did not state the specific locations of all the erosion sites. There is potential for new erosion sites to arise over time, and there is a need to continue monitoring for erosion sites throughout the creek to ensure stable pool depths and consistent habitat for steelhead.

Velocity and Dissolved Oxygen It is difficult to develop a numeric value for optimal water velocities for steelhead spawning, as numerous other pool characteristics both contribute to and are influenced by stream velocity. Examples of pool characteristics that influence velocity include: steep stream beds tend to promote greater stream velocities; wide, shallow streams generally lead to slower stream velocities; deep, narrow streams have higher velocities; number and frequency of large substrate capable of obstructing stream flow can lead to decreases in stream velocity. Stream velocity affects dissolved oxygen levels in that higher levels of dissolved oxygen are generally present in fast-moving streams (US EPA 2004). According to the US EPA Office of Water (2004), maximum dissolved oxygen concentrations should be between 10.52 and 10. 29 g/mL for stream with water temperatures between 13°C and 14°C. Figure 6 shows the average temperatures of the four study sites to be within 13°C and 14°C. However, dissolved oxygen levels are slightly below the maximums estimated by the US EPA (Fig. 9). The difference does not lead to the conclusion that dissolved oxygen levels are inadequate for trout spawning, but does lead to speculation that increases in stream velocity could lead to dissolved oxygen levels approaching the maximum estimated by the EPA. However, a linear regression analysis showed that water temperature and stream velocity could not be correlated (R^2 = 0.38, P = 0.001), ruling out this speculation. Water temperature influences dissolved oxygen in that lower water temperatures allow for greater concentrations of dissolved oxygen, which again demonstrates the need for cooler water temperatures for trout restoration.

Highest Quality Habitat Study Site 2 varied the most in dissolved oxygen levels and stream depth. The depth of Site 2 showed parallel variation to the other sites up until test week 6, when the depth began to steadily decrease. The depth reached a low of 26 cm between test week nine and ten. Site 2 was not considered the highest quality habitat for several reasons. First, there was inconsistency in depth and dissolved oxygen levels. Second, there were poor qualitative characteristics such as murky water color on test weeks four, five, and eight. Lastly, there was a strong sewage odor on test weeks four and five, which did not correlate to increased phosphorus, but which nevertheless, was considered to be unacceptable.

Larger volumes of water are more capable of buffering against changes in temperature, as more energy (or greater increases in temperature) is required to increase water temperature. Site 4 has the smallest depth and least volume of water available to buffer against changes in the water temperature (Fig. 3 and 7). The lack of buffering capability will most likely result in an increase in water temperature well beyond the acceptable maximum weekly average for embryo spawning of 13°C (US EPA 2004). Further temperature monitoring is recommended to determine whether the increase in water temperature continues into the summer months. The shallow depth combined with the least consistency in turbidity, temperature, and nitrate levels prevented Site 4 from being the most favorable habitat for trout populations.

The average water temperature for study Site 1 was the greatest from the optimal spawning temperature range of 10°C to 13°C (Fig. 6). Its depth was well below the two foot minimum stated in the Kier study, and dissolved oxygen levels were low. Site 3 was the closest of the four sites to reach the minimum depth requirements stated in the Kier study. Despite not showing greater consistencies, test Site 3 appeared to be the site that would be most favorable for trout spawning.

After analyzing the data, the upper regions were not suitable for trout populations in terms of water temperature and pool depth. Site 3 had the slightly higher quality of habitat, but no area showed very consistent characteristics. All four sites have characteristics that are unfavorable for steelhead spawning. It is recommended that further research be conducted before attempting to introduce trout to the upper reaches, as water temperatures and pool depths are not currently favorable for steelhead spawning for any of the four test sites, and could become lethal during the mid summer months.

Specifically, further research into the temperature and depth measurements in the areas of the stream that the existing trout populations inhabit and have chosen as spawning pools would assist in determining the conditions that the current populations are able to survive in. These conditions can then be compared to the remaining habitat throughout the creek to determine if there are other sites with similar depth and temperature characteristics. Hypothetically, the current trout populations could be concentrated in the deepest (greater depths usually lead to cooler temperatures) pools in the lower reaches, which as the data from the Kier study shows, is quite limited, especially in the upper reaches (LOCCNA 2004). In this case, trout populations would not survive in the upper reaches and deeper pools would need to be created before trout populations were introduced. Specific data to determine the habitat characteristics and preferences of Codornices' current steelhead population will be necessary to completely analyze the potential of the upper reaches as both spawning grounds and adult habitat.

Research that examines the survival rates of the embryos in the spawning pools of the lower reaches is also necessary. Once the locations and preferences of the current populations are known, survival rate data would indicate if, under current conditions, the trout populations are struggling to survive or flourishing. Low survival rates in the lower reaches would likely lead to even lower rates in the upper reaches where habitat is not as optimal as the lower reaches (LOCCNA 2004).

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