Water Quality Parameters and the Distribution of the Three-spined Stickleback in Strawberry Creek

Yung Ouyang

Introduction

Major efforts to improve the water quality of Strawberry Creek on the campus of the University of California at Berkeley were put into effect beginning in the mid-1980s under the Strawberry Creek Management Plan (Charbonneau, 1991, pers. comm.). Those involved in the project believed that a clean and restored Strawberry Creek, reflecting its own pristine state as much as is currently feasible, would improve the quality of life in the campus community. Therefore, they also decided to reintroduce fish native to the East Bay into the Creek. In May of 1989, 100 three-spined sticklebacks (*Gasterosteus aculeatus*) were reintroduced into Strawberry Creek as a part of a restocking project (Charbonneau *et al.*, 1990). And so after a 50-year absence, fish were again seen swimming in the pools of the Creek.

Those involved in the project have periodically added more and more fish into the Creek to increase their numbers and have also taken regular fish counts since 1989. The collected data show that sticklebacks have spawned several generations in the Creek. As a top predator, it is on the highest level of the food chain in the aquatic ecosystem of Strawberry Creek, so that its current condition indicates the water quality of the Creek throughout all ecological levels. However, other fish species native to the East Bay, such as the rainbow trout (*Salmo gairdneri*), are more sensitive to water quality than the sticklebacks. To determine whether Strawberry Creek is ready for the reintroduction of more sensitive fish, an assessment of whether or not the water quality, physical, and biological parameters are acceptable must be conducted, and necessary changes made.

Creeks are usually chemically well-buffered and well-oxygenated because they flow over varied substrates. Therefore, it is difficult to find strong correlations between chemical factors and fish distribution patterns, except under extreme conditions or where the creek has been heavily polluted (Moyle *et al*, 1982, p. 400). Extreme drought conditions have existed in California for the last five or six years. The object of this project is to study how the various water quality parameters of the Strawberry Creek affect the distribution of the three-spined sticklebacks. Parameters examined were water temperature, salinity, dissolved oxygen, pH, and ammonia content. Although the general water quality of the Creek should be high enough to support the sticklebacks (because of the water quality improvements), the goal of this project is to determine whether there are any differences in water quality parameters between pools with fish and pools without fish, as well as how many fish live in each of these pools. This research will hopefully give an understanding of which parameters need to be improved in order to better the condition of the fish and encourage a higher population.

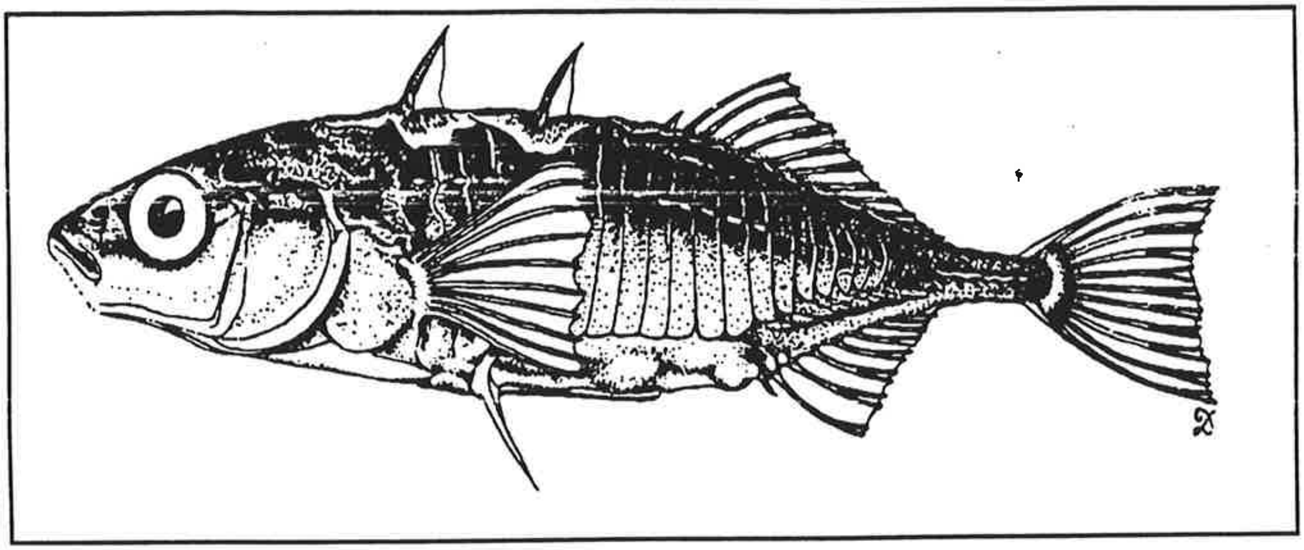

Figure 1. The Three-spined stickleback (*Gasterosteus aculeatus*).
Source: Wootton, 1984.

Past Studies

Din (1991) studied the water quality of Wildcat Creek in order to assess whether or not it was ready for the reintroduction of the unarmored three-spined stickleback, *G. a. williamsoni.* The parameters that he measured were temperature, pH, dissolved oxygen, total dissolved solids, ammonia, hardness, and salinity. He concluded that there were no reasons why the fish could not be reintroduced since the water quality of Wildcat Creek met the requirements of the fish. His study describes how various water quality parameters related to the biology of the three-spined stickleback.

A study which correlated populations of sticklebacks in different pools of Strawberry Creek with various physical parameters was conducted by Fiorillo (1990). The parameters measured were temperature ranges, substrate composition, flow rates, cross sectional, and longitudinal surveys. Fiorillo concluded that the stickleback "prefers pools that are not very deep and possess a predominantly gravel substrate with a smooth gradient" and higher flow rates (Fiorillo, 1990, pp. 4-5). Temperature was not found to be a predominant factor in the location of the fish. This study suggests where sticklebacks are most likely to be found in Strawberry Creek. My study is concerned with the chemical nature of the water in the Creek, and how that determines where the fish are found. By combining the results of his study and mine, a more comprehensive understanding of why the sticklebacks are found in certain parts of the Creek and not others will be obtained.

In *The Biology of Sticklebacks* (1976) and *A Functional Biology of Sticklebacks* (1984), Wootton summarized his own research, and also the research of other ichthyologists, on the biology of the different varieties of sticklebacks, including their physiology, reproduction, habitat, and distribution.

Background

The water quality parameters affecting the three-spined stickleback measured in this study are: temperature, salinity, oxygen content, pH, and ammonia content. Wootton (1984) believes that in any environment, the most important abiotic environmental factors affecting the sticklebacks' survival, metabolism, and reproduction are temperature, salinity, and oxygen content. Although each of these factors directly affect the stickleback, combinations of them also have synergistic effects greater than the sum of their individual effects.

The Creek's location in an urban setting makes it particularly vulnerable to pollution from man-made sources, examples of which include sewage, oil, and heavy metals that may be washed into the Creek by runoff from the surrounding streets. Such pollution can adversely affect the sticklebacks by changing the natural dissolved oxygen content, the temperature, and/or the salinity, or they can have direct effects on the stickleback. For example, sewage in the Creek may indirectly affect the sticklebacks by causing a decrease in dissolved oxygen (an increase in algal and bacterial growth results in less dissolved oxygen in water) or directly affect the fish by exposing them to diseases. There are numerous chemical factors that are indicative of pollution, and they are too many to be measured considering the scope of this study and the equipment available. Therefore, pH and ammonia content are measured as indicators of the potential presence of pollutants.

Ranges of the water quality parameters critical to the three-spined stickleback are presented in Table 1. These ranges are defined by the LD_{50}, the level of the factor that causes the death of 50 percent of a population in a definite time period. Water temperatures greater than 25°C (the LD_{50} limit) cause mortality, depending on the salinity levels and the acclimation temperature (that is, the temperature the fish has adapted to before it encounters that level); but there are no data on the effects of very cold water (Wootton, 1984, pp. 64-65). Sticklebacks can exist in water with oxygen concentrations as low as 0.25-0.5 ppm, although normal active life is not possible (Wootton, 1984, p. 67). The fish can tolerate a wide range of salinities, and its range of tolerance varies with temperature. This range can be defined to be between no salinity whatsoever and the LD_{50}, an absolute maximum of 40 ppt (just above full sea water) (Wootton, 1984, p. 65). Sticklebacks also tolerate water with a wide range of hydrogen ion concentrations. The critical range of pH (as described by LD_{50} tests) is between 5.8 and 11.4--water with a pH of 5.0 will certainly kill the fish (Wootton, 1976, pp. 102-103). As for ammonia, the upper tolerance limit was 2.1 mg/l. Its toxicity to the sticklebacks is dependent upon the salinity and temperature of the water; the fish were more resistant to ammonia poisoning at higher salinities and at lower temperatures (Wootton, 1976, p. 102).

LD_{50} values are not absolute determinants of how acceptable the water quality of the Creek is for the sticklebacks. As the above paragraph discusses, critical levels of these factors may be dependent upon each other. For example, the LD_{50} level of the temperature is dependent on the salinity level and the acclimation temperature, and the toxicity of ammonia is dependent on the salinity and temperature of the water. Furthermore, synergistic combinations of the temperature, dissolved oxygen content, and salinity determine how the fish's metabolism functions. For example, temperature generally governs the metabolic rate of the fish, but at very low oxygen levels, the metabolic rate of the sticklebacks is less than that allowed by the temperature. Moreover, high salinity levels exert an additional metabolic demand on the fish. The impact on sticklebacks of such changes in water quality include diversion of energy away from growth, feeding, or reproduction to metabolic maintenance. If enough energy is diverted from reproduction, the populations may become unviable. Therefore, these water quality factors may have effects on the fish, even if each of the factors are within the critical ranges as defined by the LD_{50} tests. However, as there are no other benchmarks readily available, the LD_{50} values are nevertheless used even though they may not be the best benchmarks indicating the suitability of the water for the stickleback.

Parameter	Critical Range as detected by LD_{50} tests
Temperature	< 25°C (no data on lower limit)
Salinity	0 - 40ppt
Oxygen	> 0.25-0.5ppm
pH	5.8 --11.4
Ammonia	< 2.1 mg/L

Table 1. Ranges of water quality parameters critical to the three-spined stickleback.
Sources: Wootton, 1976, 1984.

The presence of sticklebacks in Strawberry Creek does indicate that lethal levels of any of the parameters are not likely to be found in those parts of the Creek. However the fish are not present throughout the Creek. Are fish absent because lethal levels have been reached in those parts? Or are they absent because combinations of the factors, even though they may not be lethal, are affecting the metabolism of the fish? Or are they absent because of other reasons not related to water quality? These are the questions that I will attempt to answer.

Methodology

The basic steps to determine if a correlation existed between the various water quality parameters and the fish populations in Strawberry Creek were: 1) identify locations of fish in Strawberry Creek, 2) practice fish counting, 3) randomly pick pools without fish, 4) roughly measure physical characteristics of the pools and note down particular descriptive details, 5) count the fish, 6) measure the water quality, and 7) analyze the data.

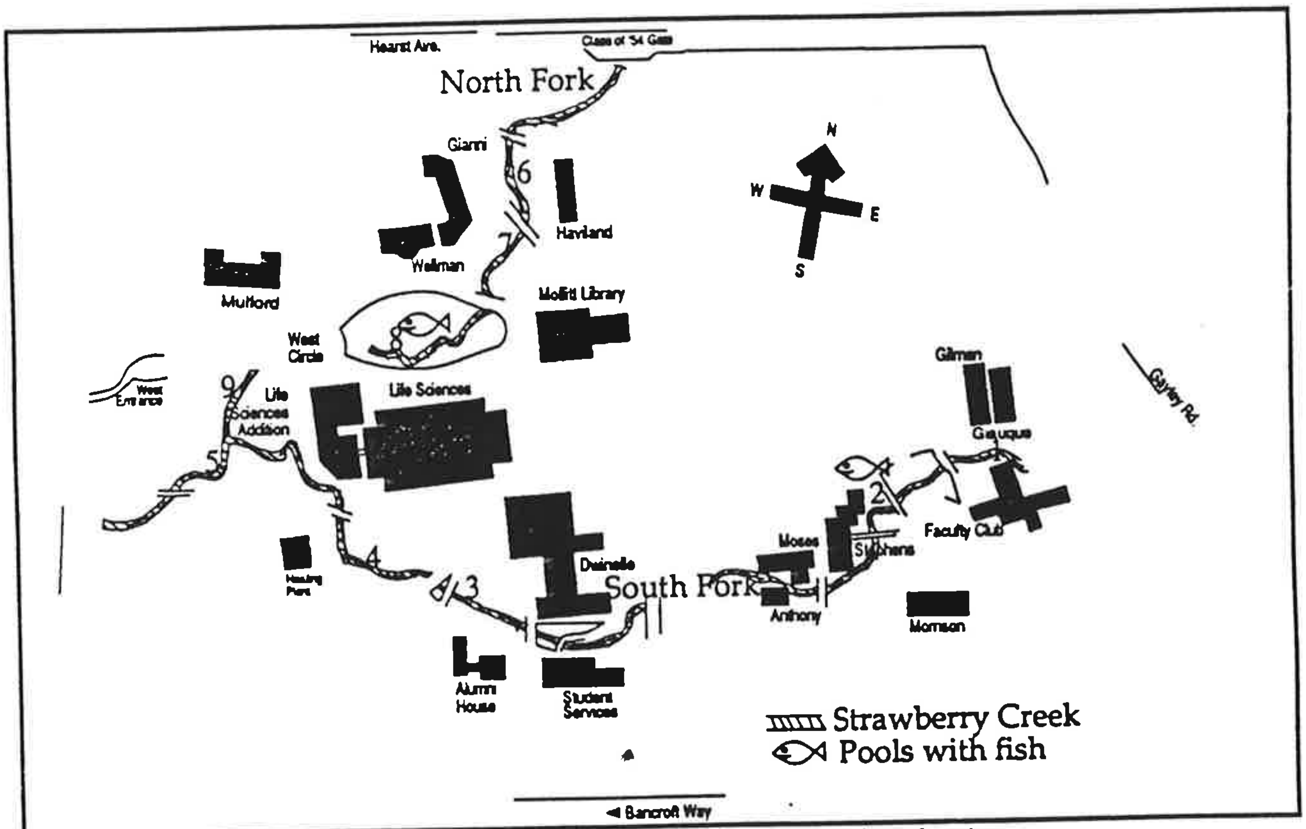

Figure 2. Strawberry Creek on the University of California at Berkeley, showing sites of pools.
Source: Berkeley Publications, 1991

Choice Of Testing Sites: The initial creek walks to document sightings of sticklebacks revealed that there was a scarcity of fish in Strawberry Creek. In fact, only three pools of the Creek had sticklebacks in them: Pool 2 and Pool 3 on the South Fork of the Creek, and Pool 8 on the North Fork (Fig. 2). These three pools were used in my study, and six other uninhabited pools were randomly picked for comparison to the three inhabited ones, for a total of nine pools. Random selection was accomplished in the following manner. A number was assigned to each of the pools of the Creek where fish were absent (not the numbers that are currently used to label the pools). Afterwards, a random number generator was used to generate six numbers, and the pools that corresponded to those six numbers are the pools that were used in my study (in addition to the three with fish). The other six pools randomly chosen are: Pool 1 and Pool 4 on the South Fork, Pool 6, Pool 7, and Pool 9 on the North Fork, and Pool 5 downstream from where the North Fork and the South Fork meet (Figure 2). Pools depicted in Figure 2 with a fish symbol were inhabited; those without were randomly selected.

Qualitative and Quantitative Habitat Measurements: In addition to the quantitative analysis of the water quality and fish population in each pool, qualitative data on the habitat of each pool were collected. Information on pool size, depth, current flow rate, percentage canopy, and substrate composition were also recorded. Percentage of canopy cover was estimated by eye, and the flow rate was calculated after measuring how long it took a disk to travel a specified distance in the pool (the specified distance differed from pool to pool according to the length of the pool). The characterizations of substrate composition as sand, gravel, pebble, cobble, and boulder were adopted from Fiorillo (1990, p. 2).

Sampling Times: All data were taken during February of 1992, during the high flow season. Water quality parameter measurements (or the taking of water samples) and fish counts were conducted once per pool, at the same time in each pool, and at approximately the same time of day for every pool, between 10 AM and noon. Weather conditions during the study were also recorded.

Water Quality Parameter	Method (from APHA, 1985)
temperature (°C)	mercury thermometer (pp. 126-127)
pH	portable pH meter (pp. 429-437)
dissolved oxygen (ppm)	iodometric method (azide modification) (pp. 416-419)
ammonia(mg/L)	automated phenate method (pp. 388-390)
TDS (ppt)	conductivity/TDS meter (pp. 76-80,101-102)

Table 2. The tests performed and their methods.
Source: APHA, 1985.

Fish Counting Method: The method of sight counting used was the Sights Per Unit Effort (SPUE) method, in which each pool of the Creek was observed for a period of twenty minutes "to ensure that each pool was given an equal amount of effort when determining if fish were present"

(Fiorillo, 1990, p. 9). Sight counting was the method undertaken because it required no special equipment (or authorization to use such equipment) and does not harm the fish.

Water Quality Testing Methods: All water quality measurements were made according to *Standard Methods* guidelines (APHA, 1985). They were all made on-site, with the exception of the ammonia test, which was done in a laboratory with samples stored in a plastic bottle and preserved with concentrated sulfuric acid. The samples were put in a freezer in the laboratory soon after they were taken, as the laboratory is on the campus where Strawberry Creek is located. A Conductivity/TDS meter was used to measure total dissolved solids; salinity and total dissolved solids are nearly equivalent in low concentrations (Hach, 1988, pp. 3-4). Table 2 indicates which methods were used.

Data

During the actual data collection, sticklebacks were sighted in only two of the three pools in which I initially saw fish. Seven fish were found in Pool 2 and 10 were counted in Pool 8 (Table 3). The lowest temperature out of all nine pools was also found in Pool 2, but the pool's values for the other water quality parameters were all near average. This pool was also somewhat shallow, with a depth of only 0.46 m, but it otherwise did not show extremes in any of the other physical parameters (Table 4). A part gravel and part pebble substrate composition was found in this pool. In contrast to Pool 2 is Pool 8, in which the lowest pH (7.83) and the highest ammonia content (1.09 mg/L) were also found. This pool also had a comparatively high temperature (15.9°C, only 0.1°C lower than the highest temperature measured on the Creek), a relatively low TDS value (0.195 ppt), and a comparatively low DO content (6.32 ppm). Pool 8 had a gravel substrate, and it also showed extremes in several physical characteristics: its canopy cover was 10 percent (the lowest out of all nine pools), and its depth was 0.36 m (the most shallow out of all nine pools). Even though this pool had such extreme values for all the parameters, it nevertheless supported sticklebacks.

The average pH for all the pools is 8.14, with a range of 7.83 (Pool 8) to 8.29 (Pool 5). Although the pH scale is a logarithmic one, the range between the highest and lowest pH values is still very small, with a difference of only about 9.66×10^{-9} M of H^+ ion concentration. In addition to pH, Pools 5 and 8 strongly contrast with each other in many of the other parameters. For example, a temperature (13.5°C) low in the range measured in Strawberry Creek was found in Pool 5, while a high temperature (15.8°C) was measured in Pool 8. The second lowest DO concentration (6.32 ppm) was measured in Pool 8, and a comparatively high one (8.48 ppm) was found in Pool 5. Furthermore, the highest ammonia content (1.09 mg/L) was found in Pool 8, while a very low one (0.17 mg/L) was recorded from Pool 5. A high pH is usually associated with a high ammonia content, so Pools 5 and 8 are unusual in that they do not observe this trend. With such extreme values of the parameters measured in Pool 8 (values that are much closer to the limits set by the LD_{50} studies than those measured in Pool 5), it is expected that fish would not be found in there. However, this is not the case, as 10 sticklebacks were counted in the pool. Instead, no fish were found in Pool 5, where values farther from the LD_{50} limits (meaning better water quality) were measured. As noted in the previous paragraph, Pool 8 had a canopy cover that was also the lowest out of all nine (10 percent). In contrast is Pool 5, where a medium canopy cover of 60 percent was estimated. The flow rate in Pool 5 was also comparatively fast (4.62 cm/sec), faster than the flow rate of Pool 8 (2.08 cm/sec).

	temperature (°C) ± 0.1	pH (±0.01 pH units)	TDS (ppt) ± 0.001	DO (ppm) ±0.01	ammonia (mg/L) ± 0.01	fish count
Pool 1	15.7	8.24	0.421	7.08	0.24	0
Pool 2	12.8	8.09	0.218	7.96	0.34	7
Pool 3	13.3	8.23	0.217	8.84	0.03	0
Pool 4	13.9	8.20	0.182	7.28	0.00	0
Pool 5	13.5	8.29	0.186	8.48	0.17	0
Pool 6	13.9	8.11	0.287	8.28	0.12	0
Pool 7	13.6	8.13	0.256	8.52	0.03	0
Pool 8	15.8	7.83	0.195	6.32	1.09	10
Pool 9	15.9	8.11	0.264	6.08	0.81	0
mean	14.3	8.14	0.254	7.65	0.31	

Table 3. Water quality data and fish counts for Pools 1 to 9.

The average of the temperatures was 14.3°C, and this parameter ranged from 12.8°C (Pool 2) to 15.9°C (Pool 9), representing a difference of only 3.1°C. Seven fish were found in the cooler waters of Pool 2. Pool 2 had a DO concentration (7.96 ppm) that was higher than that of Pool 9 (6.08 ppm), and this corresponds to the temperatures, since a higher DO concentration means a lower temperature and vice-versa. Pool 2 (70 percent) also had a higher percentage of canopy cover than Pool 9 (40 percent), and this may be responsible for its lower water temperature. However, Pool 2 had a shallower depth (0.46 m in Pool 2 compared to 0.91 m in Pool 9), and this does not correlate with the trend in water temperatures, unless temperatures were cold outside of the pools when the measurements were taken.

The mean TDS value was 0.254 ppt. Pool 8, where 10 fish were sighted, had the lowest TDS concentration of 0.195 ppt, while Pool 1 had the highest of 0.421 ppt (a difference of only 0.226 ppt). Pools with low TDS values tended to be of either a gravel or pebble substrate. Pools 2, 3, 4, 5, and 8 all had TDS values of less than the average of 0.254 ppt, and they were all of either a pebble or a gravel substrate. The other pools with higher TDS values were of either a predominantly boulder, cobble, or sand substrate (with the exception of Pool 9). Pool 1 was the only pool with a predominantly boulder substrate. There is no apparent correlation between TDS values and fish sightings.

	length (m)	width(m)	depth(m)	estimated canopy cover (%)	flow rate (cm/sec)	substrate composition
Pool 1	4.4	0.4	0.75	60	0.00	boulder
Pool 2	4.9	1.8	0.46	70	2.31	gravel & pebble
Pool 3	2.4	2.4	0.46	60	2.34	pebble
Pool 4	4.3	1.4	0.36	85	5.90	pebble
Pool 5	3.4	3.7	0.38	60	4.62	pebble
Pool 6	6.2	3.0	1.10	75	1.02	sand
Pool 7	4.0	2.1	0.76	75	1.02	cobble
Pool 8	6.2	1.4	0.36	10	2.08	gravel
Pool 9	12.2	2.4	0.91	40	4.77	gravel

Table 4. Physical characteristics of Pools 1 to 9.

For dissolved oxygen, the range was between 8.84 ppm (Pool 3) and 6.08 ppm (Pool 9), representing a difference of only 2.76 ppm. The mean was 7.65 ppm, not too far from the highest value or the lowest one. However, it is more significant to look again at the values found in Pools 5 and 8. The second highest DO concentration (8.48 ppm) was found in Pool 5, and this pool had no fish. In contrast, 10 sticklebacks were found in Pool 8, which had the second lowest DO concentration of 6.32 ppm. The opposite is expected, as fish are more likely to be found in Pool

5, and not Pool 8, since Pool 5 had a high DO concentration as well as a low ammonia content (0.17 mg/L). The highest ammonia content of the nine pools, 1.09 mg/L, was found in Pool 8.

Lastly, the lowest ammonia concentration was practically zero (Pool 4), and the highest level was found in Pool 8 (1.09 mg/L), with the average being 0.31 mg/L. Again, it is more helpful to compare Pool 8 with another pool, Pool 7, in which only 0.03 mg/L of ammonia was found. A high DO concentration (8.52 ppm) was measured in Pool 7, but this pool did not support any fish. And as mentioned above, 10 fish were counted in Pool 8, which had a low DO content. Pool 7 also had a more moderate temperature (13.6°C) than Pool 8. These differences between the two pools would cause one to expect fish to be found in Pool 7 and not Pool 8. However, this is not the case, and the opposite is true (10 fish were counted in Pool 8).

Discussion

All of the water quality values for each of the pools were well within the critical range for the three-spined stickleback (Table 1). The highest temperature of 15.9°C is well below the upper limit of 25°C. The highest salinity value does not even reach one part per thousand (with 40 ppt being the maximum tolerable to the fish). Likewise, the lowest dissolved oxygen concentration of 6.08 ppm is well above the minimum requirement of 0.25 to 0.5 ppm. Finally, even though the highest ammonia concentration of 1.09 mg/L can be considered to be approaching the upper limit of 2.1 mg/L, fish were sighted in the pool with this ammonia concentration.

From the above data, it is apparent that the water quality of Strawberry Creek more than meets the requirements of the three-spined stickleback. In fact, none of the water quality values measured are even close to the limits set by LD_{50} studies. The water quality of the Creek was so good that the two pools with fish had values on the opposite extremes of the temperature range measured on the Creek: Pool 2 had the lowest measured temperature, while Pool 8 had a temperature that was only 0.1°C lower than the highest temperature. Pool 8 also had the lowest pH, the highest ammonia concentration, and the second lowest dissolved oxygen content out of the nine pools, and it nevertheless supported 10 sticklebacks. In addition, gradients in each of the parameters do not appear to reflect a gradient in fish populations.

However, in both Pools 2 and 8, the ones where fish were found, the values for pH are the lowest out of all nine pools, suggesting that sticklebacks may prefer water with lower pH. Nevertheless, these trends are insignificant in relation to the distribution of sticklebacks, as the highest measured pH of 8.29 represents an H^+ concentration of 5.13×10^{-9} M, farther from the 3.98×10^{-12} M of the LD_{50} limit of 11.4 pH units than the pH of 8.09 (8.13×10^{-9} M H^+) found in Pool 2 with the seven sticklebacks. This presence of sticklebacks in Pool 2 and absence of sticklebacks in Pool 5 shows that the highest pH of 8.29 found in Pool 5 most likely is not affecting whether or not sticklebacks are found there.

Thus, there seems to be no correlation between the water quality of the Creek and the distribution of the three-spined sticklebacks. This may be attributed to the fact that the water quality is more than adequate for the sticklebacks. The distribution of the sticklebacks in the Creek is due to other factors, such as differences in the physical parameters and biological factors in different parts of the Creek. And in the case of Pool 3, where fish were initially sighted but were not found during the actual data collection, I suspect that they were washed downstream by the recent, heavy rains (of February 1992). They could not have moved to other parts of the Creek of their own choice, as they would have to jump over a check dam in order to move upstream and would have to fall off of another check dam in order to move downstream.

Conclusion

Although California has been in a state of drought, this extreme condition does not seem to cause the water quality parameters to affect the distribution of the sticklebacks, as would be the usual case. However, I suspected that the drought maybe somehow responsible for the small numbers of sticklebacks found in Strawberry Creek. The mechanism by which this is happening is unknown, if indeed the drought is responsible. Perhaps there is just less water so that there are fewer reaches of the Creek that are both deep enough for the fish and meet other requirements like food content, for example.

One thing is certain, though: restoration efforts have been successful, and the Strawberry Creek Management Plan has made the water quality of the Creek good enough for the sticklebacks. Perhaps, the implementation of the fish-restocking project should have been delayed until the drought is over, and a more comprehensive study of the effect of the drought on the Creek and its inhabitants should be conducted before the restocking project is continued.

Once an assessment of the effects of the drought on the Creek and its inhabitants has been conducted, a study of the effects of rain runoff on the Creek's flow rates and how that affects the fish should also be conducted. After all, what is the point of reintroducing fish into the Creek when they are easily washed downstream during the rains? Physical changes in the Creek need to be made to ensure that the fish have a refuge from the strong currents caused by runoff from rainfall. Furthermore, the effects of nonnative species, such as the mosquitofish (*Gambusia affinis*), on the native species should also be assessed, in addition to the studies that need to be conducted in order to determine whether or not Strawberry Creek fulfills the requirements of other fish species that are to be reintroduced in the future.

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