Groundwater Sources and their Influence on the Distribution of Steelhead in Topanga Creek, Topanga, California

by

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A thesis submitted
in partial fulfillment of the requirements
for the degree of Master of Science
Natural Resources and Environment
in the University of Michigan
August 2006

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Abstract

This study examined the effects of groundwater on the distribution of steelhead (*Oncorhynchus mykiss*) in Topanga Creek, a small coastal stream in Los Angeles County, California. Water quality was monitored in Topanga Creek and in surface discharge from 20 springs on a monthly basis from April to December 2005. Instream habitat mapping and monthly snorkel surveys were also conducted to determine whether steelhead preferentially selected habitat units with groundwater.

Sixteen percent of habitat units in the Topanga Creek study area received groundwater from known springs. For six out of the nine months of the study, significantly more trout were found in groundwater areas than would be expected by the frequency of such sites. The most likely reason for steelhead to select habitat units with groundwater during this study was differences in habitat between areas with and without groundwater. Habitat units with groundwater had characteristics that were more favorable for steelhead such as greater surface area, greater depth, and higher shelter value. Habitat units with groundwater may also have acted as refugia from high stream temperatures. While there was no significant difference between temperature of the creek and temperature of surface discharge from springs, deep pools were significantly cooler than shallow pools. Water quality in both the creek and springs was sufficiently good for trout throughout the study. These findings suggest that groundwater may play an important role in maintaining steelhead populations near the southern extent of their Pacific coastal range

Acknowledgements

Funding for this study was provided by the California Department of Fish and Game, Pacific States Marine Fisheries Commission, and the Resource Conservation District of the Santa Monica Mountains.

Thanks are due to many people who assisted in this project. Members of the Topanga Creek Stream Team and the staff of the Resource Conservation District of the Santa Monica Mountains assisted me with data collection and allowed me to use their data, equipment, and office space. Steve Duke and Rebecca Fusee of GeoPentech, Inc. helped in the field, shared lab data, and explained enigmatic geology diagrams. Jim Diana commented on drafts of this manuscript and allowed me to work independently on this project. Dave Allan helped in the final stages of revisions.

I would especially like to thank Rosi Dagit for her assistance at all stages of this project and for her excellent feedback on several drafts of this manuscript. Thanks also for your generosity and for booking my “world tour”.

Thanks to my family and friends for your love and support. I could not possibly list everyone here, but trust that your encouragements (and occasional distractions) are always appreciated.

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Introduction

Steelhead are the anadromous variety of rainbow trout (*Oncorhynchus mykiss*). Throughout their Pacific range, steelhead are iteroparous and exhibit several possible life history patterns (Shapavolov and Taft 1954, McEwan and Jackson 1996, National Marine Fisheries Service 1996). The large variation in life histories is an evolutionary response to the extremely variable environmental conditions in the small coastal streams used by steelhead for spawning (Taylor 1991, McEwan and Jackson 1996). In addition to resident rainbow trout and anadromous steelhead, there are two different life histories of anadromy in individual steelhead. Some individuals mature in the ocean before returning to streams to breed while others enter the streams before becoming mature (Shapavolov and Taft 1954, Taylor 1991, McEwan and Jackson 1996).

Anadromous adults enter the stream between December and April after spending one to three years in the ocean (National Marine Fisheries Service 1997). Although fall and summer spawning populations of steelhead also exist in other streams (Shapavolov and Taft 1954), the steelhead in Topanga Creek are a winter-run population (Dagit and Reagan 2006). Usually the first spawning is at three to four years of age. Fry hatch and swim up after approximately one month (National Marine Fisheries Service 1997). Juvenile steelhead spend longer in freshwater than most Pacific salmon, approximately one to three years (National Marine Fisheries Service 1996). Both eggs and juvenile fish do best in streams that are cool and well-oxygenated (Shapavolov and Taft 1954, McEwan and Jackson 1996).

The historic range of steelhead along the Pacific coast of North America is from Alaska to the California-Mexico border and possibly as far south as Baja California (Shapavolov and Taft 1954). Populations of steelhead occurring south of San Francisco Bay are referred to as southern steelhead (McEwan and Jackson 1996). Most sources identify Malibu Creek as the current southern extent of the range of southern steelhead but steelhead adults were rediscovered in Topanga Creek in 2000 (Dagit et al. 2003).

Many factors have contributed to the decline in steelhead populations throughout their range. Natural pressures on steelhead populations include highly variable rainfall, streamflow, and temperatures both on a yearly and seasonal basis (Nielsen 1999). Along with the already highly variable environment, anthropogenic influences negatively impact trout populations. In particular, diverting water for irrigation and residential use has severely limited streamflow in rivers where steelhead and other fish were once abundant (Moyle 1994, Nehlsen 1994, McEwan and Jackson 1996). Reduction in streamflow has made some areas inaccessible that were once important spawning and feeding grounds for steelhead. Habitat loss due to dam construction and river channelization are also major problems for steelhead populations (Nehlsen et al. 1991). Dams reduce access to potential spawning habitat upstream as well as alter temperature and flow regimes that are critical for the timing of spawning. Other human interferences such as over fishing and impairment of water quality also negatively impact steelhead populations (Moyle 1994, Nehlsen 1994). Steelhead populations in Southern California are under heavy pressure because a wide range of those factors occur together in this region.

There has been a rapid decline in steelhead numbers since the mid 1960s but populations of steelhead throughout their Pacific range have probably been declining for a much longer period of time (McEwan and Jackson 1996). Despite the long decline of southern steelhead, it was not until 1997 that the National Marine Fisheries Service (NMFS) listed many evolutionarily significant units (ESUs) of steelhead as endangered under the Endangered Species Act of 1973. Topanga Creek's steelhead population was added to the Southern California ESU (ESU 11) in 2002 when NMFS extended the southern boundary of the Southern California ESU to include the entire coast of Southern California (Dagit and Reagan 2006). In 2000, the NMFS designated critical habitat for steelhead as all Pacific coastal streams where steelhead are known to occur and their associated riparian areas. In some cases, NMFS designated critical habitat up to long-standing barriers such as dams, rather than to the headwaters of the streams, where there was historically no suitable steelhead habitat upstream of the dam sites (NMFS 2000).

Records from the 1910s to early 1960s indicate that Topanga Creek once supported a large population of steelhead and non-anadromous rainbow trout (Dagit et al. 2005). While the current population of steelhead in Topanga Creek is lower than the creek has historically supported, the population appears to be increasing since 2001 (Dagit and Reagan 2006). The Resource Conservation District of the Santa Monica Mountains (RCDSMM) has been monitoring steelhead populations with monthly snorkel surveys and habitat conditions in Topanga Creek since 2001. The goal of these studies is to collect data continuously on the status of the population of steelhead in Topanga Creek (Dagit and Reagan 2006).

Several studies have found that rainbow trout use areas of streams that receive groundwater as refugia from high temperatures during summer months (Nielsen et al. 1994, Matthews and Berg 1997, Ebersole et al. 2001, Baird and Krueger 2003). During dry years and dry periods such as late summer and early fall, lack of water and high temperatures can cause stress in steelhead populations. Droughts and water withdrawals are also important factors in the decline of steelhead in Southern California (Vadas 2000). The best recruitment of steelhead young occurred in above-average flow years, as higher flows maintain coldwater conditions and proper habitat for spawning and rearing in addition to allowing fish to move throughout the river (Vadas 2000). During periods of low stream discharge, trout may become trapped in deep areas that are isolated by surrounding shallow water. The minimum depth required for adult fish to move through a stream is 17.8 cm (Thompson 1972, as cited in McEwan and Jackson 1996). Water depth requirements change throughout the life cycle of steelhead. Bigger fish tend to use deeper portions of habitat units such as pools and smaller fish (age-0) use shallow areas with low-velocity water (Spina 2003).

Studies suggest that in some cases, physical habitat characteristics such as pool size, substrate, cover, and flow are more important factors in determining habitat use by steelhead than availability of thermal refugia (Nakamoto 1994). If this is the case in Topanga Creek, steelhead should choose areas with favorable habitat, regardless of groundwater inputs. Steelhead are also able to detect poor water quality and should be able to avoid areas where water quality is impaired (Atchison et al. 1987, Svecevičius 2005). Matthews and Berg (1997) found that the ability of steelhead to use groundwater as refugia from high stream temperatures was limited by low dissolved oxygen concentrations in groundwater.

Several characteristics of southern steelhead populations suggest that they have different habitat requirements than steelhead in northern streams. Considerable evidence exists to suggest that adaptation has lead to the maintenance of steelhead near the southern extent of their range (Taylor 1991). Populations of steelhead south of Point Conception (near Santa Barbara, California) show more genetic variation than populations north of Point Conception (Nielsen 1999). This genetic variation may be due to spawning fish straying from their natal streams in response to unfavorable conditions (Nielsen 1999). Steelhead from Southern California are also able to withstand higher temperatures than steelhead from Northern California (McEwan and Jackson 1996, Matthews and Berg 1997, Myrick and Cech 2004).

Much of the research done on habitat and biology of west-coast steelhead has been conducted on fish in Northern California and Pacific Northwest streams (Douglas 1995). The flow regimes, climates, and ecology of these areas are very different from those of streams in Southern California. In many cases, the research on northern steelhead populations does not seem to apply to steelhead in Southern California. This is likely due to the need of the southern populations to adapt to more variable rainfall and extremes in habitat availability, streamflow, and temperatures in Southern California streams (Douglas 1995, Nielsen 1999). There is also evidence that the populations of steelhead that live in Southern California have very different habitat needs than their northern counterparts (Douglas 1995). One major difference is that in Southern California streams there are no other anadromous salmonids to interact with steelhead as there are in northern streams (Spina 2003).

The purpose of this study was to determine what effect, if any, groundwater resources have on the distribution of steelhead trout in a small, coastal stream near the southern extent of their Pacific range. To achieve this goal, the following hypotheses were analyzed. (1) Steelhead should be observed near areas with groundwater inflows when temperatures exceed comfortable levels. (2) If the quality of groundwater is intolerable or habitat is unsuitable where groundwater enters the creek, fish would not be expected to select groundwater sites. To determine whether water quality was acceptable, I compared the quality of groundwater and water from the creek. To determine whether habitat was suitable near groundwater, I compared physical habitat characteristics of habitat units that receive groundwater to those that do not. GeoPentech, Inc., a geology consulting firm in Santa Ana California, provided a report describing geology of the canyon and summarizing chemical composition and isotope ratios of water collected during the study (GeoPentech 2006).

Materials & Methods

Site Description

Topanga Creek is a small coastal creek located in western Los Angeles County, California. The 46.8 km^2 watershed stretches from the western side of the Santa Monica Mountains near Calabasas, through Topanga Canyon, and ends at the Pacific Ocean in Santa Monica Bay. It is the third largest watershed that drains into Santa Monica Bay. The study reach begins at the upstream side of the Pacific Coast Highway (US Highway 1) bridge over the creek and extends 5900 meters upstream (**Figure 1**). The bridge is near the upper side of Topanga Lagoon and provides a stable starting point for surveys (Dagit & Reagan 2006). In the study reach, the creek forms a single, narrow channel that runs through a steep-sided canyon.

The geology of Topanga Canyon includes several different formations that are faulted and folded in many places. These formations include volcanic, sedimentary, and conglomerate rocks. The majority of the study reach is made up of sandstone and limestone. Siltstone, shale, and volcanic sediments are interspersed but are not the dominant sediments in the lower section of Topanga Canyon. Several faults and landslides intersecting Topanga Creek allow groundwater to surface and feed the creek.

The region's Mediterranean climate includes dry summers and mild, wet winters. Peak rainfall is usually in January or February and the driest months are in late fall. During the dry season, flow in sections of the lower creek usually becomes subsurface and disconnected pools of standing water remain on the surface (Dagit & Reagan 2006). Average annual rainfall for Topanga Canyon is approximately 50.8 cm (LACDPW).

During the 2004-2005 water year, Topanga Canyon received approximately 154.9 cm of rain (LACDPW); 75% of the yearly total fell during December, January, and February (**Figure 2**). Because of the extremely wet winter, no sections of creek became dry during the study period and creek levels never reached low-flow conditions.

Native vegetation in the canyon is mainly coastal sage scrub and chaparral. Sycamore (*Platanus racemosa*), California bay (*Umbellularia californica*), alder (*Ulnus rhombifolia*), coast live oak (*Quercus agrifolia*), and arroyo willow (*Salix lasiplepis*) are common near the stream and other water sources. Non-native plants include giant reed (*Arundo donax*), cape ivy (*Hedera helix canariensis*), nasturtium (*Tropacolum majus*), periwinkle (*Vinca minor*), and eucalyptus (*Eucalyptus spp.*) as well as various other plants that have spread from landscaping in backyards and businesses.

The main human influences on water quality within the study reach are Topanga Canyon Blvd., Pacific Coast Highway, and a housing development on the southeast side of the creek, approximately one kilometer upstream of the Pacific Coast Highway bridge. The anthropogenic barriers to migration within the reach are impassible only under low-flow conditions (Dagit & Reagan 2006).

Fish Locations

Fish were located by conducting monthly snorkel surveys (Dagit and Reagan 2006). Snorkelers moved upstream through the creek on the surveys to prevent disturbance from reducing visibility during the survey (Hauer and Lamberti 1996). Teams of two people searched larger pools. A single snorkeler surveyed narrow portions of the creek. In all areas snorkelers looked under banks, rocks, and bubble curtains where present using hand-held dive lights. A third person observed from the bank on a rock, looking for fish that darted upstream after disturbance by the snorkelers. When survey teams found a fish, they recorded the upstream distance from the Pacific Coast Highway bridge and/or landmarks, type of habitat, average depth, maximum depth, percent canopy cover, dominant substrate, and size of each fish.

Habitat Data

Habitat data were recorded during stream mapping which was part of the ongoing Topanga Creek Watershed Southern Steelhead Trout Watershed Assessment and Restoration project (Dagit et al. 2003). Stream Team volunteers mapped the creek from its mouth to 5900 meters upstream in October 2005. Stream mapping methods followed the California Salmonid Stream Habitat Restoration Manual (Flosi and Reynolds 1994). Researchers identified distinct habitat units and recorded the instream distance of both the upper and lower limits of each habitat unit. They also recorded physical and biological habitat characteristics such as depth, width, substrate type, and vegetation present for each habitat unit and classified habitat units according to the types outlined by Flosi and Reynolds (1994). Shelter values are a measure of instream shelter complexity and are based on the amount and type of shelter available in a habitat unit (Flosi and Reynolds 1994). Higher shelter values indicate that a habitat unit contains overhanging banks and boulders that steelhead can use for shelter from stream currents and predators. Possible values for the shelter value score range from 0 to 3 where 0 indicates no shelter; 1 indicates one to five sheltered spaces; 2 indicates more than 5 sheltered spaces but limited types of shelter; and 3 indicates combinations of at least two of the following types of shelter: boulders, undercut banks, woody debris, root wads, bubble curtains, and submerged vegetation. Members of the Topanga Creek Stream Team marked distances every 100 meters by tying flags on trees or other stationary objects. These markers were also used as a basis for referencing fish locations and groundwater sites within the creek. For additional information about stream mapping data and methods, see Dagit and Reagan (2006).

Monitoring Site Selection

Selection of monitoring sites was not truly random. Monitoring sites were not randomly selected for two reasons: (1) it was necessary to obtain a representative sample of geologic formations in the canyon, and (2) random sampling was not possible because many locations of springs were not safely accessible due to terrain. GeoPentech and RCDSMM staff identified springs and possible monitoring locations using aerial photographs and field observations in early spring 2005. Sixty-seven springs were identified within the study reach. Twenty monitoring sites were selected to produce a fairly even distribution throughout the study reach, obtain water samples from a representative sample of each geologic formation, and ensure safe conditions for researchers (**Figure 3).** In addition to springs, I chose five locations in the creek without groundwater at which to monitor water quality. These five sites corresponded with the locations of Onset Stowaway recording thermometers.

Water Quality

I collected water quality and flow data monthly from June through December 2005, usually over 2 consecutive days. Due to the large number of sites, their spatial distribution, and the difficult terrain in the creek bed, it was not possible to sample all sites in a single day. During the September sampling, the second day of field work had to be postponed to early October due to high fire danger and an uncontrolled brush fire that threatened the area. To eliminate time of sampling as an influence on results, I visited sites in the same order each month and tried to sample each location at the same time of day each time. Most samples were collected in the morning and early afternoon, although some samples were collected as late as 5:00 PM. A few of the sites were also sampled during April and May.

Water quality tests were conducted both on water from surface flows of known groundwater sources in Topanga Creek and from the creek itself. Instream samples were taken directly upstream of where surface flows of groundwater entered the creek to provide information on the quality of stream water for comparison to groundwater quality. Conductivity, pH, salinity, dissolved oxygen, temperature, and estimates of volumetric discharge were taken in the field. Water samples taken for nutrient testing were kept in coolers, on ice, until tests could be performed at the RCDSMM office.

I took samples and measurements at the same place and in the same way from month to month whenever possible. When water levels became too low at four of the sampling locations, I chose a similar location (usually upslope) that still had water from which to sample. The largest distance a sampling location had to be moved was approximately ten meters. In most cases this appeared to have no effect on my measurements and the location only had to be moved once during the study.

I monitored temperature in two different ways. I measured water temperature at each of the groundwater and instream control sites using the dissolved oxygen meter. I also installed Onset Stowaway recording thermometers in 8 pools. These thermometers recorded temperature in the creek every 30 minutes from June to October 2005.

I measured dissolved oxygen (to 0.01 mg/L) using a YSI model 55 dissolved oxygen meter. I measured salinity for each site as well as the elevation and entered them in the meter before measuring dissolved oxygen. The dissolved oxygen meter was calibrated by moist air each morning before testing and it remained on throughout the day to avoid having to be recalibrated.

I tested pH using an Oakton Waterproof pH Testr2. Before each sampling event, I calibrated the pH meter to a standard neutral 7 solution and either a standard 4 or 10 solution.

I tested conductivity using WP Oakton ECTestr probes. I used the low range probe (200 µs to 1990 µS/cm) at all sites. Where the conductivity was over 1990 µS/cm, I measured conductivity using a high range probe (0 to 19.90 mS/cm). I calibrated the conductivity meter using a standardized test solution (1413 µS/cm) prior to each field day.

I measured salinity to one part per thousand using a Vista model A366ATC refractometer (0-10% salinity). The refractometer was calibrated the morning of each sampling event using distilled water to set the zero point.

I collected samples in Nalgene bottles for nutrient analysis later in the Resource Conservation District office. Samples were collected using a standard protocol of opening and capping sample bottles under the surface of the water when possible. When depth was insufficient to do this, water was captured in the bottle, catching as little sediment as possible. I used a LaMotte Smart 2 Colorimeter to test samples for concentrations of ammonia. For ammonia (as nitrogen) I used the low range (0.00-1.00 ppm) test for all sites. This test uses a salicylate reaction (Taras 1971). If sites tested over 1.00 ppm, they were retested using a high range (0.00-4.00 ppm) test which uses a Nesslerization method (Taras 1971).

Discharge

I estimated surface discharge from springs using a calibrated 18.9 L bucket or a calibrated 1.9 L pitcher, depending on amount of discharge. I used plastic sheeting to direct all surface flow from groundwater sites into the bucket. I then measured the rate of discharge by capturing flow for a specified length of time (usually 20 seconds). I repeated the measurement to make sure I had captured all surface discharge. When measurements were not similar, I repeated the measurements until at least three measurements gave the same value.

At some sites it was impossible to capture all discharge because the seep was either too spread out to capture or more water was seeping from the ground down slope of the sampling site. At each site, discharge was always measured in a consistent place and manner to ensure discharge measurements were comparable over time. Spring flows could not be compared between sites. My method only quantified surface flows and I had no way of measuring subsurface groundwater entering the creek, so it was not possible to quantify the total spring discharge into the stream.

Site Names

Sampling sites were numbered in order moving upstream from Topanga Lagoon. The numbers were preceded by the letters HG to prevent confusion with the numbers originally assigned to all known groundwater sources in the watershed **(Table 1).** The only exception to the spatial numbering scheme was that HG 23 is below HG 22. HG 22, which was an instream sampling site, also served as the upstream water sampling site for HG 23. I also gave sites names to facilitate communication about them. Each of the names describes the location of the site in some way: usually by taking the name of a nearby pool or other instream landmark.

Spatial Analyses

To be able to compare data from snorkel surveys, stream mapping, and spring locations, I created a route using a National Hydrography Dataset (USGS 1999) shapefile of the main stem of Topanga Creek in ArcMap 9.0. A route is a tool that displays spatial data along a line feature such as a road or a river. Routes use measurements from a point along the line to create a new shapefile that can display attributes of sections of the line feature. I created a shapefile of instream mapping data by locating the upstream distances of the upper and lower limit of each habitat unit along the route I created for Topanga Creek. This route used the Pacific Coast Highway bridge over Topanga Creek as the reference point (0 m). This allowed all instream measurements to be located along the route using the same instream mapping distances which were used to locate fish and landmarks in the field. This shapefile provided the basis for identifying which habitat units received groundwater from springs in the canyon.

To determine where surface flows from springs intersected the creek, I used three methods. Springs that were immediately adjacent to the creek were located along the route using their upstream distance, which was identified during field surveys. For springs that were on tributaries of Topanga Creek, I used the location of the confluence of the tributary with the creek. For spring sites that were not in the creek or on a tributary, I used a National Elevation Data (USGS) map to determine the most likely place where surface flows would intersect the creek. Once the intersection of surface flows from springs were located on the route, I used these route locations and their corresponding instream distances to determine which habitat units were likely to have groundwater input.

Statistical Analyses

I used SPSS student version 12.0 for all statistical analyses. I used a chi-squared goodness-of-fit test to test the null hypothesis that the proportion of steelhead in habitat units that received groundwater was the same as the proportion of habitat units receiving groundwater in the creek as a whole. This method is similar to the one used by Spina (2003) to test mesohabitat preferences among steelhead. I compared the distribution of groundwater areas to the distribution of steelhead separately for each month to ensure that observations of fish locations were independent of each other. This is important because testing all of the observations as a single group would lead to including the same fish multiple times in a single comparison. Doing this would invalidate the assumptions of the χ^2 goodness-of-fit test and make its results irrelevant. By analyzing the distribution of fish by month, it is reasonable to assume that the fish were only counted once in each snorkel survey because of the way snorkel data were collected.

Prior to doing any other tests on habitat data, I used a correlation matrix for all habitat parameters to determine which were related. I also used correlation to determine the relationships between water quality values, flow, temperature and numbers of trout observed. Because none of the habitat data were normally distributed, I used a log+1 transformation on the data before performing any comparisons. I used a two-sample t-test (independent samples t-test in SPSS) to determine whether there were physical differences between habitat units with and without groundwater. For habitat parameters where the variance was not the same for the habitat units with and without groundwater input, I used a non-parametric version of the same test. For all statistical tests, alpha was set at 0.05.

Electivity Index

After analyzing the differences between habitat units with groundwater and those without, I used Jacobs' electivity index and the methods for interpreting the numbers as reported by Baltz (1990) to compare habitat unit use by steelhead based on habitat types:

$$D = \frac{r - p}{(r + p) - 2rp} ,$$

where r is the proportion of a resource used by a species and p is the proportion of the resource available in the system. The purpose of using this index was to provide a method of comparing the types of habitat in which steelhead were observed to the types of habitats present in the study reach of Topanga Creek. Using this index, Baltz recommends the following interpretation of the resulting values for D: values between -1.00 and –0.50 indicate strong avoidance, -0.49 to -0.26 indicate moderate avoidance, -0.25 to 0.25 indicate neutral selection, 0.26 to 0.49 indicate moderate selection, and 0.50 to 1.00 indicate strong selection.

Results

Distribution of Groundwater

Habitat units with groundwater input made up approximately 16% of the habitat units in Topanga creek. Although there were approximately 70 known springs in the study area, many of the springs drained into the same area of the creek because they were close together or they ran into the same sub-drainage. Out of the 306 habitat units that were identified during stream mapping, 50 habitat units were classified as having groundwater input (**Figure 4**).

Distribution of Steelhead

A total of 500 steelhead sightings in Topanga Creek for 2005 was below the six-year average of approximately 610 total sightings per year. The lowest number of sightings was in 2001 (379 fish) and the highest number was in 2004 (682 fish) (Dagit and Reagan 2006). More trout were observed from late spring through summer 2005 than during fall or winter. The lowest numbers of fish observed were during fall with the exception of November, when the second highest number of fish was observed.

During 2005 trout of all sizes were observed in Topanga Creek. Most trout were of intermediate size (10-25cm) (Dagit and Reagan 2006). Juvenile fish (<10cm), which make up the smallest proportion of the observed population, were observed most often in late summer. No juvenile fish were observed in the creek during October, which could indicate outmigration. The highest numbers of adult fish (>25cm) were observed in October and November. Length of fish was significantly correlated with both mean depth ($r=0.24$, $p<0.05$) and maximum depth ($r=0.20$, $p<0.05$) of habitat units in which fish were observed. The maximum number of trout observed at a time was ten and the average number seen together was 2. Fish were observed in an average of 34 separate habitat units (11% of all habitat units in the study area).

Steelhead in Topanga Creek were found more often in pools than any other habitat type. However, steelhead showed different levels of preference for different types of pools. They showed strong selection of trench pools, neutral to moderate selection of mid-channel and step pools, and strong avoidance of plunge pools, corner pools, and lateral scour pools (**Table 2**). Steelhead showed neutral selection of glides and step-runs and moderate avoidance of riffles and cascades.

Steelhead were found more frequently near groundwater sites than would be expected if the fish were evenly distributed. If the steelhead in Topanga Creek were evenly distributed throughout the habitat units, I would expect to find 16% of the fish in groundwater areas. For six out of the nine months of the study, significantly more trout were found in groundwater areas than expected by the frequency of such sites **(Table 3).**

Habitat

Habitat units with groundwater inputs mostly included types of habitat that steelhead selected. Approximately 40% of habitat units with groundwater were pools (**Figure 5**). Glides were the next most abundant habitat type at 16%. Eight percent of habitat units with groundwater were classified as riffles. Habitat units with groundwater were rarely classified as bedrock sheets and never as runs.

There were many differences in characteristics such as size, complexity, and substrate between habitat units with and without groundwater inputs. Habitat units with groundwater were larger overall than habitat units without groundwater (**Table 4**).

Habitat units with groundwater input had larger surface areas, as calculated by the product of average length and average width of habitat units (t-test, $p < 0.05$). This appears to be more the product of length than width because mean length was significantly higher in groundwater habitat units than in habitat units without groundwater. Groundwater habitat units were also deeper on average than the habitat units without groundwater. The shelter value was higher for areas with groundwater, although there was no particular type of cover that was significantly different **(Table 5)**. While it did not appear that there was any particular type of substrate that characterized groundwater areas over other areas, there were significantly fewer boulders and more exposed bedrock in groundwater habitat units (**Table 6**). No vegetation measurements were significantly different between habitats with and without groundwater (**Table 7**).

Temperature

There was no significant difference between temperature of springs and temperature of the stream as measured by Onset Stowaway temperature loggers (paired-samples t-test, $p = 0.179$). However, instream temperature measured directly upstream of each spring was positively correlated to the temperature of the springs (paired-samples correlation, $r = 0.84$, $p = 0.000$). Although there was no difference between the water temperatures in the stream and springs, there was a significant difference between temperatures of a shallow pool (0.75 m) and a deep pool (3 m) (independent-samples t-test, $p = 0.02$). The highest average daily temperature of the creek, as measured using Onset Stowaway temperature loggers was during July at almost 22°C (**Figure 6**). The lowest average daily temperature was in October at around 15°C. The highest water temperature recorded by the Onset Stowaway temperature loggers was during July at approximately 35°C in a shallow pool; the lowest was around 12°C.

Average temperatures of groundwater for each sampling event during the study had a narrower range than instream temperatures. The highest groundwater temperature was in July at around 18°C and the lowest temperature was in December at approximately 16°C. There was a significant difference in mean daily temperature between the deepest pool (14.8°C) and the shallowest pool (24.3°C) where Onset Stowaway temperature loggers were installed (independent samples t-test, $p = 0.019$).

Minimum daily stream temperature on snorkel survey days, as calculated from Onset Stowaway temperature logger data, was positively correlated with the total number of fish observed during each snorkel survey ($r = 0.95$, $p = 0.013$). Neither maximum daily temperature nor average daily temperature was significantly correlated with the total number of fish observed.

Water Quality

Although dissolved oxygen (DO) was significantly higher in the creek than in the springs (independent samples t-test, $p = 0.000$), DO levels were sufficient to sustain trout in nearly all sampling locations throughout the study. A value of 5.0 mg/L is the lowest level of DO salmonids can tolerate for prolonged periods of time (Barwick et al. 2004). There were very few instances where DO was less than 5.0 mg/L **(Figure 7)**. Only HG 18, the Tadpole Pool, averaged less than 5.0 mg/L for the length of time it had water in it. That site was below 5.0 mg/L for May, June, and July and only marginally above that level in August. The instream dissolved oxygen at this location was below 5.0 mg/L in June and marginally above that in August. The only other site that had DO levels less than 5 mg/L was HG 21, the Up and Down Tributary, in August and October. HG 21 was one of the sites that required moving the sampling location to continue monitoring after the original sampling location went dry. Unfortunately, the only accessible location with surface flows was unlike the original site. The original site was in a cascade and the new site was in much less turbulent flow. This resulted in a marked difference in DO levels at this site. Other than these occurrences, DO levels at instream sites and springs were usually well above the generally accepted standards of DO for salmonids.

Conductivity was significantly higher in the creek than in springs (independent samples t-test, p = 0.000) (**Figure 8**). The average conductivity of the creek was 1408 µS/cm while the average conductivity of the springs was 1221 µS/cm. There was no significant difference between the springs and the stream in terms of pH and salinity. For most sites measured, pH was neutral to slightly basic. The lowest pH recorded was 6.5 and the highest was 9.0. Salinity ranged between 0 and 4 ppt in both the stream and springs. The average salinity for both the stream and springs was approximately 1.4 ppt.

Nutrients

Only two ammonia concentrations measured in either the creek or in the springs exceeded 2.2 mg/L (at 15°C and $6.5 < \text{pH} < 7.5$), a value that could be a problem for salmonids and other sensitive cold-water fish species (EPA 1986). There was no significant difference between ammonia levels measured in the creek and springs. The highest ammonia concentration observed was at HG 10 during October at 3.06 mg/L. The lowest ammonia concentration was at HG 16 in June at 0.01 mg/L. The average ammonia concentration was 0.28 mg/L. Most ammonia concentrations were below 0.50 mg/L.

Discharge

Discharge from Topanga Creek was highest in April and lowest in September following a sharp decline at the end of August (**Figure 2**). Discharge increased slowly from September through December and was punctuated by small peaks following storms.

Overall, discharge from the springs I monitored appeared to be both highest and most variable during spring **(Figures 9-10)**. Most sites settled into a low, relatively stable pattern of flow in September and stayed that way throughout the rest of the study. Notable exceptions are the few sites that had spikes in flow during October. It is likely that these sites gained some flow from rainfall because our October sampling days were during and after a storm event.

While most of the other monitoring sites started out with extremely high flows in spring, several of the sites showed low, stable flows throughout the study. HG 14, HG13, and HG 10 all remained relatively consistent in discharge. A few springs on the East bank of the creek showed especially high flows during spring. In particular, HG 15, HG 16, and HG 17 were extremely high in discharge during May and June. HG 06, the Culvert Inlet East Side, also showed a similar pattern, but did not decline as dramatically in discharge during the summer as the other sites.

Discussion

While habitat units with groundwater inputs made up only 16% of habitat units in the study reach, they constituted an important resource for steelhead in Topanga Creek. During six out of the nine months of this study, snorkel surveys indicated that steelhead selected habitat units with groundwater inputs more frequently than would be expected based on the distribution of habitat units. However, whether steelhead selected these areas because of groundwater inputs or habitat characteristics is not something this study can discern. Temperatures in Topanga Creek were high enough that steelhead would be expected to seek cooler water throughout most of the study period. The overall quality of groundwater was similar to the quality of creek water and was never sufficiently bad to deter steelhead from occupying habitat units receiving groundwater. Similarly, characteristics of habitat units receiving groundwater were such that steelhead would be expected to prefer these habitat units rather than avoid them.

Steelhead should select areas with groundwater, especially when creek temperatures exceed optimal levels (Baltz et al. 1987, Nielsen et al. 1994, Matthews and Berg 1997, Ebersole et al. 2001, Baird and Krueger 2003). In Topanga Creek, temperatures exceed comfortable levels on a daily basis. Under a fluctuating temperature regime similar to that of Topanga Creek, the critical thermal maximum for steelhead may be as low as 21°C (Lee and Rinne 1980). Lee and Rinne (1980) defined critical thermal maximum as the temperature at which a fish loses the ability to escape lethal conditions. Average daily temperatures in the creek were at or above 21°C regularly during summer months. McCauley et al. (1977) found that the preferred water temperature for steelhead was 11.3°C regardless of acclimation temperature. Water in Topanga Creek rarely reached temperatures as low this during this study and average daily temperatures were above 15°C for nearly every day for which continuously recorded temperature data were available.

Although temperatures exceeded comfortable levels for steelhead in September and October, fish were not found significantly more often than expected in areas with groundwater. Low minimum daily creek temperatures in September and October (**Figure 6**) are the likely reason for low total numbers of fish observed during these months because of the significant correlation between minimum temperatures and number of fish observed. Snorkel surveys are more accurate at temperatures greater than 14°C (Hillman et al. 1992). When creek temperatures drop below that level, snorkelers are likely count less than 50% of the fish present (Hillman et al. 1992). The low numbers of fish observed in these months was not likely related to fish migrating out of the stream because the mouth of the creek was not open to the ocean during these months (Dagit and Reagan 2006).

I cannot determine if the lack of significant selection of groundwater areas in December was due to cooler temperatures in the creek or low total numbers of fish observed during snorkel surveys. No continuously recorded temperature data were available for December; however daytime temperatures recorded in the stream at the time of groundwater monitoring were well below critical levels. The fewest fish were observed during the December snorkel survey, so it is possible that the low number of observations interfered with the ability of the chi-squared test to determine significant differences.

The findings of previous studies conflict over whether habitat or temperature is more important in determining the distribution of steelhead in a creek. One study concluded that physical characteristics of habitat units may play a more important role in habitat selection than the availability of thermal refugia (Nakamoto 1994). Other studies suggest that thermal refugia may play an important role in thermal regulation and survival of steelhead in warm streams (Ebersole et al. 2001, Baird and Krueger 2003).

In a warm creek, temperature was an extremely important influence on steelhead but cooler areas also appear to have favorable habitat. Areas with groundwater in Topanga Creek contain better habitat for steelhead than areas without groundwater because they are likely to have a combination of better physical characteristics and lower temperatures than areas without groundwater. Groundwater habitat units were deeper, longer, and had a higher shelter value than habitat units without groundwater. Although no significant difference in temperature was detected between spring water and creek water, habitat units with groundwater probably can still act as thermal refugia because they are deeper than other habitat units. Deep pools with cool water have been shown to act as refugia from high temperatures (Matthews et al. 1994, Nielsen et al. 1994). Significantly lower temperatures in deeper pools than in shallow pools suggest that deep habitat units may act as refugia from high temperatures in the stream. Besides serving as refuges from temperature extremes, deeper habitat units provide better shelter from predation and high flows (Baltz et al. 1991). Deeper and longer habitat units probably offer more protection from terrestrial predators such as bobcats (*Lynx rufus*) and raccoons (*Procyon lotor*).

Whether groundwater inputs were the cause or result of the differences in habitat characteristics cannot be answered by this study. Increased groundwater inflow is thought to increase survival of trout eggs (Latta 1965) which could be a result of the inability of fine sediments to settle on the substrate. Groundwater entering the creek could prevent entrained sediments from settling onto the substrate which would prevent these habitat units from filling up with fine grained sediments following periods of high stream discharge. However, it is also possible that the deeper parts of the creek receive more surface groundwater input because the bottom of the creek intersects aquifers or faults which would allow groundwater to enter the creek.

Steelhead are capable of detecting and avoiding pollutants and poor water quality (Svečevicius 2005) and would thus would not be expected to select habitat units with groundwater if the quality of groundwater was poor. Water quality in both the springs and stream was consistently good throughout the study and did not explain the lack of selection of habitat units with groundwater during September, October, and December. During the study period, water quality in monitored springs was good enough to sustain trout if they were trapped there during low-flow conditions. Although groundwater quality was not better than surrounding creek water, it appeared to be just as good. DO was significantly lower in groundwater than in the creek but few DO measurements were below 5.0 mg/L, a level which could be harmful to trout (Barwick et al. 2004). Conductivity was also higher in the creek than in the springs. There was no difference between levels of any other chemical variables measured in springs or the creek.

It is important for groundwater chemistry to be good enough to sustain the fish because they are attracted to these sites by habitat characteristics and temperature differences. The likelihood of fish being trapped in these habitat units is higher than the likelihood of them being trapped in other habitats because bigger, deeper sites with groundwater inputs are more likely to have remant water during dry periods.

Had this study been conducted during drier water years, more fish would have likely been observed in groundwater areas. During the study period, high water levels in Topanga Creek allowed steelhead to use habitat units that would have been too shallow during drier years. Steelhead experience lower growth and survival rates as a result of higher densities (Spina 2000, Harvey et al. 2005); thus trout would be expected to increase density only when lack of water or other resources reduced the number of suitable habitat units. Because shallow areas of the creek tended to be warmer than deeper ones, steelhead would be likely to avoid shallower areas and move into habitat units with groundwater, especially when lack of water increases the number of shallow habitats (Baltz et al. 1987, Matthews et al. 1994, Nielsen et al. 1994). Habitat units with groundwater inputs would be more likely to have water in them when other areas of the creek run dry because of the groundwater inflows. They would also be more likely to retain creek water because they are deeper and larger than habitat units without groundwater.

One source of bias in this study is the method of measuring the temperature of surface discharge from springs. Temperature measurements in the springs were likely to be somewhat elevated above the actual temperature of subsurface groundwater entering the creek. I suspect that greater quantities of groundwater entered the creek through the substrate than the amount measured as surface flow. Surface discharge is likely to be warmer than the water coming from the substrate directly into the creek due to the effects of running over the warm canyon walls.

Another potential bias is due to human error in snorkel surveys. However, observations of the fish more often found near groundwater sites was not likely influenced by snorkelers looking for them more carefully near those sites. Most snorkelers who looked for fish were not involved in the groundwater study. Although they were aware of cooler areas of the creek while they snorkeled, for the most part they did not know which areas of the creek were being monitored or where other potential groundwater sites were. Some areas that did not have groundwater, such as the Transient Pool (HG 3), may have been searched more thoroughly because fish were usually found there and snorkelers knew where fish hid in those pools. If anything, snorkelers searched areas without groundwater more thoroughly.

Management decisions based on standards of favorable habitat for steelhead in the Pacific Northwest or Northern California should only be applied with caution to southern streams because southern streams offer a very different range of habitat characteristics. One major difference between northern and southern streams is the size of the habitat units they contain. With surface areas around 300 m^2, the largest pools in Topanga Creek would be considered small to moderate-sized pools by the standards used for steelhead habitat at the northern extent of their range (Nakamoto 1994). Another major difference is the role of instream cover. In northern streams, instream cover does not improve survival of steelhead (Harvey et al. 2005). Spina (2003) found that at the southern extent of their range, however, steelhead select habitat units with higher physical complexity.

Management and restoration plans for steelhead should include studies of groundwater resources that feed streams, especially in streams near the southern extent of the range of steelhead. Where interfaces between groundwater and streams may be altered by restoration practices, particular care should be taken to understand how steelhead distribution depends on groundwater resources. Groundwater resources in areas where steelhead are present should also be protected against contamination and consumption by human activities. This is especially important in areas where streams are likely to desiccate during dry years or dry seasons because springs are likely to be more important for steelhead during dry times.

Steelhead in southern streams may choose to inhabit habitat units with groundwater input as a way to deal with less than favorable temperatures. In southern streams, localized conditions created by groundwater inflow may play a bigger role in determining steelhead distribution and survival than condition of the stream as a whole. Temperatures in shallow areas of Topanga Creek are also likely to exceed levels that steelhead prefer for most of the year. Steelhead populations have adapted to these less than favorable conditions, however, and the large range of life history patterns exhibited by populations near the southern extent of their range is evidence of that (Taylor 1991).

Figures

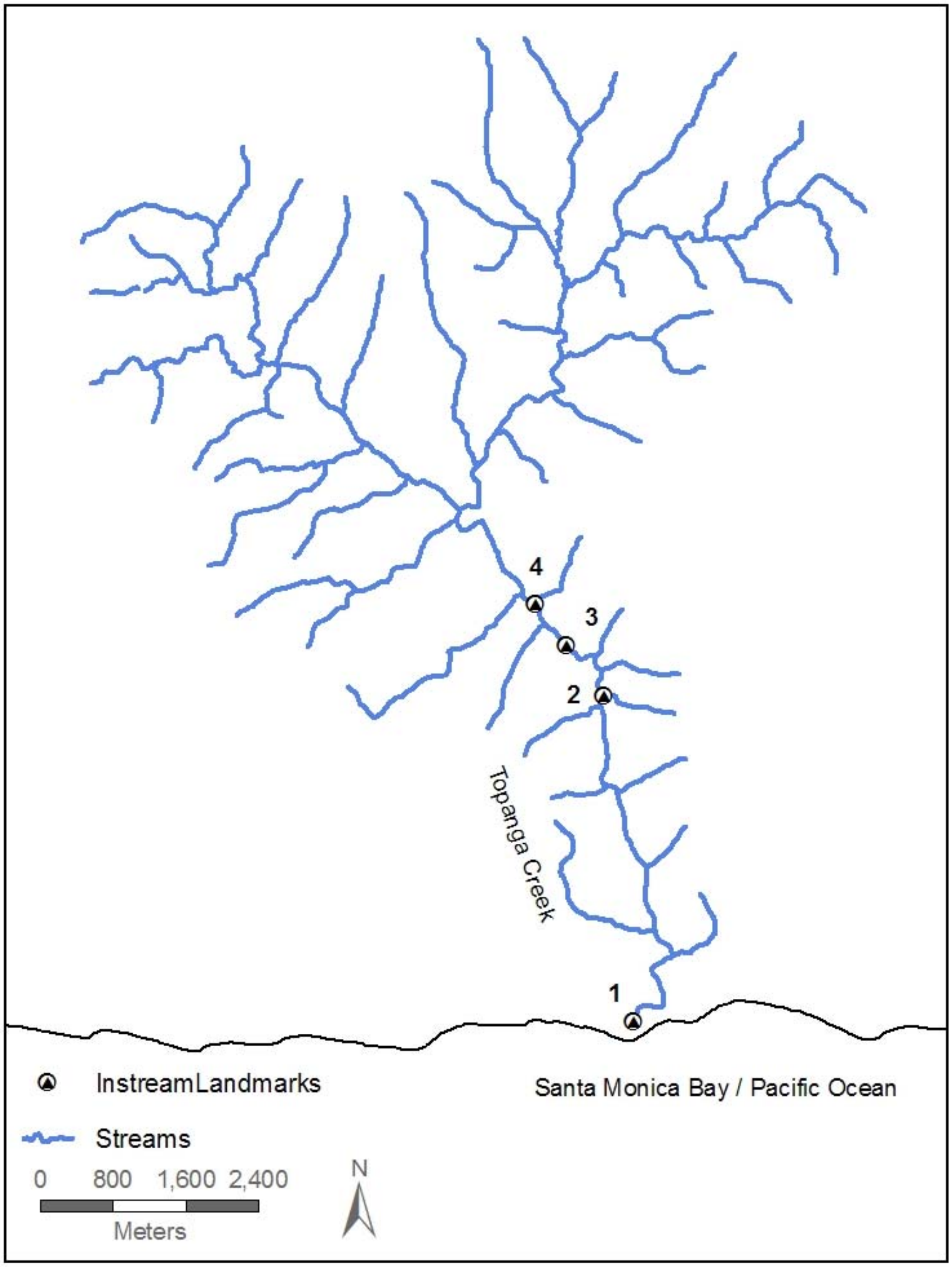

Figure 1: Extent of study reach in relation to Topanga Creek, CA, watershed. Numbered points indicate instream landmarks. (1) Topanga Lagoon at Pacific Coast Highway Bridge (0 m), (2) Barrier Falls (4400 m), (3) The Grotto, current absolute limit of anadromy (5300 m), (4) Upstream limit of the study reach (5900 m). Stream and coastline shapefiles were taken from the National Hydrography Dataset (USGS 1999). Shapefiles were created in geographic coordinate system using North American Datum 1983 (NAD 83) and were re-projected using coordinate system State Plane California V FIPS 04, NAD 83.

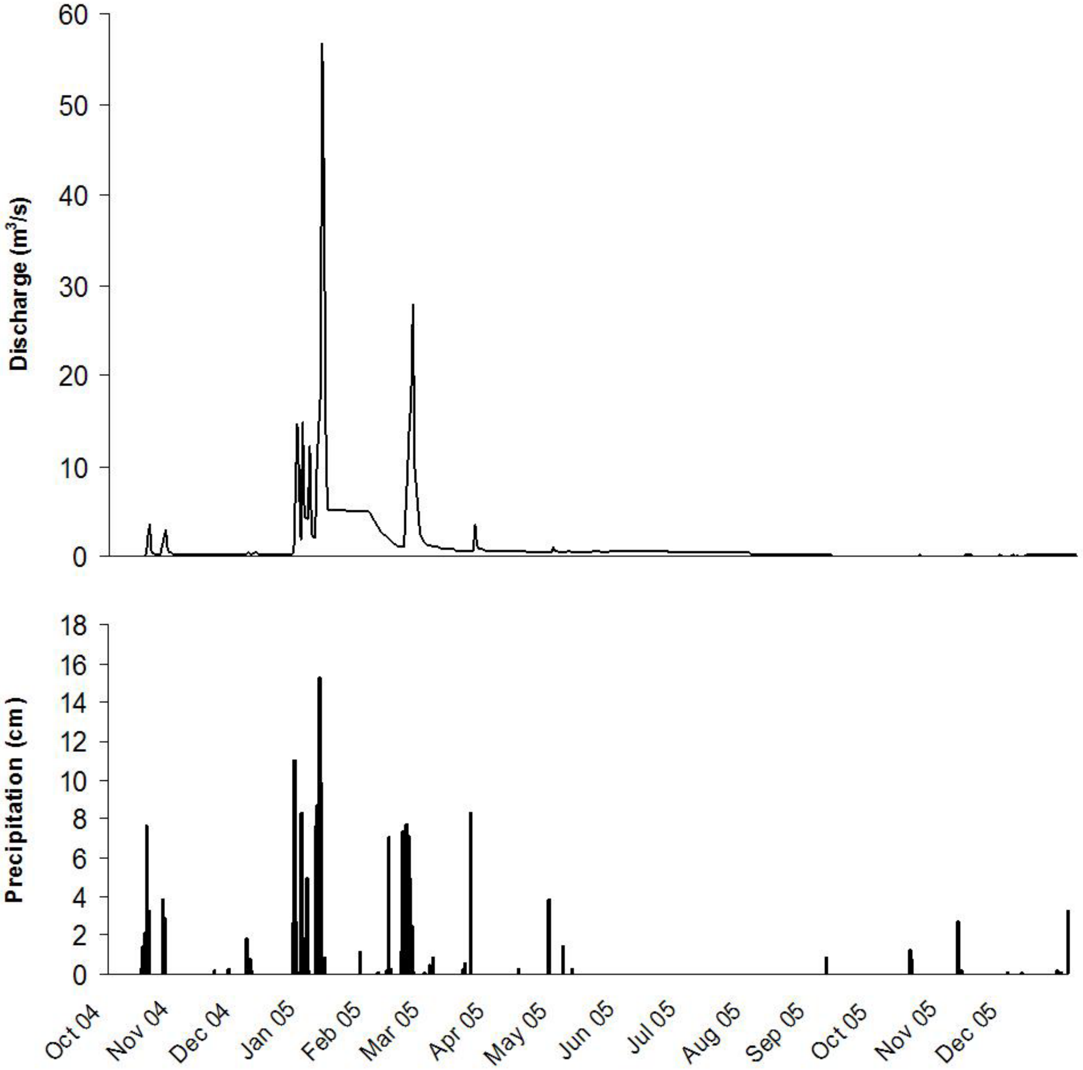

Figure 2: Precipitation (cm) and daily discharge (m^3/s) in Topanga Canyon and discharge from Topanga Creek, 1 October 2004-31 December 2005. Discharge was measured by Los Angeles County Department of Public Works stream gage F54F at Topanga Canyon Blvd. mile marker 2.02 near HG 9 (LACDPW unpublished data). Rainfall was measured by Los Angeles County Department of Pubic Works precipitation gage 6 (LACDPW unpublished data).

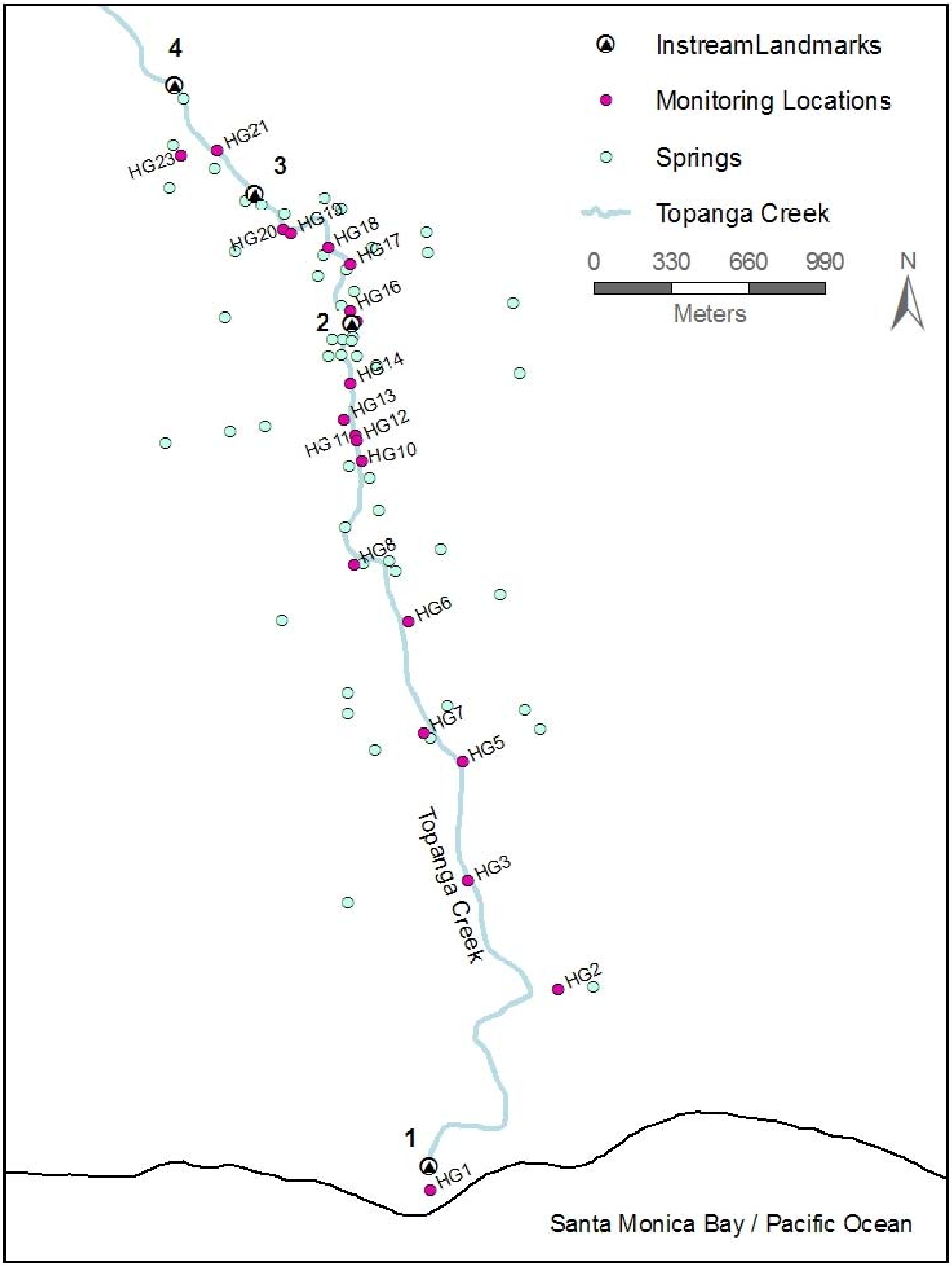

Figure 3: Groundwater monitoring sites and known springs of Topanga Canyon, CA. Monitoring locations are labeled with study site numbers corresponding to those listed in Table 1. Instream landmarks are enumerated as follows: (1) Topanga Lagoon at Pacific Coast Highway Bridge (0 m), (2) Barrier Falls (4400 m), (3) The Grotto, current absolute limit of anadromy (5300 m), (4) Upstream limit of the study reach (5900 m).

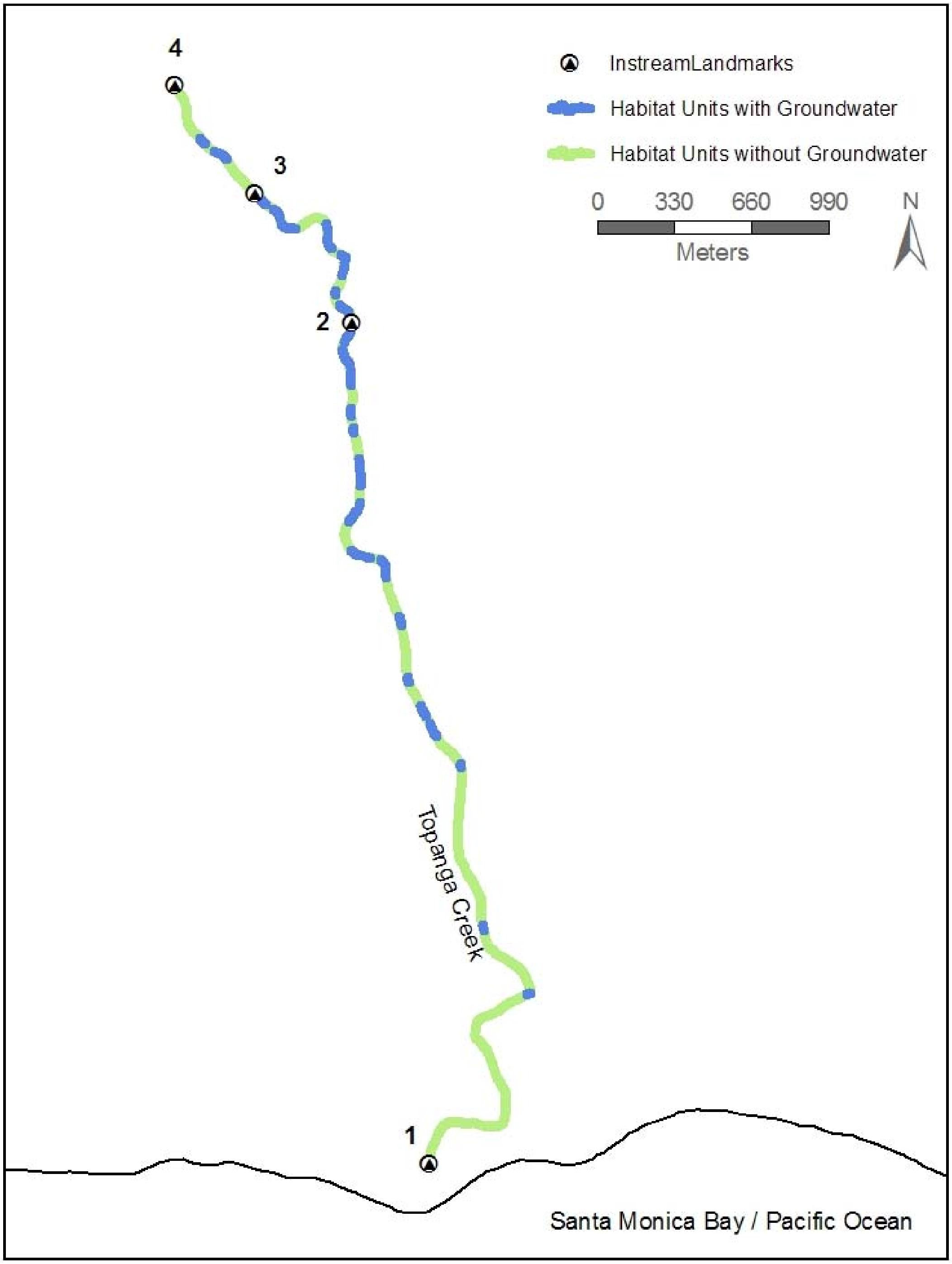

Figure 4: Habitat units with groundwater inputs in Topanga Creek, CA. Habitat units were mapped in October 2005 following the California Salmonid Stream Habitat Restoration Manual (Flosi and Reynolds 1994). Landmarks and GIS methods are as indicated in Figure 1.

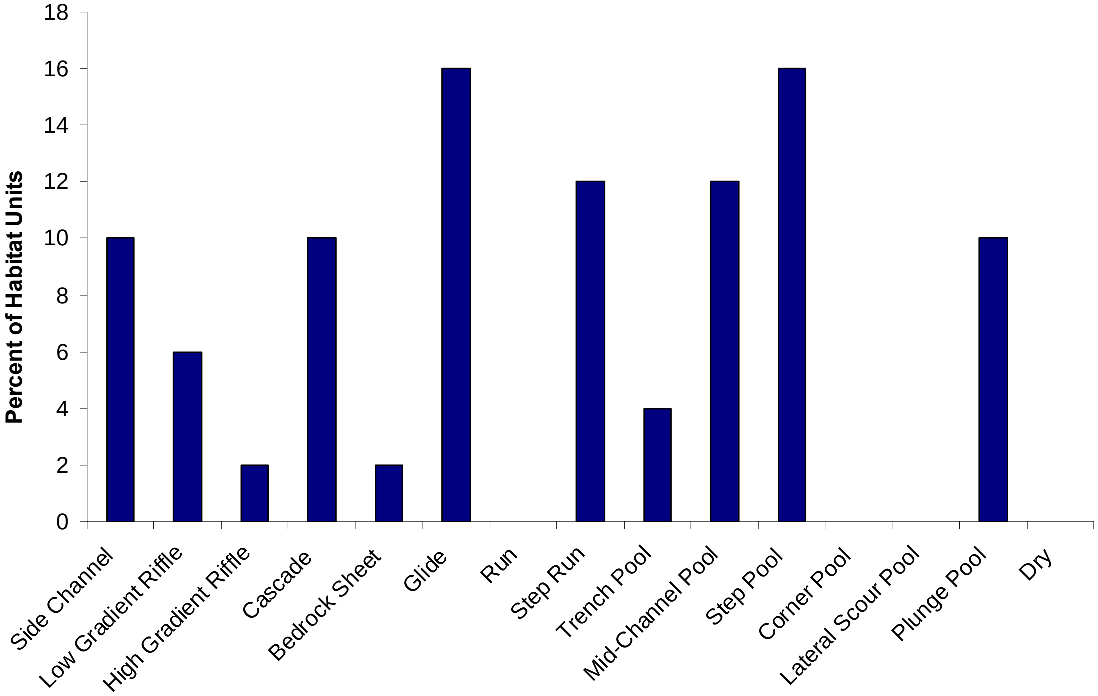

Figure 5: Percent of each habitat type with groundwater in Topanga Creek, Topanga, CA.

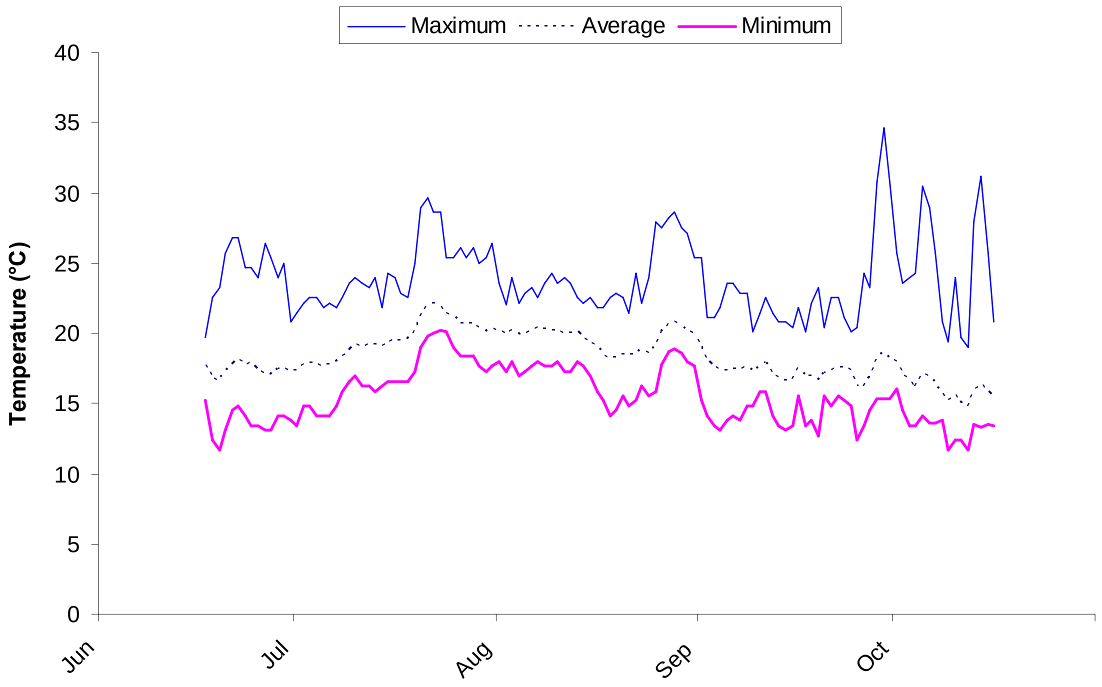

Figure 6: Maximum, average, and minimum daily temperatures recorded in Topanga Creek by Onset Stowaway recording thermometers (17 June-16 October 2005).

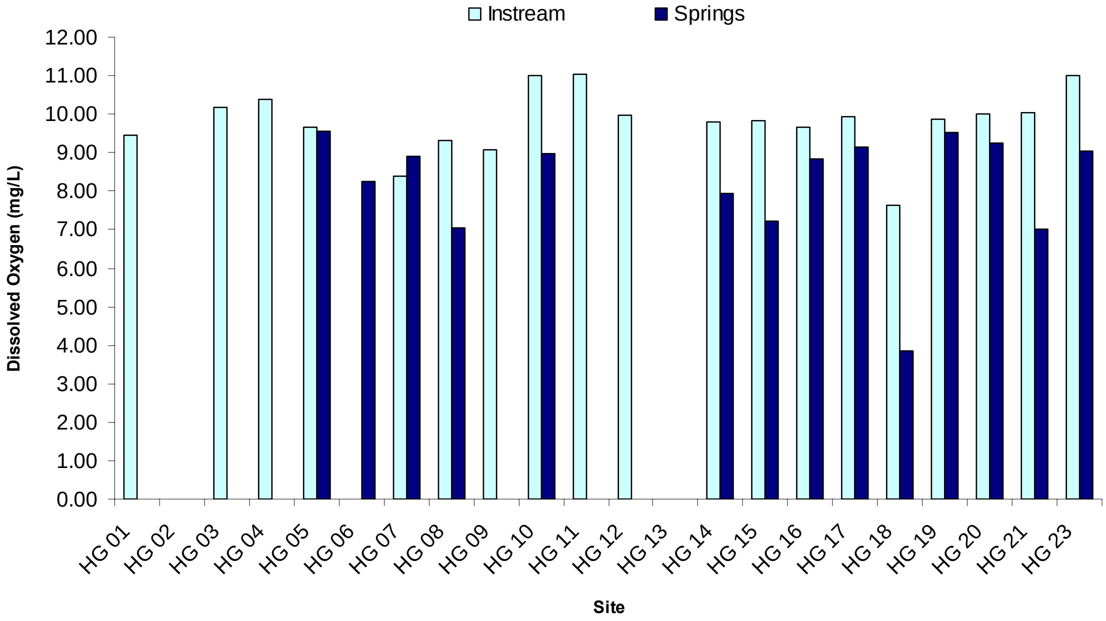

Figure 7: Average dissolved oxygen (mg/L) of surface discharge from springs and Topanga Creek immediately upstream of spring monitoring locations (April through December 2005).

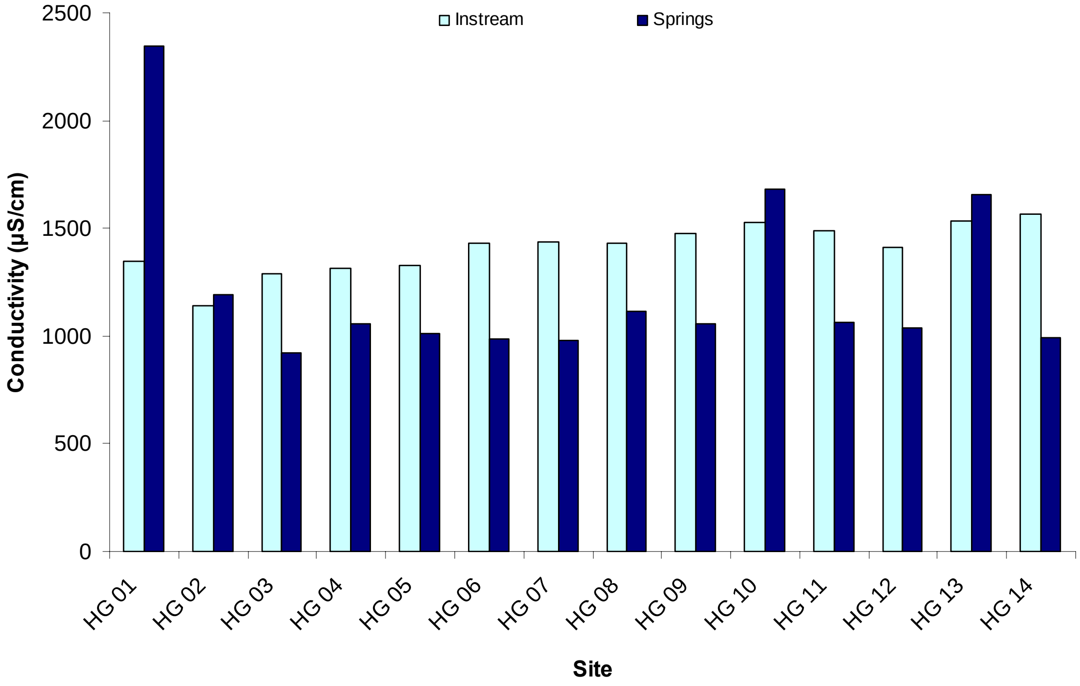

Figure 8: Average conductivity (µS/cm) by site for measurements in springs and Topanga Creek, immediately upstream of spring monitoring locations (April-December 2005).

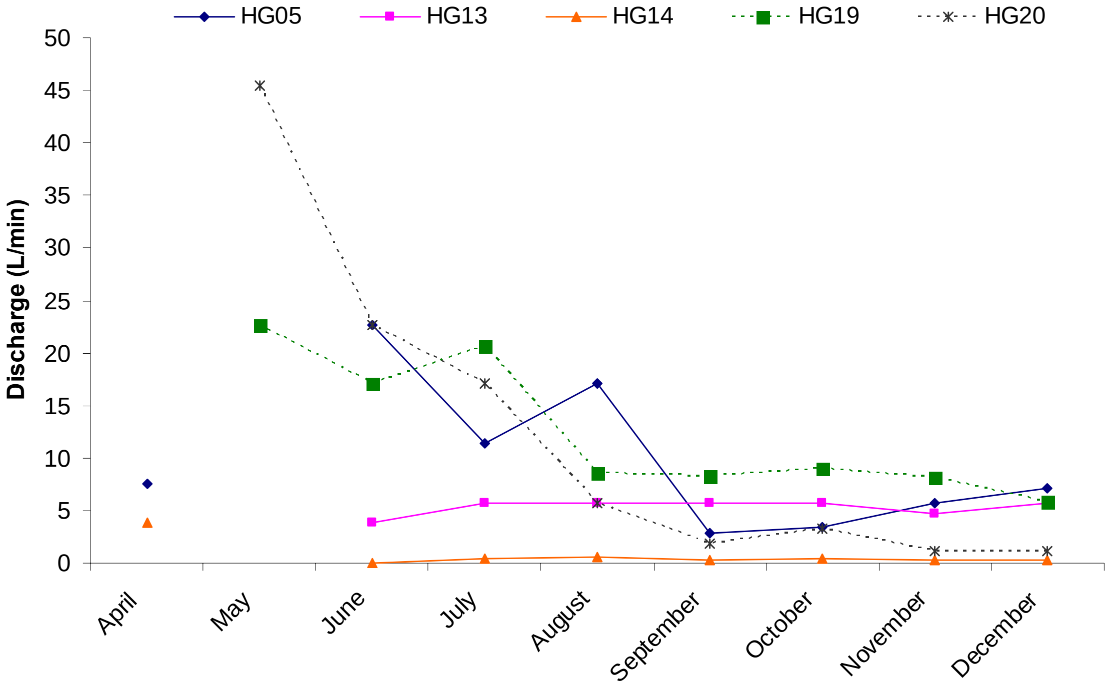

Figure 9: Discharge (L/min) from groundwater sites on the West bank of Topanga Creek (April-December 2005).

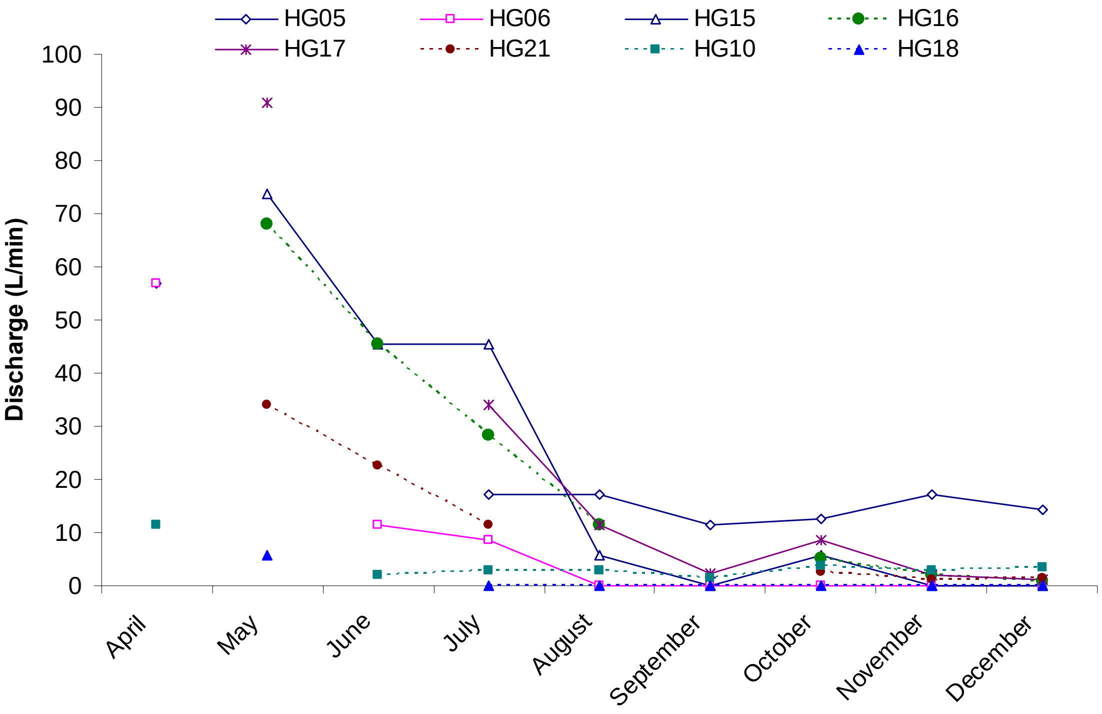

Figure 10: Discharge (L/min) from groundwater sites on the East bank of Topanga Creek (April-December 2005).

Tables

Table 1: Names, numbers, instream locations, and sampling dates (in 2005) of groundwater monitoring locations.

Study Site Number	Site Name	Abbreviation	Instream Distance	HG Static Data Reference Number	Dates Sampled								
					Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
HG1	Topanga Lagoon	Lag		301	-	-	13	13	15	28	17	21	19
HG2	Mile Marker 0.05	MM	1100m	1	26	-	13	Dry	Dry	Dry	Dry	Dry	Dry
HG3	Transient Pool	Trans	1900m	3	26	-	14	14	15	28	17	21	19
HG4	Ski Pole Pool	Ski	2000m		-	-	14	14	15	28	17	21	19
HG5	Green House Culvert	GHC	2430m	4	26	-	14	13	15	28	17	21	19
HG6	Culvert Inlet East Side	CIE		8	26	-	14	13	15	Dry	Dry	Dry	Dry
HG7	Ken2 Pool	Ken	2600m	6	-	26	14	13	15	28	17	21	19
HG8	Alder Grove	AG	3500m	13	26	-	14	13	15	28	17	21	19
HG9	Bridge MM 2.02	Bri	3600m			-	27	13	15	28	17	21	19
	Noel Pool	NP	4000m		-	-	-	13	15	28	17	21	19
HG10	Sycamore Tree	Syc	3977m	17	26	-	15	13	19	28	17	21	19
HG11	Maidenhair Fern Seep	MHF	4100m	18	26	-	15	13	15	28	17	21	19
HG12	No Parking Alder Seep	NPS	4316m	302		-	15	13	15	28	17	21	19
HG13	Narrows Seep	Nar		19	26	-	15	13	15	28	17	21	19
	Josh Pool	JP	4400m		-	-	-	13	15	28	17	-	-
HG14	Duck Seep/ Kevin Pool	DSK	4550m	20	-	31	15	14	16	7-Oct	18	22	20
HG15	Storm Falls	SF	4637m	27	-	31	15	14	16	7-Oct	Dry	22	20
HG16	Dead Alder Falls	DAF	4718m	31	-	31	15	14	16	7-Oct	18	22	20
HG17	Elderberry Falls	EF	5000m	52	-	31	15	14	16	7-Oct	18	22	20
HG18	Tadpole Pool	TPP	5150m	53	-	31	15	14	16	Dry	Dry	Dry	Dry
HG19	Pool of Many Drips	PMD	5300m	54	-	31	16	14	16	7-Oct	18	22	20
HG20	Bigleaf Maple Pool	BMP	5350m	35	-	31	16	14	16	7-Oct	18	22	20
HG21	Up and Down Trib	UDT	5700m	56	-	31	16	14	16	-	18	22	20
HG22	Ropeswing Pool	RSP	5900m		-	-	16	14	16	7-Oct	18	22	20
HG23	Time Tunnel	TT	5900m	39	-	31	16	Dry	Dry	Dry	Dry	Dry	Dry

Table 2: Habitat type choice by steelhead as indicated by Jacob's electivity index. Bold indicates strong selection and italic indicates strong avoidance.

	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
Low Gradient Riffle	-0.32	*-0.50*	*-0.75*	-0.36	-0.45	-0.36	*-0.55*	*-0.70*	*-0.60*	*-0.51*
High Gradient Riffle	*-1.00*	-0.25	-0.30	-0.09	-0.18	-0.09	-1.00	-0.21	-0.03	-0.35
Cascade	*-0.79*	*-1.00*	-0.09	*-0.72*	-0.41	*-0.50*	-0.40	-0.43	*-1.00*	*-0.59*
Bedrock Sheet	*-1.00*	*-1.00*	*-1.00*	*-1.00*	*-1.00*	*-1.00*	*-1.00*	*-1.00*	*-1.00*	*-1.00*
Glide	-0.13	-0.13	-0.34	-0.11	-0.21	-0.32	-0.52	0.04	0.12	-0.18
Run	*-1.00*	*-1.00*	*-1.00*	*-1.00*	*-1.00*	*-1.00*	*-1.00*	*-1.00*	*-1.00*	*-1.00*
Step Run	0.25	0.32	0.18	0.04	-0.07	0.17	0.00	-0.26	0.10	0.08
Trench Pool	**0.77**	**0.77**	**0.68**	**0.79**	**0.74**	**0.72**	**0.78**	**0.73**	**0.63**	**0.73**
Mid-Channel Pool	0.02	0.26	0.31	0.21	0.46	0.10	0.35	0.16	0.17	0.23
Step Pool	0.41	0.19	0.28	0.14	0.03	0.45	0.11	0.46	0.33	0.27
Corner Pool	*-1.00*	*-1.00*	*-1.00*	*-1.00*	*-1.00*	*-1.00*	*-1.00*	*-1.00*	*-1.00*	*-1.00*
Lateral Scour Pool	*-1.00*	*-1.00*	*-1.00*	*-1.00*	*-1.00*	*-1.00*	*-1.00*	*-1.00*	*-1.00*	*-1.00*
Plunge Pool	-0.47	*-1.00*	*-1.00*	*-1.00*	-0.42	*-1.00*	-0.22	*-1.00*	*-1.00*	*-0.79*
Side Channel	-0.30	-0.15	*-0.52*	0.04	-0.42	-0.34	0.00	-0.10	0.10	-0.19

Table 3: Results of the chi-squared goodness of fit test on the null hypothesis that the proportion of steelhead in habitat units with groundwater was the same as the proportion of habitat units that received groundwater (April-December 2005).

		April	May	June	July	August	September	October	November	December
Groundwater	Steelhead Observed	25	25	20	19	37	10	12	26	11
	Steelhead Expected	12.12	12.61	12.77	12.61	12.93	10.18	9.21	12.61	7.11
	Residual	12.88	12.39	7.23	6.39	24.07	-0.18	2.79	13.39	3.89
No Groundwater	Steelhead Observed	50	53	59	59	43	53	45	52	33
	Steelhead Expected	62.88	65.39	66.23	65.39	67.07	52.82	47.79	65.39	36.89
	Residual	-12.88	-12.39	-7.23	-6.39	-24.07	0.18	-2.79	-13.39	-3.89
Total	Total Steelhead	75	78	79	78	80	63	57	78	44
	Chi-Square	16.32	14.53	4.89	3.87	53.45	0.00	1.01	16.97	2.54
	df	1	1	1	1	1	1	1	1	1
	Asymp. Sig.	0.000	0.000	0.027	0.049	0.000	0.950	0.316	0.000	0.111

Table 4: Differences in various measurements of the size of habitat units with and without groundwater input as determined by an independent samples t-test (October 2005). Bold values indicate $p < 0.05$.

	Groundwater	N	Mean	t	df	Sig. (2-tailed)
Mean Length (m)	Present	50	27.18	3.66	304	**0.00**
	Absent	256	19.18			
Mean Width (m)	Present	50	6.42	1.85	304	0.07
	Absent	256	4.96			
Area (m^2)	Present	50	181.26	3.11	304	**0.00**
	Absent	256	111.17			
Mean Depth (m)	Present	50	33.50	2.61	304	**0.01**
	Absent	256	25.69			
Maximum Depth (m)	Present	50	73.50	3.02	304	**0.00**
	Absent	256	54.11			

Table 5: Differences in the shelter available in habitat units with and without groundwater input as determined by an independent samples t-test (October 2005). Bold values indicate $p < 0.05$.

	Groundwater	N	Mean	t	df	Sig. (2-tailed)
Shelter Value (score)	Present	50	1.86	3.28	304	**0.00**
	Absent	256	1.34			
Undercut Banks (% of banl	Present	50	14.36	1.66	64	0.10
	Absent	256	9.17			
Small Woody Debris (% of	Present	50	7.62	-0.93	304	0.35
	Absent	256	7.59			
Large Woody Debris (% of	Present	50	2.06	1.78	54	0.08
	Absent	256	0.65			
Root Masses (% of habitat	Present	50	4.12	1.52	304	0.13
	Absent	256	3.76			
Terrestrial Vegetation (% o	Present	50	3.12	0.49	304	0.63
	Absent	256	1.59			
Aquatic Vegetation (% of h	Present	50	2.10	0.26	304	0.79
	Absent	256	2.56			
Bubble Curtain (% of habit	Present	50	8.92	-0.11	304	0.91
	Absent	256	9.57			
Boulders (% of habitat unit	Present	50	27.10	-0.79	304	0.43
	Absent	256	32.12			
Bedrock Ledge (% of habit	Present	50	7.84	1.74	63	0.09
	Absent	256	4.43			

Table 6: Differences in substrate available in habitat units with and without groundwater input as determined by an independent samples t-test (October 2005). Bold values indicate $p < 0.05$. Dry length is a measure of the length (m) of a dry section of substrate within a habitat unit. Other categories are a measured as a percentage of the area of a habitat unit that were covered by that type of substrate.

	Groundwater	N	Mean	t	df	Sig. (2-tailed)
Dry Length (m)	Present	50	0.00	-0.63	304	0.53
	Absent	256	0.41			
Silt or Clay (%)	Present	50	2.00	-0.64	304	0.52
	Absent	256	2.67			
Sand (%)	Present	50	27.10	1.77	304	0.08
	Absent	256	22.01			
Gravel (%)	Present	50	15.30	1.11	304	0.27
	Absent	256	14.55			
Cobble (%)	Present	50	18.72	-0.45	304	0.65
	Absent	256	22.04			
Boulder (%)	Present	50	19.82	-2.84	304	**0.00**
	Absent	256	31.07			
Bedrock (%)	Present	50	16.36	2.96	63	**0.00**
	Absent	256	7.18			
Exposed Substrate (%)	Present	50	17.38	-1.51	304	0.13
	Absent	256	24.84			

Table 7: Differences in vegetation in habitat units with and without groundwater input as determined by an independent samples t-test (October 2005).

	Groundwater	N	Mean	t	df	Sig. (2-tailed)
Total Canopy (%)	Present	50	32.60	-0.46	304	0.64
	Absent	256	36.46			
Broadleaf Vegetation (%)	Present	50	31.08	-0.42	304	0.68
	Absent	256	35.05			
Non-Native Vegetation (%)	Present	50	1.52	1.01	64	0.32
	Absent	256	1.30			
West Bank Vegetated (%)	Present	50	22.96	-1.48	304	0.14
	Absent	256	27.28			
East Bank Vegetated (%)	Present	50	24.84	-1.21	304	0.23
	Absent	256	32.79			

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