Discovery Bay Watershed
Water Quality and Fishes
A Comprehensive Review

Washington State Conservation Commission

and

Jefferson County Environmental Health

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For

Washington State Conservation Commission

Olympia, Washington

and

Jefferson County Environmental Health

Port Townsend, Washington

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PURPOSE

The Jefferson County Conservation District (JCCD) began monitoring water quality in the Discovery Bay watershed in 1994. Prior to 1994, the Jefferson County Planning Department conducted monitoring in 1988-89. In the 1980s, JCCD began implementing Best Management Practices (BMPs) in agricultural areas of the watershed to improve water quality and salmonid habitat.
The purpose of this report is to:

1. establish a baseline for future studies to refer to;
2. report the JCCD's most recent water quality findings;
3. report water quality trends over time;
4. consolidate the water quality data, fish data, and restoration projects for the past three plus decades.

SUMMARY

Fecal Coliform Bacteria and Microbial Source Tracking

Livestock manure entering the stream channel has been the greatest factor of concern, as far as detrimental effects of farming on water quality. Manure can harbor pathogenic bacteria and viruses that are harmful to people. These pathogens may enter humans through ingestion of contaminated water when swimming or through consumption of contaminated shellfish. Clams, oysters, and mussels are filter-feeders and can concentrate pathogens in their organs.

Fecal coliform (FC) bacteria, which occur in the gut of all warm-blooded animals, have been used for years as an indicator of the potential presence of pathogenic bacteria and viruses. The state standard has two parts. Part 1 requires that the geometric mean value (GMV), a logarithmic average of the bacteria counts, not exceed 100 colonies in 100 milliliters of water (expressed as 100 FC/100mL). Part 2 requires that not more than 10% of the samples exceed 200 FC/100 mL. Both parts need to be met to pass the standard. Additionally, wet months (October – April) and dry months (May – September) are analyzed separately and the standard must be met during both periods.

The Jefferson County Conservation District began monitoring fecal coliform in the Discovery Bay Watershed in 1994 and last monitored it in 2017-19. In the most recent monitoring, which covered two wet seasons and one dry season, 9 of the 19 monitoring stations failed the fecal coliform standard. Failures occurred at one or more stations on Andrews Creek, Contractors Creek, Salmon Creek, Snow Creek, Tucker Ditch, Uncas Valley Ditch, and Zerr Drain. Only Houck Creek passed the standard in all three seasons.

GMVs for the 18-month period were highest for Uncas Valley Ditch (43 FC/100 mL) and Zerr Drain (41 FC/100 mL). GMVs generally increased from upstream to downstream in Salmon Creek, Snow Creek, and Tucker Ditch.

In 24-hour monitoring in March 2018 at 2-hour intervals, FC concentrations ranged from 24 FC/100 mL to 144 FC/100 mL in Salmon Creek and from 1 FC/100 mL to 28 FC/100 mL in Snow Creek.

Long-term data, since 1988, showed downward trends in Salmon Creek, Snow Creek, Andrews Creek, Houck Creek, Tucker Valley Ditch, and Zerr Drain. Whereas, upward trends occurred in Contractors Creek and Uncas Valley Ditch.

FC concentrations were positively correlated to temperature at all monitoring stations. Highest concentrations were observed in August and September. Seven of the nine stations that failed the standard failed it from May through September. Similar positive correlations between FC/*E. coli* and temperature were observed in Chimacum Creek and other streams.

In 2012-13, Microbial Source Tracking (MST) showed human biomarkers present in Andrews Creek, Houck Creek, Salmon Creek, Snow Creek, and Uncas Valley Ditch. The ruminant biomarker was found in Andrews Creek and Snow Creek. Human biomarkers occurred in 13% of the samples compared to 3% for the ruminant biomarker. Fifty-five percent of the samples were attributed to birds and animals other than ruminants. The remainder of samples did not contain any biomarkers.

In 2018-19, human biomarkers were present in Salmon Creek, Snow Creek, and Contractors Creek. Human biomarkers were found in 2% of the samples. Cattle biomarkers were not found in any samples. The avian biomarker was found in 64% of the samples from Zerr Drain. Due to the high concentrations of fecal coliform and high frequency of the avian biomarker in Zerr Drain samples, birds could be responsible for the “threatened” status at nearby marine station 196.

Based on the two Discovery Bay studies as well as other studies, human bacterial pollution appears to be greater than that of cattle, but a variety of birds and animals appear to contribute more than humans and cattle combined.

FC/*E. coli* have the ability to survive and grow in stream sediment and algae, in cow pies, and in soil. They are more concentrated near the upper layer of stream bottom sediment. Attached to sediment, they may become suspended in the water column during high flow, especially on the rising limb of the hydrograph. They may also become suspended under low flow conditions by water moving through pores in the bottom sediment.

Bacteroides are an obligate anaerobic bacteria and are therefore short-lived in oxygenated stream water. This probably accounts for its lower frequency of occurrence compared to fecal coliform bacteria.

Human fecal coliform bacteria may enter a waterbody via ground water flow, especially in coarse soil and especially when the water table is high. In the absence of coarse soil, bacteria may reach a waterbody through preferential flow (i.e., through worm holes, plant route holes, animal burrows, etc.). The closer the septic drainfield is to the waterbody, the greater is the probability for pollution. This principal probably holds true for livestock manure as well.

Temperature

The state temperature standard is based on an average of the daily maximum temperatures for seven consecutive days (7-DADMax); the 7-DADMax is 16ºC from July 1 to August 30 and 13ºC from September 1 to June 30.

In 2019, Salmon Creek failed the 7-DADMax-16ºC standard at 2 of its 3 temperature data logger stations; Snow Creek failed at 5 of its 5 stations; and Andrews Creek failed at all 5 of its stations. Houck Creek failed at its downstream station and Uncas Valley Ditch passed at its downstream station.

Salmon, Snow, and Andrews creeks failed the 7-DADMax-13ºC standard at all the stations monitored. The 7-DADMax-13ºC standard does not apply to Houck Creek or Uncas Valley Ditch.

Temperature increased in a downstream manner in Salmon, Snow, and Andrews creeks.

Prior to the 2003 restoration project, Snow Creek and Salmon Creek exhibited slightly increasing trends, similar to those of the temperature controls. After the restoration project, Salmon Creek showed a decreasing trend. Andrews Creek, upstream of Crocker Lake, exhibited a slightly increasing trend. Whereas, downstream of the lake, Andrews Creek's temperature trend was constant, neither increasing nor decreasing.

Although the temperatures on most of the streams exceeded the standard, they were probably not high enough to be deleterious to the salmonids. Some studies have shown that a little warmer water can actually be beneficial. When dissolved oxygen and food supply are adequate, juvenile salmonids grow larger, which is beneficial to their survival.

Surface Dissolved Oxygen

Dissolved oxygen (DO) is one of the most important indicators of water quality. It is essential for the survival of fish and the macroinvertebrates which fish feed on.

In the monthly monitoring conducted from November 2017 to April 2019, 10 of the 19 stations failed the 9.5 mg/L state standard. However, the DO concentrations at four of the failed stations were above the EPA 8 mg/L "no production impairment level." And four other failures occurred at stations on Tucker Ditch and Uncas Valley Ditch. Both of these ditches dry up during the summer, but it is likely that the lower reaches of these tributary ditches to Salmon Creek serve as refugia for salmonids during periods of high flow. DO levels were high in these ditches during the high-flow winter months. Juvenile Coho have been trapped in lower Uncas Valley Ditch in the past.

Historically, Andrews Creek downstream from Crocker has had low dissolved oxygen levels. In July 2018, DO measured 4.7 mg/L. This reach is fed by anaerobic groundwater, which is apparent by a coating of brownish ferric hydroxide on the stream bottom. Dissolved ferrous iron in the groundwater precipitates out as ferric hydroxide when it comes in contact with oxygen. This reaction consumes oxygen and lowers the DO level.

Decaying canary grass and aquatic vegetation in the channel probably also contributed to the low dissolved oxygen. A cursory sampling of macroinvertebrates on August 7, 2019 revealed predominantly scuds, leeches, and sow bugs, all indicators of poor water quality. Despite this, a high density of juvenile Coho were present at the same location on the same date. The Coho could have originated in the reach where they were trapped or they could have swum up from Snow Creek, only 600 feet downstream.

Salmonids survive as long as DO remains above the 3 mg/L critical level. However, production (biomass/$ft.^2$) decreases as DO decreases below 8 mg/L. Because survival is related to fish size, it is best that the DO concentration be as high as possible. Also, because intragravel dissolved oxygen (see following section) will be no greater than surface dissolved oxygen, it is best that surface DO be as high as possible during egg incubation.

Intragravel Dissolved Oxygen, Sediment, and Turbidity

Because juvenile Chum spend about 95 percent of their freshwater stage in the gravel, an adequate level of dissolved oxygen in the gravel is crucial to their survival. Of course, adequate DO in the gravel is necessary for all salmonids.

Intragravel dissolved oxygen (IGDO) was monitored only in Salmon Creek. IGDO levels in two reaches between River Mile (RM) 0.2 and RM 0.7 merited a "fair" rating with 50% to 95% of redds receiving adequate DO (>3.0 mg/L) during the years 2001 to 2009, excluding years 2004 to 2006 when the stream was recovering from channel excavation. The two reaches, upstream and downstream from Houck Creek at RM 1.0 merited a "good" rating for the years 2002 to 2007 with 80% to 100% of redds receiving adequate DO. The higher rating for the reaches at RM 1.0 may be due to the steeper gradient there.

Total suspended solids, turbidity, and McNeil sampler measurements along with stream surveys show that Salmon Creek, Snow Creek, Andrews Creek, and Houck Creek have all been affected by fines resulting from logging activity. It is encouraging to know, as shown by the purging of fines in the excavated channel on Salmon Creek, that streams can recover from excessive fines.

Intragravel dissolved oxygen, besides being important to fish, is important to macroinvertebrates, which salmonids feed on. IGDO concentrations on Salmon Creek were highly correlated to an Index of Biotic Integrity (B-IBI), which is based on the number and diversity of macroinvertebrates in riffles. Excluding the recovery years for the new channel, Salmon Creek received a B-IBI rating of "fair."

Large Woody Debris

Both riffles and pools are important for salmonids and Large Woody Debris (LWD) is the key to both. LWD creates pools, which provide temporary storage for fines, keeping fines out of the spawning gravel. Pools provide ideal rearing habitat for juvenile salmonids and holding areas for returning adults. Spawning riffles naturally occur between the pools. Numerous studies have shown that juvenile salmonid abundance increases when LWD is added.

In reaches lacking riparian buffers, planting trees will eventually provide the needed LWD as the trees grow and fall into the stream. Installing LWD as was done on lower Salmon Creek (WDFW restoration project) speeds up the process.

Salmon Trends

Except for 2017 and 2018, Summer Chum returns to Salmon Creek have increased since 2001, reaching a maximum of 6,846 in 2015. In Snow Creek, Summer Chum returns have remained below 1000 since 1974, showing no noticeable trend.

Based on redd counts since 1999, Salmon Creek Coho have not exceeded 206 redds. Snow Creek Coho have exhibited an increasing trend since 1976. A maximum of 2,916 Coho returned in 2012.

Snow Creek Steelhead returns reached a maximum of 192 fish in 2000. Returns since 2004 ranged from only 8 to 50 fish, markedly less than returns prior to 2003.

BACKGROUND

Location, Topography, and Climate

The Discovery Bay Watershed is located in the northeastern portion of the Olympic Peninsula in Jefferson (73%) and Clallam counties (27%), Washington (Figure1). The watershed covers about 50,000 acres, and Discovery Bay itself covers about 9,200 acres (Nelson et al. 1992). The topography of the watershed varies from being relatively flat in the Snow Creek valley to hilly and mountainous in the Olympic Foothills and Mountains. The climate is generally mild. Typical summer high temperatures in the lowlands range from 60^{o} to 70^{o} F and typical winter lows range from 28^{o} to 35^{o} F (Nelson et al. 1992). Precipitation varies considerably from an average of 19 inches per year measured at Port Townsend in the northern end of the watershed to 52 inches per year measured at Quilcene in the southern end. Precipitation also varies considerably from year to year. Annual precipitation in Port Townsend ranged from 13 to 28 inches from 1910 to 2016 and ranged from 26 to 79 inches in Quilcene from 1921 to 2018 (Figure 2). Average monthly rainfall in Port Townsend from 1981 to 2010 ranged from 0.7 inches in August to 2.7 inches in November; in Quilcene from 1921 to 2016, average rainfall ranged from 1.1 inches in July to 9.2 inches in December (Figure 2). For a more detailed description of the watershed, the reader is referred to two in-depth characterization reports: *The Discovery Bay Watershed*, prepared by the Puget Sound Cooperative River Basin Team (Nelson et al. 1992) and *Watershed Characteristics and Conditions Inventory* by Jones and Stokes Associates (1991).

Land Cover and Use

The Discovery Bay Watershed, when visited by Captain George Vancouver, was heavily forested to the salt water's edge, except for small open meadows and wetland marshes. Western red cedar and Douglas-fir were the dominant conifer species. Minor amounts of Sitka spruce were found along the lower stream corridor areas, and western hemlock was found in the higher elevation foothill areas. Hardwoods such as red alder, black cottonwood, and big-leaf maple were found along stream corridors, lakes, and wetland areas (Nelson et al. 1992). In their 1991 report of the Snow Creek Watershed, Jones and Stokes reported the following percentages of dominant species: Douglas-fir, 57%; western hemlock, 20%; red alder, 13%; western red cedar, <1%; true firs (noble fir and Pacific silver fir), <1%; non-forest areas, 8%.

Today, forests, with some scattered residential areas and farmland, typify Discovery Bay's mostly rural nature. Forestland constitutes 87% of the watershed and agricultural land comprises 4%. Most of the agricultural land occurs in the lower Snow Creek valley and is used for livestock grazing and hay production; a small amount is used for growing commercial vegetable crops. Residential land comprises about 3%, and

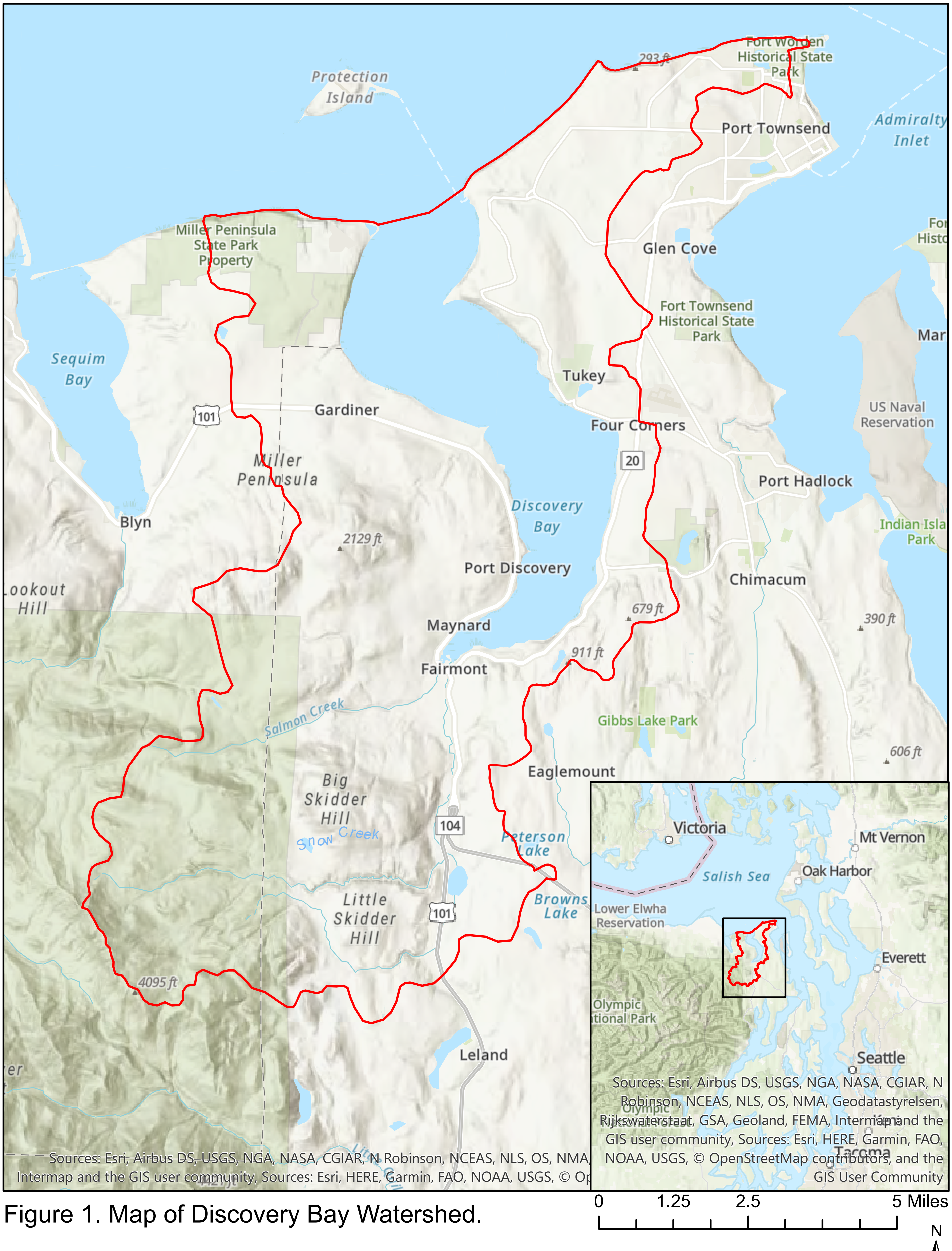


Figure 1. Map of Discovery Bay Watershed.

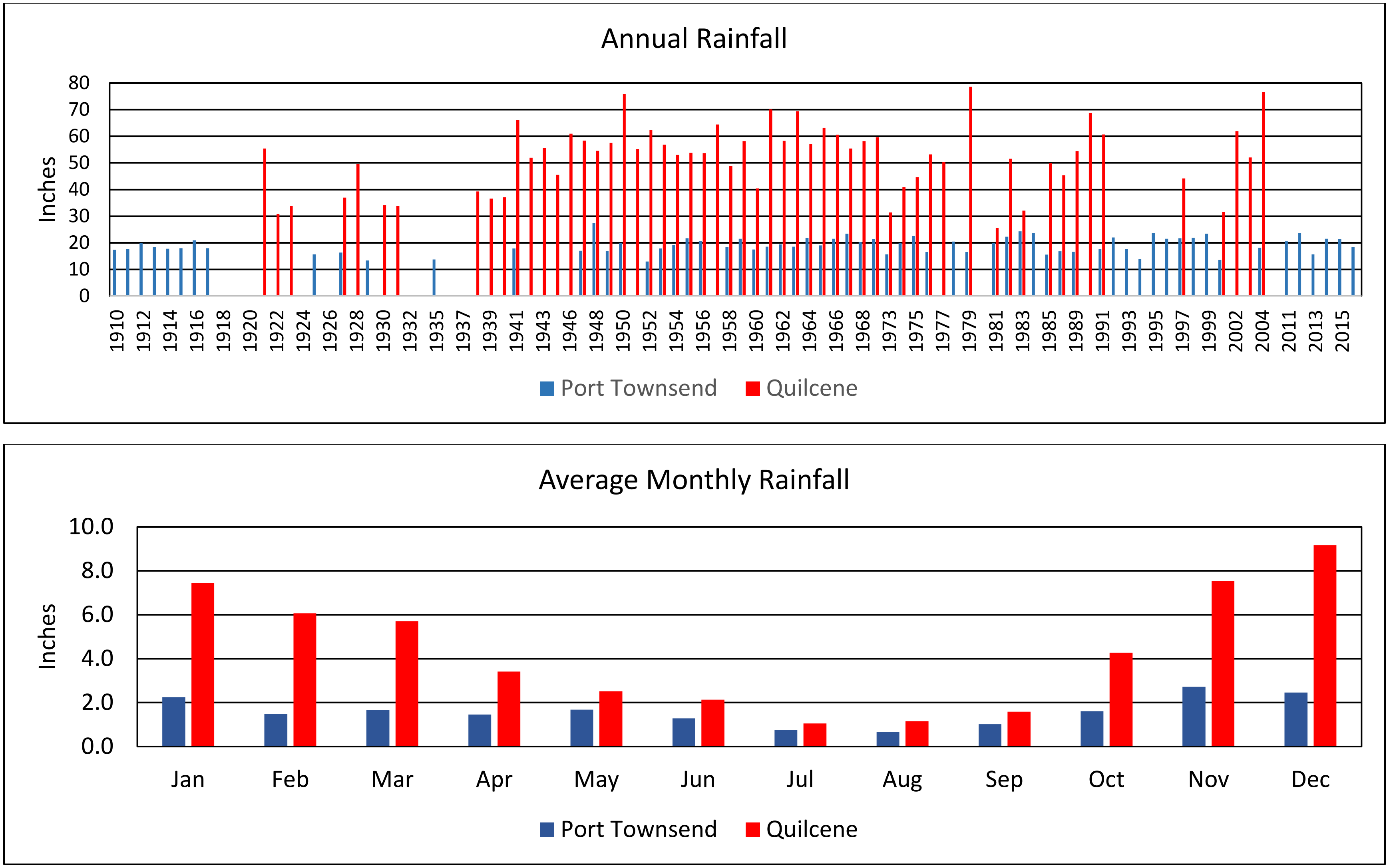


Figure 2. Annual rainfall for Port Townsend and Quilcene (top) and average monthly rainfall (bottom). Port Townsend monthly averages are for the years 1981 to 2010; Quilcene averages are for the years 1921 to 2016. Data provided by National Oceanic and Atmospheric Agency's National Centers for Environmental Information, Asheville, North Carolina.

includes the communities of Cape George, Beckett Point, Adelma Beach, Diamond Point, and Gardiner. The remaining 6% of the watershed is made up of miscellaneous cover types/land uses including grass/shrub areas and waterbodies (Nelson et al. 1992).

Soils

Soils in the watershed comprise four major types: soils on glacial till, 57%; soils on glacial outwash, 18%; soils on bedrock, 17%; and marine, lacustrine, alluvial, or organic soils, 8%. Permeability ratings for the four types range from slow to rapid. For varying reasons, 99% of the soil from the four types is categorized as presenting severe limitations to on-site sewage disposal (Nelson et al. 1992).

Streams

Snow Creek and Salmon Creek, which enter Discovery Bay at its south end, are the two major streams to Discovery Bay and have watersheds comprising 14,649 acres and 10,576 acres respectively. Contractors Creek, which enters the bay midway on its west side, has a drainage area of 1,958 acres (Nelson et al. 1992).

From 1977 to 1991, Snow Creek had an annual average flow of 22 cubic feet per second (cfs). The average annual low flow in August was 4 cfs. The largest peak flow recorded was 1,309 cfs on January 29, 1983 and the lowest flow recorded was 0.6 cfs on September 17, 1981 (Nelson et al. 1992).

From 1977 to 1982 Salmon Creek had an annual average flow of 8.4 cfs. The highest flow recorded was 1,048 on February 8, 1978 and the lowest flow was 0.3 cfs on September 13, 1981 (Nelson et al. 1992).

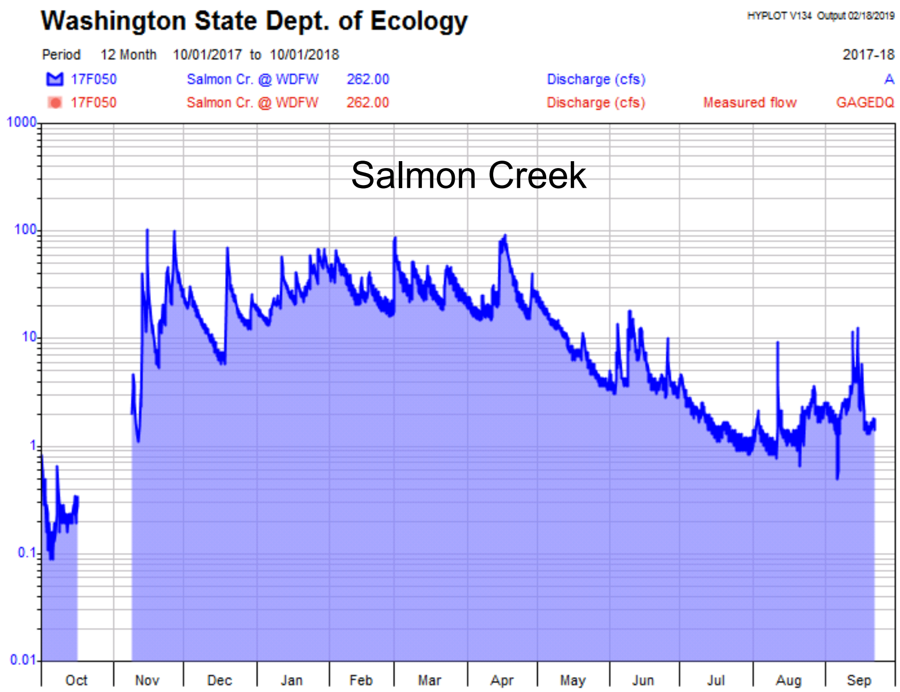
Salmon Creek and Snow Creek flows for the 2017-18 water year are shown in Figure 3.

Flow for Contractors Creek is limited to data collected by JCCD in 1994. Monthly flow measurements made that year ranged from 0.01 cfs to 0.98 cfs.

Fishes

Finfish inhabiting Discovery Bay streams include Coho Salmon, Chum Salmon, Steelhead (Rainbow Trout), Cutthroat Trout, Eastern Brook Trout (Andrews Creek), Sculpin, Three-spine Stickleback (*Gasterosteus aculeatus*), and Western Brook Lamprey (*Lampetra richardsoni*) (JCCD data). Pacific Lamprey (*Entosphenus tridentatus*), bluegill (*Lepomis macrochirus*), and brown bullhead (*Ameiurus nebulosus*) were caught at the Snow Creek weir (Washington Department of Fish and Wildlife data).

As part of the Salmon Creek Estuary Project, North Olympic Salmon Coalition (NOSC) conducted fyke netting in Salmon Creek's estuary from February to May each year from



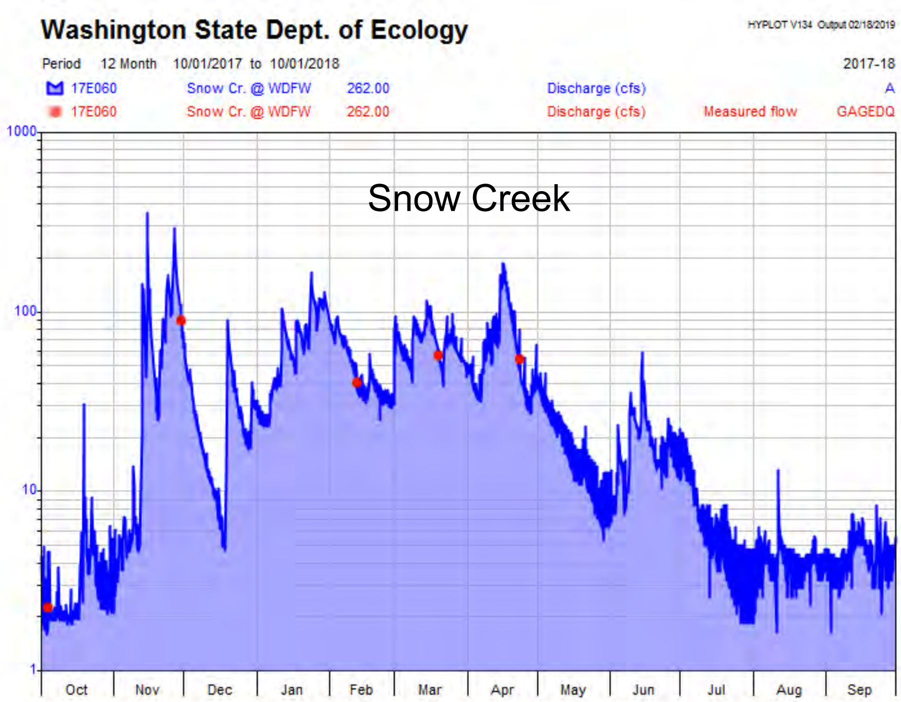


Figure 3. Comparison of Salmon Creek and Snow Creek flows measured from October 2017 to September 2018. Flows were obtained at Ecology's gaging stations at SAL/ 0.15 and SNO/0.8.

2009 to 2013. Of the 8,522 fish caught, 47 percent were juvenile Chum Salmon, 46 percent Staghorn Sculpin (*Leptocottus armatus*), and 5.5 percent Shiner Surfperch (*Cymatogaster aggregata*); in decreasing order of abundance, the remaining 1.5 percent were made up of Pacific Herring (*Clupea pallasii*), juvenile Pink Salmon (*Oncorhynchus gorbuscha*), juvenile Coho Salmon, Threespine Stickleback, Surf Smelt (*Hypomesus pretiosus*), Pacific Sardine (*Sardinops sagax*), and Pacific Sanddab (*Citharichthys sordidus*) (Sarah Doyle, personal communication, August 2018).

Fishes known to inhabit Discovery Bay are Coho Salmon, Chum Salmon, Steelhead (Rainbow Trout), Cutthroat Trout, White Sturgeon, Yelloweye Rockfish, Yellowtale Rockfish, Copper Rockfish, Quillback Rockfish, Rock Sole, English Sole, Starry Flounder, Pacific True Cod, Ling Cod, Surf Perch, Striped Perch, Herring, Sand Lance, and Smelt (Nelson et al. 1992).

Shellfish

Shellfish include Cockles, Littleneck Clams, Manila Clams, Butter Clams, Horse Clams, Softshell Clams, Mud Clams, Geoduck Clams, Coon Shrimp, Stripe Shrimp, Spot Shrimp, Pink Shrimp, Dungeness Crab, and Red Rock Crab. Sea Cucumbers are also found in the bay. In the early 1990s, shellfish brought about one-half million dollars a year to Discovery Bay growers and harvesters (Nelson et al. 1992).

Fecal Coliform Bacteria

In December 2006, Washington Department of Health (DOH) recommended a downgrade in classification from *Approved* for commercial harvesting to *Restricted* for commercial harvesting for approximately 50 acres in the southern part of Discovery Bay (Figure 4; Sargeant 2006). This was due to samples from station 48, the closest station to the mouths of Salmon Creek, Snow Creek, and Zerr Drain, failing the state fecal coliform standard. Since then, three more monitoring stations, closer to the creek mouths were added. In DOH’s December 2018 report, all Discovery Bay stations passed the standard. However, due to moderately high fecal coliform levels at station 196, the station currently closest to the creek mouths, the southern part of Discovery Bay was classified as “threatened with a downgrade.” The southern-most 50 acres is currently listed as “unclassified.”

Figure 4. Map of Discovery Bay showing marine stations monitored by Washington Department of Health.

METHODS

Monitoring Stations

Monitoring stations were selected using two criteria: 1) sites that were used in previous studies in order that comparisons can be made, and 2) sites bracketing (i.e. upstream and downstream) BMPs. Most recent monitoring was conducted monthly from November 2017 to April 2019, except that MST monitoring was conducted only from May 2018 to April 2019. No monitoring was conducted in January 2019 due to the federal government shutdown. The 19 stations monitored are shown in Figure 5.

Monitoring station numbers contain the river mile, which is the distance measured upstream from the mouth. For instance, water quality station SNO/3.5 on Snow Creek is located 3.5 miles upstream from the mouth. Water Resource Inventory Area 17 maps (Williams et al. 1975), topographic maps, and aerial photos were used in establishing station numbers. Monitoring station coordinates are provided in Appendix Table A-1.

Fecal Coliform Concentration

Fecal coliform samples were collected in sterilized bottles and analyzed within 30 hours at Spectra Laboratories in Poulsbo, Washington. All sample bottles were placed in a cooler containing ice. Spectra Laboratories carried out dilutions of 10% and 50%.

Replicate fecal coliform samples were collected at two stations on each sampling date. A different pair of stations was selected on each date. Quality control results are reported in Appendix B.

Fecal Coliform Loading

Fecal coliform loading, the number of fecal coliform bacteria flowing past a point in a given period of time, was calculated by the formula:

$$\text{FC loading (billions per day)} = FC \times Q \times 0.0246$$

where FC is the fecal coliform count per 100 mL of water; and Q is the stream flow (cfs).

Nitrate-Nitrogen and Total Phosphorus Loading

Nitrate-nitrogen (NO_3-N) and Total Phosphorus (TP) loading were calculated by the formula:

$$\text{Loading (pounds per day)} = C \times Q \times 5.39$$

where C is the concentration of NO_3-N or TP expressed as mg/L; and Q is the stream flow (cfs).

Figure 5. Map showing water quality stations.

Stream Flow

Washington Department of Ecology (Ecology) operates gauging stations at RM 0.2 on Salmon Creek and RM 0.8 on Snow Creek. Flow data were obtained from Ecology's web site https://fortress.wa.gov/ecy/eap/flows/station.asp?sta=17F050.

Flows for tributary streams and ditches were obtained by establishing regressions (i.e., correlations) to Snow Creek and Salmon Creek. Flows were measured on both the gaged and ungaged streams on the same day within a few hours of one another. Numerous velocity measurements were taken across each stream with a Marsh-McBirney current meter (Model 201D), calculating flows for the individual subsections, and summing them.

The formula used was:

$$Q = \Sigma (A \times V)$$

where Q is the total flow (cubic feet per second or cfs);

A is the area ($ft.^2$) of an individual subsection;

and V is the corresponding mean velocity (feet per second)

of that subsection.

Regression analyses yielded the following equations:

Waterbody	Station	Regression Equation	No. of cases	Slope probability
Salmon Creek	SAL/0.15	SAL/0.15=0.403*SNO/0.8	11	0.0000
Andrews Creek	AND/0.0	AND/0.0=0.429*SNO/0.8	18	0.0000
Uncas Valley Ditch	UVD/0.0	UVD/0.0=0.00483*SAL/0.7	3	0.001
Tucker Ditch	TUD/0.1	TUD/0.1=0.00785*SAL/0.7	3	0.0261
Houck Creek	HOU/0.02	HOU/0.02=0.073*SAL/0.7	13	0.0000
Contractors Creek	CON/0.0	CON/0.0=0.0559*SAL/0.7	11	0.0001

Microbial Source Tracking in 2012-13

In the 2012-13 water-year, samples were collected for deoxyribonucleic acid (DNA) analysis of the bacteria *Bacteroides* spp. for "microbial source tracking" or MST. Samples were collected in 250 mL sterilized bottles, packed in a cooler with ice, and shipped to the Environmental Protection Agency (EPA) laboratory in Port Orchard, Washington where they arrived the next day. The samples were filtered and frozen within 48 hours of sample collection and analyzed by polymerase chain reaction (PCR) and electrophoresis at a later date. The samples were analyzed for "general" (any warm-blooded animal), "ruminant," or "human" biomarkers.

As part of the quality control procedure, two laboratory duplicates were analyzed for each batch of samples. Additionally, several "blind" samples were submitted for analysis during the course of the study. The blind samples were made by placing about 1 gram of manure from known sources (cattle, chicken, and human) into bottles containing sterilized water. They were submitted to the laboratory for analysis without identifying the source.

In order to better assess the MST results, additional details of the methods used are provided in the Results and Discussion section.

Microbial Source Tracking in 2018-19

From May 2018 to April 2019 (excluding January), MST samples were collected monthly for deoxyribonucleic acid (DNA) analysis. Samples were collected in 250 mL sterilized bottles, packed in a cooler with ice, and hand-delivered to the Environmental Protection Agency (EPA) laboratory in Port Orchard, Washington. The samples were filtered and frozen within 24 hours of sample collection. At a later date the samples were analyzed by quantitative polymerase chain reaction (qPCR). Through a process of amplification, copies were made of each target biomarker (if present in the sample). The number of copies (quantification number) of each kind of biomarker was recorded. All samples were tested for two "human" biomarkers and two "cattle" biomarkers. Station ZER/0.11 was also tested for one "avian" biomarker.

As part of the quality control procedure, a field duplicate and a transfer blank were collected on each sampling date. Additionally, reference samples were collected in the form of one primary effluent sample from the Port Townsend Sewage Treatment Plant and one sample each of cattle manure and goose feces. Sources (e.g., human, cattle, or avian) were made known to laboratory personnel.

Temperature

Hobo U22 Water Temp Pro v2 temperature data loggers (TDLs), manufactured by Onset Computer Corporation, were used in this study. The TDLs have an accuracy of plus or minus 0.2 degrees Celsius.

TDLs were programmed to record temperature every hour. In 2019, they were maintained at 15 stations in the Discovery Bay Watershed from May 1 or June 1 to mid-October throughout the study (Figure 6). Most of these TDL stations were monitored in previous years by JCCD. Coordinates of station locations are provided in Appendix Table A-2. Data loggers were placed on the stream bottom in deeper areas of the stream. They were attached to 0.5 inch rebar with #14 black, single-strand electrical wire.

Temperature profile graphs were made for each station and the number of days on which the 7-DADMax exceeded the standard was calculated. Prior to 2004 the state

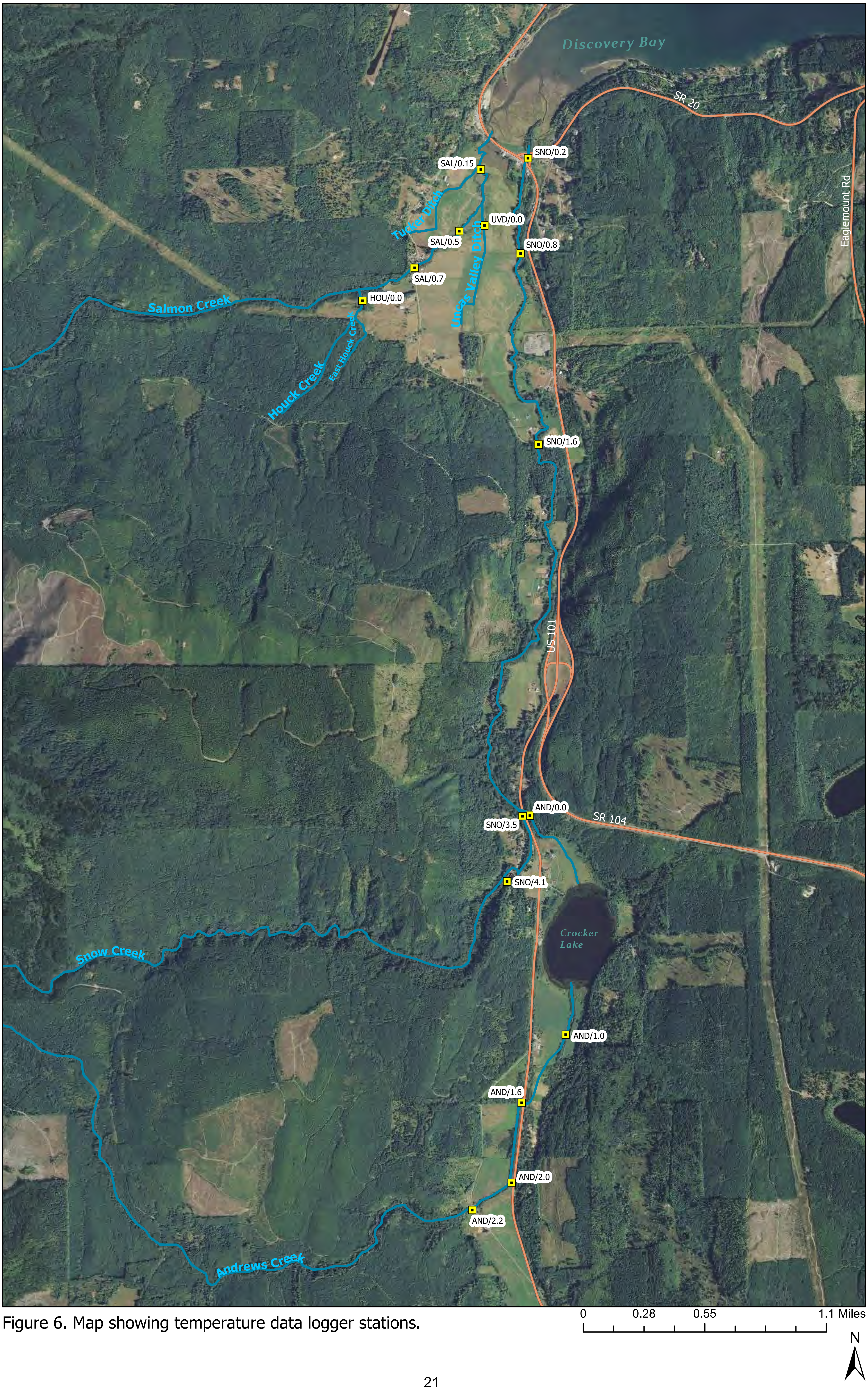


Figure 6. Map showing temperature data logger stations.

standard was based on a single temperature measurement that was not to exceed 16 degrees Celsius. The number of days that the 7-DADMax exceeded 16 degrees Celsius was calculated for the pre-2004 data in order to assess temperature trends consistently.

Because the data loggers were not in the streams all year (data loggers can be easily lost during winter high flows), the number of days that the 13 degree Celsius standard was exceeded should be considered a minimum.

Single temperature measurements were also taken at the time the fecal coliform samples were collected. Temperature was measured with Yellow Springs Instrument (YSI) model 556 and model Pro Dss meters. The YSI meters were not designed to alter the factory-set temperature calibration. However, temperature measurements of the two YSIs used in this study were periodically compared to each other and were always within 0.2 degrees Celsius of one another.

Turbidity

JCCD staff collected turbidity samples in 125 mL high density polyethylene bottles and analyzed the samples with a Hach model 2100N turbidity meter at the JCCD laboratory in Port Hadlock within the prescribed 2-day holding time. JCCD staff used turbidity procedure 214 A in Standard Methods (APHA 1981).

Surface Dissolved Oxygen, pH, and Conductivity

Dissolved oxygen, pH, and conductivity were measured with YSI models 556 and Pro Dss meters. The meters were calibrated prior to sampling on each sampling date.

pH was calibrated in the JCCD laboratory using 4.00, 7.02, and 10.06 buffer standards.

Conductivity was calibrated in the laboratory using a 718 umho/cm standard.

Additional checks were periodically accomplished in the field by comparing measurements of the two meters.

Intragravel Dissolved Oxygen

Intragravel dissolved oxygen (IGDO) monitoring was conducted in the historical Summer Chum spawning ground in Salmon Creek from 2001 to 2010. In late July/early August, simulated "redds" were dug to a depth of about 7 inches in different riffles of several reaches of Salmon Creek from just above the estuary at RM 0.1 to its confluence with Houck Creek at RM 1.0. A 4-inch aquarium air stone was placed in the "redd" with 6 feet of tubing trailing in the current. Two or three 1-2 inch stones were placed over the air stone and then the "redd" was filled in with bottom material from immediately upstream. An aluminum tag, engraved with a station identification number, was secured to the tubing with aluminum wire.

Water samples were collected by means of a battery-powered drill and peristaltic pump. Samples were collected in 60-mL BOD bottles after discarding the first 60 mL to clear the tubing. Samples were analyzed using the azide modification of the Winkler method (APHA 1981 Standard Methods 421B). Samples were "fixed" on-site with 8 drops of manganous sulfate solution and 8 drops of alkaline-iodide azide solution. The samples were transported to the JCCD lab where 0.5 mL 50%-sulfuric acid was added to the sample bottles to dissolve the precipitate. When the precipitate was dissolved (10-20 minutes), the samples were titrated with a Hach digital titrator using 0.0250 N sodium thiosulfate solution. Two 20-mL titrations were made on each sample and the results averaged. A third titration was made if the results of the first two were not within 0.5 mg/L. If three measurements were made, the two closest measurements were averaged.

Relative Fish Abundance

Fish trapping was conducted to obtain an index of relative fish abundance (RFA) for a particular stream reach in order to assess BMPs in terms of salmonid habitat improvement. Landowners and other volunteers were trained in fish trapping and fish identification. The traps used were standard minnow traps (Cuba Specialty Mfg. Co.) made of ¼-inch wire mesh with a $^7/_8$-inch opening in each of the funnel ends. Traps were baited with bread and set overnight for a one-day trapping period. Volunteers identified, enumerated, and then released the fish. Data were recorded on standardized forms. Usually at least two traps were set in a stream reach on each trapping day and a minimum of 9 sets were made each quarter. Traps were often moved around within the stream reach. RFAs were calculated for each species for each of the four quarters (Q) of the year, roughly corresponding to winter (Q1), spring (Q2), summer (Q3), and fall (Q4). The formula used was:

$$RFA = \sum F / \sum T$$

where F is the number of fish caught (by species) within the quarter;
and T is the number of traps set in that quarter.

Climate Data

Rainfall and temperature data were obtained from the National Climatic Data Center (NCDC) in Asheville, North Carolina from their website (http://www.ncdc.noaa.gov/).

Statistics

Box and whisker plots were used to graphically show parameter concentrations at the various monitoring stations. Interpretation of the box and whisker plot is shown in Figure 7.

Two statistical tests, linear regression and Spearman rank coefficient, were used to determine if one parameter is related to another parameter. With linear regression a

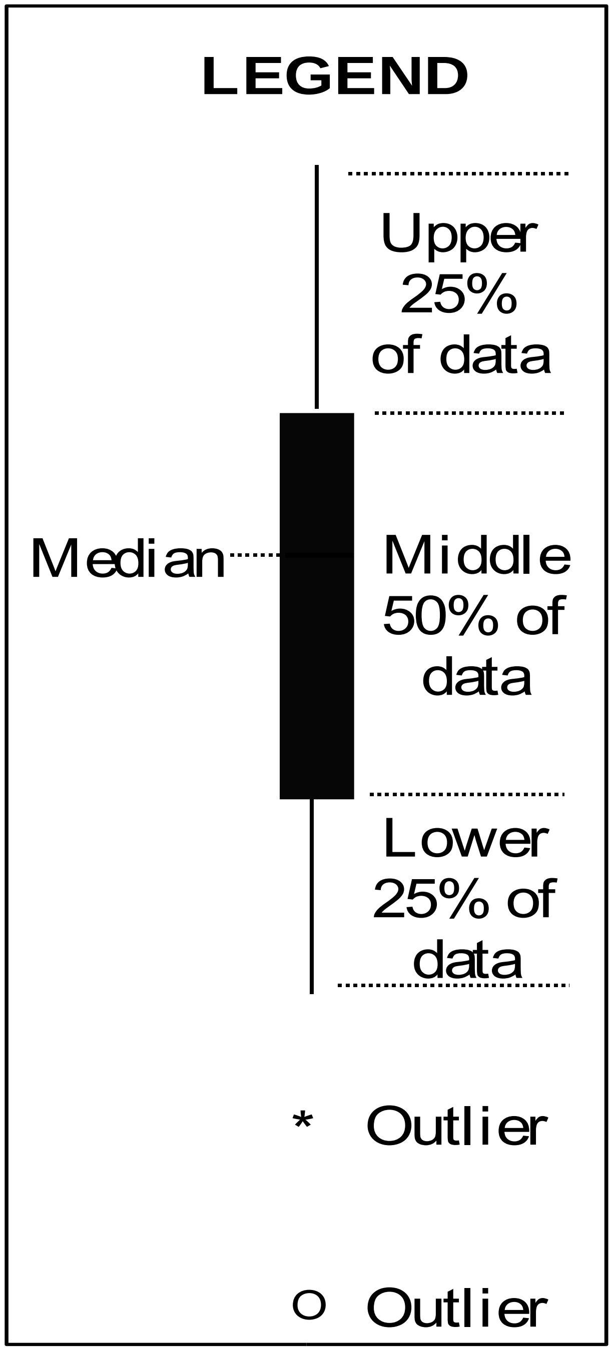


Figure 7. In the box and whisker plot shown above the shaded area within the box represents the middle 50 percent of the data and the horizontal line within the box is the median. Fifty percent of the data points are above the median and 50 percent are below it. The upper vertical line or "whisker" represents the upper 25 percent of the data, and the lower "whisker" represents the lower 25 percent. A "whisker" always ends at a data point and cannot be more than 1.5 times the length of the box. Data points which fall beyond 1.5 times the length of the box are called "outliers." An outlier 1.5-3.0 times the length of the box is represented by an asterisk (*) and a data point greater than 3 times the length of the box is represented by a circle (o).

“best fit” line is drawn through points on an x-y graph. If the line slopes upward, the correlation is positive; if it slopes downward, the correlation is negative. An R^2 value and probability (p) are associated with the regression line. The R^2 value can be between 0 and 1. If there were a perfect correlation with all the points on the line, R^2 would equal 1. The closer R^2 is to zero, the worse is the correlation. The probability (p) value denotes the degree of confidence one can have in the correlation. A p value of 0.05 denotes a confidence of 95%; p=0.01 denotes 99% confidence. The lower the p value, the greater is the confidence. One can also get a feel for the degree of correlation by visually observing how close the points are to the line. See Figures 13, 14, 16, and 17 for examples. The trend lines in Figures 46-49 are actually regression lines.

Spearman Rank coefficients vary from -1 to +1, with +1 being a perfect positive correlation and -1 being a perfect negative or inverse correlation. Zero indicates no correlation. Probability (p) values denote the degree of confidence in the correlation coefficients. See Table 3 for examples.

Statistical tests were made with *Statistix 10* from Analytical Software, PO Box 12185, Tallahassee, Florida 32317-2185, www.statistix.com. Additionally, trends (i.e. regression lines) were obtained using Microsoft Excel 2013.

RESULTS AND DISCUSSION

Bacteria

Indicator of Potential Disease

Fecal coliform bacteria originate in the digestive tract of warm-blooded animals and are released into the environment through excretion. They serve as an indicator of disease-causing organisms released with them. The rationale is that an increase in the bacteria's concentration indicates an increased chance that pathogens are also present. The higher the concentration of fecal coliform, the greater is the chance for disease.

The use of coliform bacteria as an indicator of potential pathogens has some limitations. The coliform indicator system was initially based on a series of assumptions about the relationships between coliform bacteria, pathogenic organisms, and human sewage. Originally intended for large, somewhat predictable discharges of human sewage, the coliform indicator system has been broadened to include nonpoint sources such as on-site septic systems, boater wastes, stormwater run-off and animal wastes (Lilja and Glasoe 1993). Some authorities believe that the coliform indicator system is poorly suited for assessing these more variable pollution sources. This is particularly true for animal wastes because research suggests that the risk of viral infection from animal wastes may be less than that associated with human sewage (Stelma and McCabe 1992; Lilja and Glasoe 1993). Also, *E. coli* has been shown to persist longer than some pathogens in the presence of algae and may overestimate the risk (Englebert et al. 2008 A).

However, to say that the risk is less is not to say that no risk exists. Many bacterial pathogens are known to be communicated from animals to man (Acha and Szyfres 1980) and can be transmitted via shellfish (Bidwell and Kelly 1950; Stelma and McCabe 1992; Lilja and Glasoe 1993). Bacterial pathogens of greatest concern include various species in the genera *Salmonella, Shigella, Escherichia, Listeria*, *Yersinia, Campylobacter, Vibrio*, and *Leptospira* (Lilja and Glasoe 1993). *Salmonella*, one of the more common of these pathogens, occurs in a broad range of domestic and wild animals including cattle, swine, sheep, goats, horses, dogs, cats, rodents, chickens, ducks, and geese (Acha and Szyfres 1980).

Two Protozoan parasites, *Giardia lamblia* and *Cryptosporidium spp.*, have the potential to be transmitted from animals to humans via shellfish and water (Stelma and McCabe 1992). *Giardia duodenalis* and *Cryptosporidium spp.* have been found in sheep, cattle, goats, swine, and horses (Willis et al. 2013). Cysts from these parasites can remain viable in water for up to 1 year.

Some viruses common to both humans and animals are capable of crossing species barriers and producing disease (Stelma and McCabe 1992). Therefore, it is conceivable that humans could acquire viral illnesses from shellfish contaminated with animal viruses, especially the rotaviruses, which are environmentally stable in fresh water and seawater (Stelma and McCabe 1992).

Until the 1980s, fecal coliform bacteria have been considered only as indicators of potential pathogens. However, it is now recognized that *Escherichia coli O157:H7*, a fecal coliform bacterium, is itself a pathogen. *E. coli O157:H7* was first recognized as a pathogen in the early 1980s. In 1990, its contamination of a drinking water supply in Missouri resulted in over 200 illnesses (Swerdlow et al. 1992). In 1993, *E. coli O157:H7* received nationwide attention when it caused a serious outbreak of illnesses in Washington State (Bell et al. 1994). Undercooked beef hamburgers, contaminated with *E. coli O157:H7* proved to be the cause of the deaths and illnesses.

In a study conducted throughout Washington State, *E. coli O157:H7* was found in 10 of 3,570 (0.28%) fecal samples (rectal swabs and cow pies) from 5 of 60 (8.3%) dairy herds (Hancock et al. 1994). The prevalence was almost twice as high in weaned calves as in older animals. Of the 10 months sampled, *E. coli O157:H7* was identified only during the months of June, July, and September. *E. coli O157:H7* was found in 10 of 1,412 (0.71%) fecal samples (rectal swabs) from *pastured* beef cattle from 4 of 25 (16%) herds. The prevalence in *feedlot* cattle was 2 of 600 (0.33%) samples (cow pies) from 2 of 20 (10%) feedlot pens.

In another study, 1,266 fecal samples from dairy cows from 22 dairy farms, a stockyard, and a packinghouse in Washington, Oregon, and Wisconsin were analyzed for *E. coli O157:H7* (Wells et al. 1991). *E. coli O157:H7* was identified in fecal samples from 0.15% of healthy adult cows (>24 months old) and in 2.8% of samples from healthy heifers (4-24 months) and calves (<4 months). The authors concluded that dairy cows are a reservoir of *E. coli O157:H7*.

In a survey of the literature, Ferens and Hovde (2011) stated: *E. coli O157:H7* strains are carried primarily by healthy cattle and other ruminants; the incidence of *E. coli O157:H7* is higher in post-weaned calves and heifers than in younger and older animals; the prevalence of *E. coli O157:H7* in cattle peaks in summer. Virulent strains of *E. coli O157:H7* are rarely found in pigs or chickens, but are found in turkeys. With the exception of deer, *E. coli O157:H7* is only sporadically carried by domestic animals and wildlife associated with humans (e.g., rodents and birds). *E. coli O157:H7* occurs in amphibians, fishes, and invertebrates, and can colonize plant surfaces and tissues via attachment mechanisms different from those used in intestinal tracts.

The possibility exists that animal feces containing *E. coli O157:H7* could contaminate a stream and eventually the marine water, where it could be concentrated in shellfish. This is essentially what researchers at the U.S. Food and Drug Administration (FDA) Seafood Products Research Center concluded after conducting experiments on *E. coli O157:H7* survival rates in waters of varying salinities and temperatures and in oysters injected with this bacterium (Kaysner et al. 1994). They concluded, "It appears that *E. coli O157:H7* can survive under aquatic [freshwater] and estuarine conditions for extended periods which may lead to possible contamination of shellfish and their growing area."

It should be understood that *E. coli O157:H7* is a relatively rare strain of *E. coli* and one should not equate this rare pathogenic strain with the much more prevalent non-pathogenic ones. *E. coli O157:H7* has not been associated with JCCD studies or any other monitoring study conducted in Jefferson County. However, it is a possibility and is one more reason for preventing cattle manure from entering the streams and being concentrated in shellfish in Discovery Bay.

Ecology's New Bacteria Standard

In February 2019, Ecology replaced the fecal coliform standard with an *E. coli* standard. However, the fecal coliform standard remains in effect until December 31, 2020 and will be used to evaluate this study.

Another change that took place in February 2019 was eliminating the "extraordinary primary contact recreation" criteria for fecal coliform bacteria. Jefferson County streams now need only meet the criteria for "primary contact recreation." This change effectively doubled the allowable fecal coliform concentration for both parts of the standard.

The current "primary contact recreation" criteria are as follows: Part 1 requires that the geometric mean value (GMV) not exceed 100 colonies of fecal coliform bacteria in 100 milliliters of water (100 FC/100mL). Part 2 requires that not more than 10% of the samples exceed 200 FC/100 mL. Both parts need to be met to pass the standard. Additionally, wet months (October – April) and dry months (May – September) are analyzed separately and the standard must be met during both periods.

Monitoring Results for 2017 – 2019

During the entire 18-month monitoring period from November 2017 to April 2019, which covered two wet seasons and one dry season, 9 of the 19 stations failed the standard (Table 1). Failures occurred at one or more stations on Andrews Creek, Contractors Creek, Salmon Creek, Snow Creek, Tucker Ditch, Uncas Valley Ditch, and Zerr Drain. Only Houck Creek passed the standard in all three seasons. Most of the failures occurred in the dry season and most were due to not meeting part 2 of the standard.

Table 1. Discovery Bay Watershed monitoring stations showing status relative to state fecal coliform standard. Part 1 of the standard requires that the geometric mean value (GMV) not exceed 100 FC/100 mL and part 2 requires that not more than 10% of the samples exceed 200 FC/100 mL. Both parts need to pass for the standard to be met . Stations were monitored monthly from November 2017 to April 2019. Highlighted cells indicate failures under the previous fecal coliform stanard.

Station	Wet Season Nov 17 - Apr 18		Dry Season May 18 - Sep 18		Wet Season Oct 18 - Apr 19	
	Part 1	Part 2	Part 1	Part 2	Part 1	Part 2
AND/0.0	Pass	Pass	Pass	Pass	Pass	Pass
AND/1.71	Pass	Pass	Pass	Pass	Pass	Pass
CON/0.4	Pass	Pass	Pass	Fail	Pass	Pass
HOU/0.0	Pass	Pass	Pass	Pass	Pass	Pass
SAL/0.15	Pass	Pass	Pass	Fail	Pass	Pass
SAL/0.5	Pass	Pass	Pass	Fail	Pass	Pass
SAL/0.7	Pass	Pass	Pass	Pass	Pass	Pass
SAL/1.0	Pass	Pass	Pass	Pass	Pass	Pass
SNO/0.2	Pass	Pass	Pass	Pass	Pass	Pass
SNO/0.8	Pass	Pass	Pass	Pass	Pass	Pass
SNO/1.6	Pass	Pass	Pass	Pass	Pass	Pass
SNO/2.3	Pass	Pass	Pass	Fail	Pass	Pass
SNO/3.5	Pass	Pass	Pass	Fail	Pass	Pass
SNO/3.9	Pass	Pass	Pass	Fail	Pass	Pass
TUD/0.0	Pass	Pass	Pass	Pass	Pass	Pass
TUD/0.4	Pass	Pass	Pass	Pass	Pass	Pass
TUD/0.5	Pass	Pass	Pass	Fail	Pass	Pass
UVD/0.0	Pass	Fail	Pass	Fail	Pass	Fail
ZER/0.11	Pass	Fail	Fail	Fail	Pass	Pass

Had the “extraordinary primary contact recreation” criteria still been in effect, an additional four stations would have failed the standard: one on Andrews Creek (AND/1.71) and three on Snow Creek (SNO/0.2, SNO/0.8, SNO/1.6).

Over the entire 18-month period, GMVs were highest for Uncas Valley Ditch (43 FC/100 mL) and Zerr Drain (41 FC/100 mL; Figure 8). GMVs generally increased from upstream to downstream in Salmon Creek, Snow Creek, and Tucker Ditch. In contrast, Andrews Creek had a higher GMV at the upstream station, but this comparison is compromised because Crocker Lake is between the two stations.

Samples taken every two hours on Salmon Creek showed much variation within the 24-hour monitoring period (Figure 9). In March 2018, the FC concentration at station SAL/0.5 increased from 24 FC/100 mL at 20:00 hours to 144 FC/100 mL at midnight. In July, the concentration at station SAL/0.2 increased from 64 FC/100 mL at 22:00 hours to 130 FC/100 mL at 04:00 hours the following morning. Less variation occurred in Snow Creek. In March 2018, the fecal coliform level at station SNO/0.8 ranged from 1 FC/100 mL to 10 FC/100 mL for all hours except at 04:00 hours when it reached a high of 28 FC/100 mL.

Trends and Correlations

Examination of long-term data (1988-2019) showed downward trends in Salmon Creek, Snow Creek, Andrews Creek, Houck Creek, Tucker Valley Ditch, and Zerr Drain (Figures 10 and 11). Whereas, upward trends occurred in Contractors Creek and Uncas Valley Ditch.

Spearman rank analysis of long-term data showed moderately high positive correlations (average = 0.57) of fecal coliform with temperature at all monitoring stations (Table 2). Fecal coliform concentrations at downstream stations on Salmon Creek and Snow Creek followed a seasonal temperature pattern with the highest concentrations in August and September (Figure 12).

Fecal coliform’s correlation with conductivity was also positive and fairly high (average = 0.43; Table 2). Correlation with dissolved oxygen was almost always negative (inversely correlated) with an average of -0.43. Correlation with stream flow was mostly negative, averaging -0.36. Correlation with pH was positive at 17 of the 20 stations with 13 of the correlations being significant ($p<0.05$).

Correlation of fecal coliform with turbidity was negative at 13 stations and positive at 7 stations (Table 2). Only 6 of the 20 correlations were significant ($p<0.05$): 3 being positive and 3 negative. Ten of 11 Salmon Creek and Snow Creek stations had negative turbidity correlations. Andrews Creek’s downstream station had a moderately high (0.55) significant positive correlation ($p=0.00$) with turbidity.

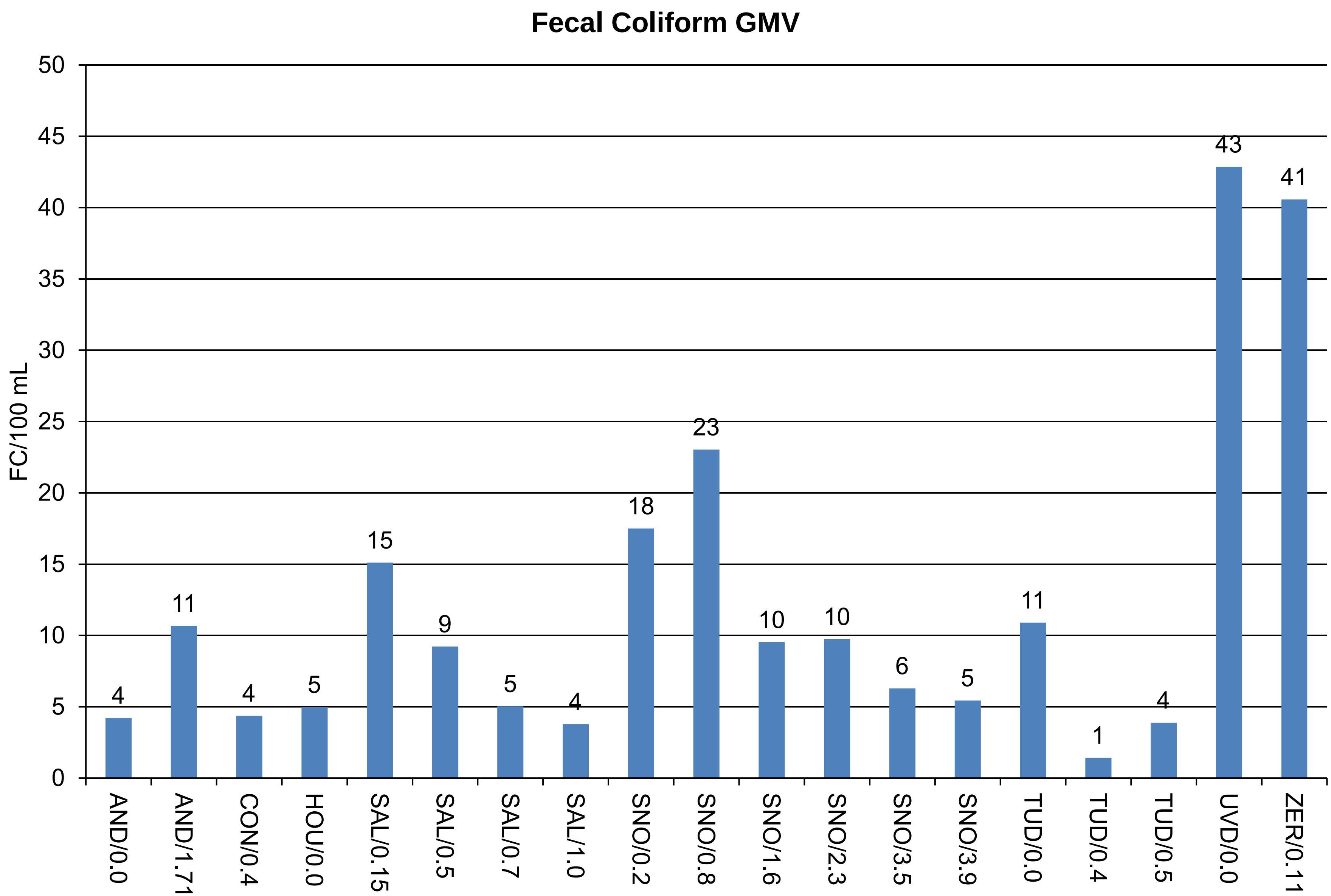


Figure 8. Fecal coliform GMVs for stations monitored monthly in the Discovery Bay Watershed from November 2017 to April 2019.

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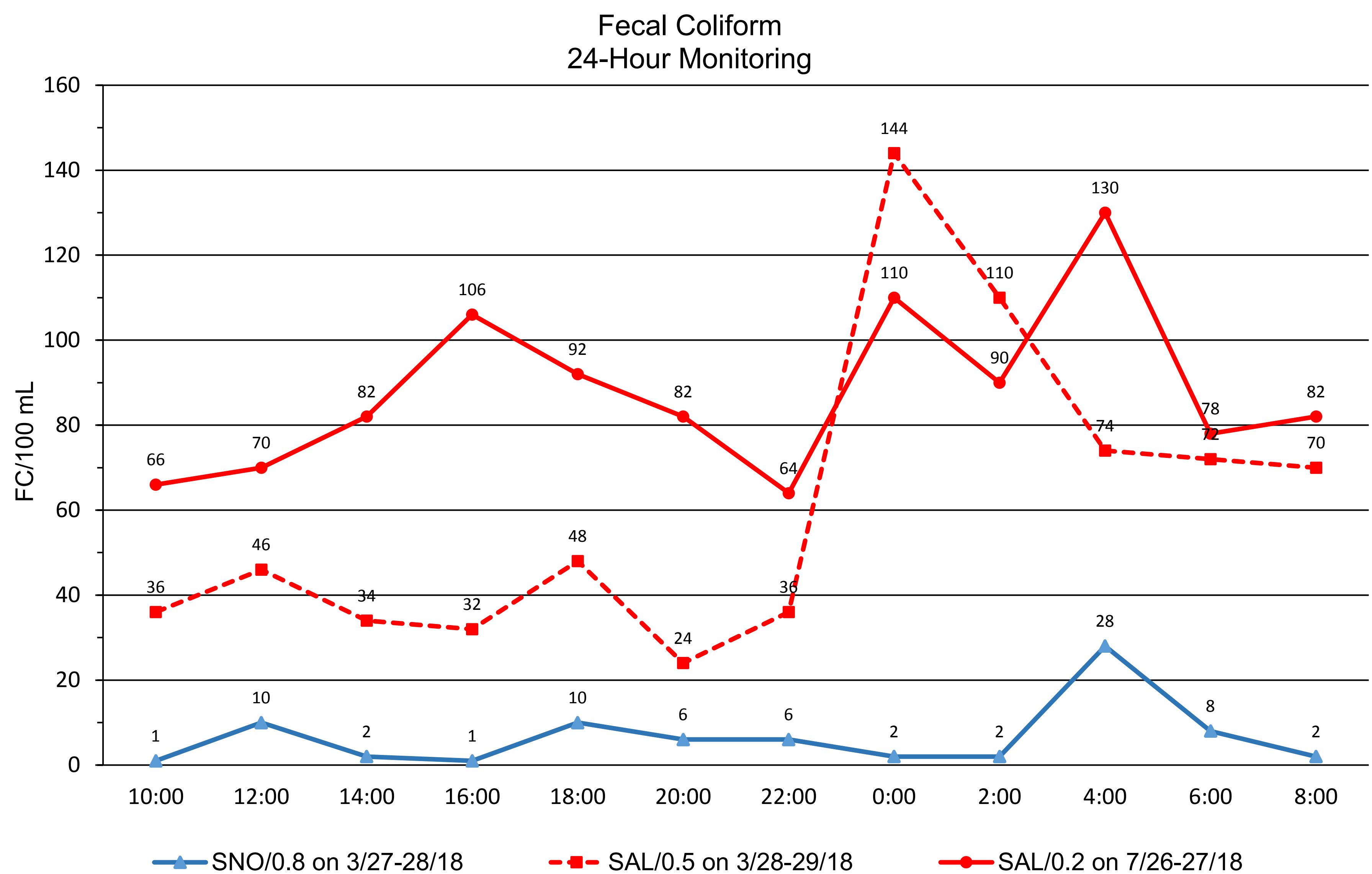

Figure 9. Fecal coliform concentration sampled every 2 hours over a 24-hour period on Snow Creek station SNO/0.8 on March 27-28, 2018 and on Salmon Creek station SAL/0.5 on March 28-29, 2018 and station SAL/0.2 on July 26-27, 2018.

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Fecal Coliform Trends

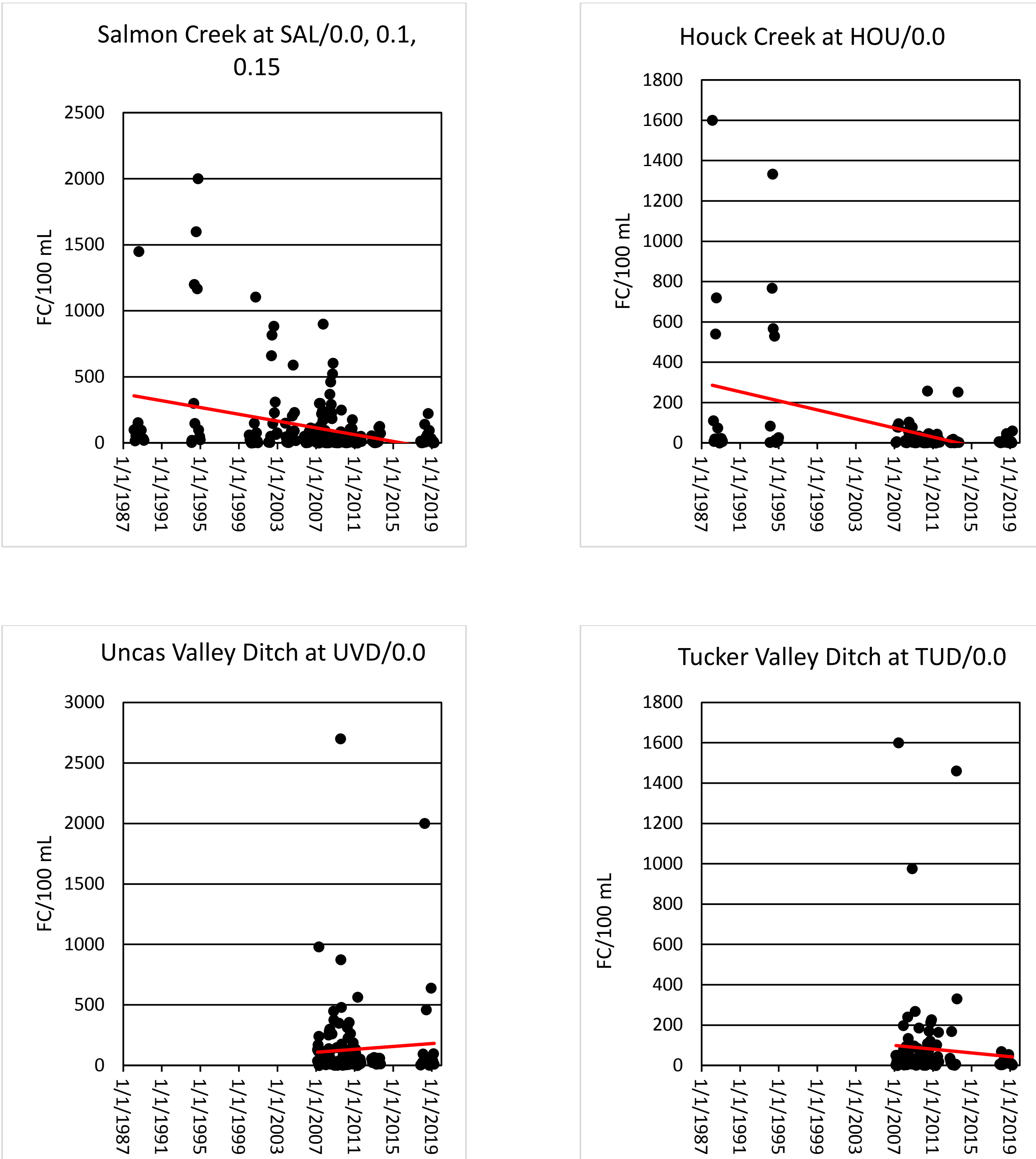

Figure 10. Time series plots of fecal coliform concentration (with regression line) at downstream stations on Discovery Bay streams. Note different scales in different graphs.

Fecal Coliform Trends

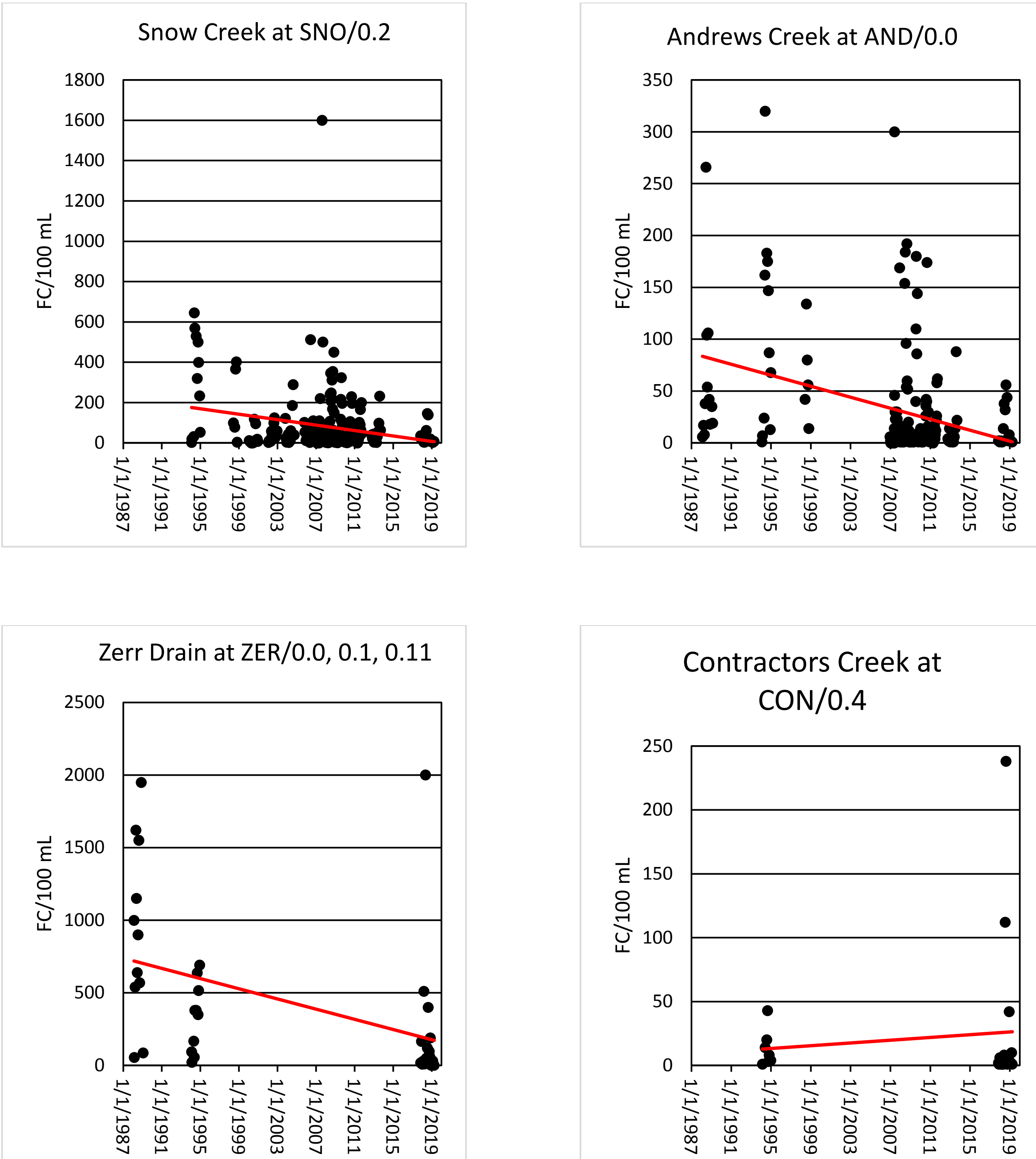

Figure 11. Time series plots of fecal coliform concentration (with regression line) at downstream stations on Discovery Bay streams. Note different scales in different graphs.

Table 2. Correlation of fecal coliform with other parameters by Spearman rank for data collected in the Discovery Bay Watershed from 1993 to 2018; +1 indicates a perfect positive correlation; -1 indicates a perfect inverse correation; and 0 indicates no correlation. Probability is shown below coefficient.

	AND/0.0	AND/1.71	CON/0.4	HOU/0.0	SAL/0.1	SAL/0.15	SAL/0.5	SAL/0.7	SAL/1.0	SNO/0.2	SNO/0.8
Sample size	64	86	16	58	30	67	71	103	85	103	51
Temperature	0.49	0.45	0.41	0.48	0.64	0.72	0.76	0.70	0.66	0.67	0.70
p-value	0.0000	0.0000	0.1172	0.0002	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Turbidity	0.55	-0.19	0.32	0.38	-0.04	-0.15	-0.17	0.04	-0.11	-0.19	-0.40
p-value	0.0000	0.0738	0.2302	0.0035	0.8252	0.2256	0.1443	0.6599	0.4017	0.0615	0.0043
Conductivity	0.42	0.28	0.35	0.25	0.49	0.58	0.63	0.49	0.52	0.42	0.54
p-value	0.0005	0.0081	0.1841	0.0554	0.0061	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001
pH	-0.31	0.31	0.06	0.21	-0.12	0.58	0.40	0.38	0.49	-0.01	0.33
p-value	0.0122	0.0043	0.8307	0.1104	0.5326	0.0000	0.0005	0.0001	0.0001	0.9263	0.0176
Dissolved Oxygen	-0.53	-0.19	-0.08	-0.44	-0.61	-0.64	-0.76	-0.63	-0.50	-0.65	-0.63
p-value	0.0000	0.0833	0.7629	0.0006	0.0004	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000
Flow	-0.56			-0.13		-0.53					-0.69
p-value	0.0054			0.5975		0.0081					0.0000
Flow sample size	24			18		24					51

	SNO/1.6	SNO/2.3	SNO/3.5	SNO/3.9	TUD/0.0	TUD/0.4	TUD/0.5	UVD/0.0	ZER/0.11	Average
Sample size	71	49	58	38	41	39	83	83	47	63
Temperature	0.67	0.67	0.66	0.53	0.48	0.44	0.49	0.30	0.45	0.57
p-value	0.0000	0.0000	0.0000	0.0007	0.0018	0.0051	0.0000	0.0067	0.0016	0.0064
Turbidity	-0.37	-0.48	-0.21	-0.31	0.35	-0.13	0.16	0.02	-0.09	-0.05
p-value	0.0019	0.0005	0.1106	0.0590	0.0240	0.4203	0.1485	0.8888	0.5320	0.2429
Conductivity	0.43	0.46	0.42	0.28	0.43	0.55	0.37	0.25	0.48	0.43
p-value	0.0002	0.0009	0.0012	0.0878	0.0056	0.0004	0.0006	0.0241	0.0006	0.0179
pH	0.08	0.41	0.42	0.39	-0.26	0.58	0.25	0.09	0.47	0.24
p-value	0.5104	0.0035	0.0010	0.0172	0.1065	0.0002	0.0258	0.4170	0.0008	0.1678
Dissolved Oxygen	-0.60	-0.60	-0.57	-0.46	-0.48	0.06	-0.17	0.02	-0.07	-0.43
p-value	0.0000	0.0000	0.0000	0.0036	0.0017	0.7016	0.1326	0.8368	0.6623	0.1517
Flow					0.13					-0.36
p-value					0.7090					0.2640
Flow sample size					9					25

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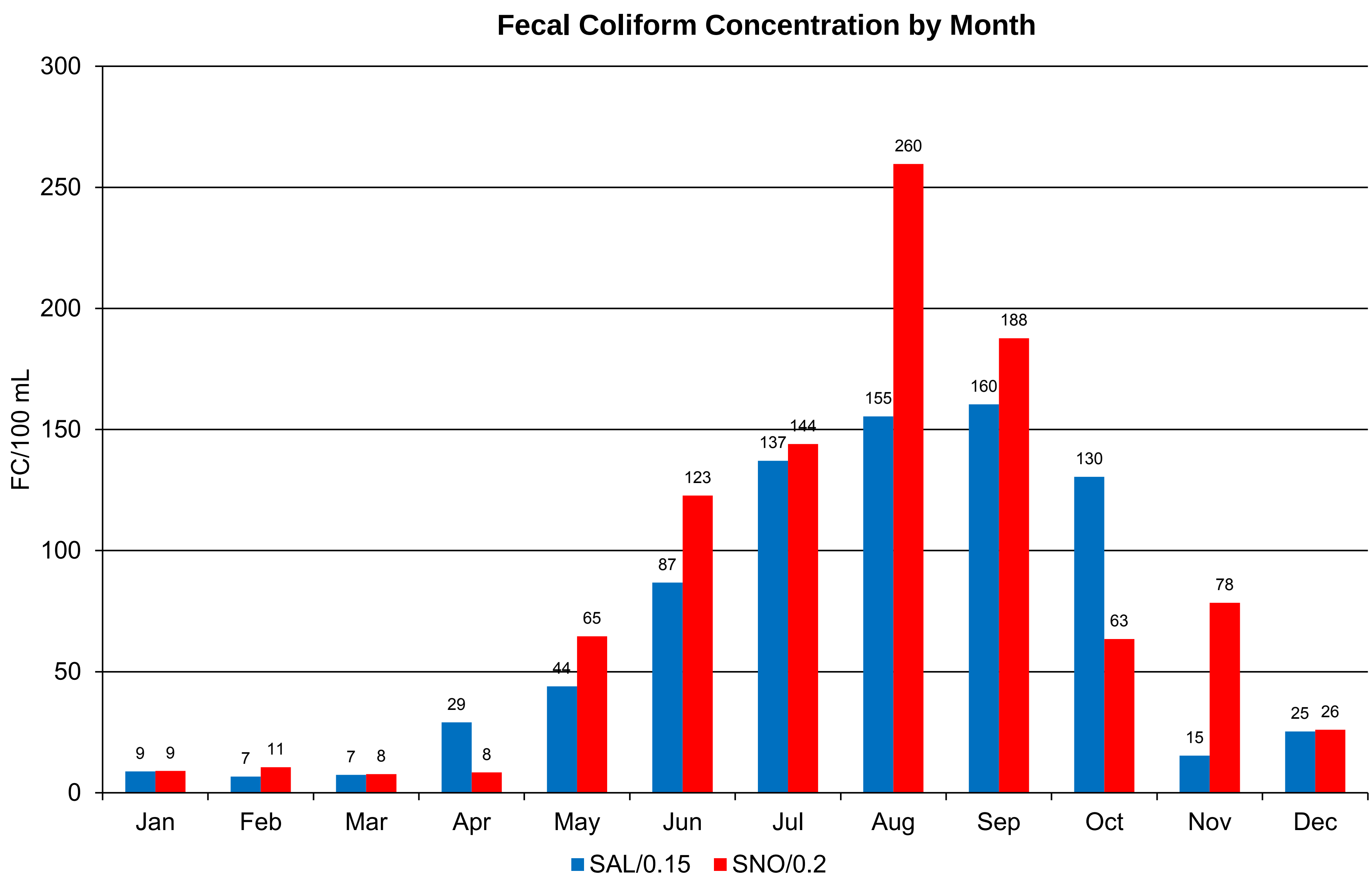


Figure 12. Average fecal coliform concentration by month for downstream stations on Salmon Creek and Snow Creek, based on 163 samples for SAL/0.15 and 217 samples for SNO/0.2 collected from 1993 to 2019.

Total phosphorus was sampled 16 times at Salmon Creek's station SAL/0.15. It had a moderately high positive correlation (0.59; p=0.00) with fecal coliform. Regression analysis of fecal coliform on total phosphorus showed a weak, but significant positive relationship (R^2=0.27, p=0.04).

The relationship at Snow Creek's station SNO/0.2 with total phosphorus was not as strong as it was on Salmon Creek. Spearman's rank was 0.24 (p=0.22, n=28). Regression of fecal coliform on total phosphorus showed no correlation (R^2=0.01, p=0.69).

Nitrate-nitrogen was sampled 51 times at Salmon Creek's downstream station SAL/0.15. It had a moderately high negative correlation (-0.60, p=0.00) with fecal coliform. Regression analysis of fecal coliform on nitrate-nitrogen showed an inverse relationship (R^2=0.18, p=0.00).

Snow Creek at station SNO/0.2 showed a negative correlation with nitrate-nitrogen (-0.40, p=0.00, n=89). Regression analysis showed a week inverse relationship (R^2=0.11, p=0.00, n=89).

Because fecal coliform is correlated with a parameter does not necessarily mean that there is a cause and effect relationship. Both may be correlated to a common third parameter.

The negative correlation between nitrate-nitrogen and fecal coliform concentration is more likely due to seasonal conditions. Nitrate-nitrogen levels are highest during the colder, wetter months. The higher nitrate levels during the wetter months may be due to the leaching of nitrates by rainfall from the decaying leaves and other organic matter in the uplands. JCCD staff has observed that the highest nitrate levels occur after the first heavy rains after soil saturation. Temperature is lower at this time of the year and may be the actual cause of the lower fecal coliform levels.

Table 3 shows all the possible combinations of correlations among parameters at stations SAL/0.15 and SNO/0.8. The high negative correlations (-0.92 and -0.84) between flow and conductivity probably occur because ions are more concentrated under base (low) flow conditions. Also, under base flow conditions when a stream is fed entirely by groundwater, there is more opportunity for soil minerals to dissolve in the groundwater.

Turbidity was moderately correlated to flow (0.67 and 0.71; Table 3). One would expect turbidity to increase as stream velocity increased, causing bank erosion and bottom sediment suspension.

Table 3. Spearman rank coeficients for parameters sampled at Salmon Creek station SAL/0.15 and Snow Creek station SNO/0.8 from 1993 to 2019.

Salmon Creek at SAL/0.15

Sample size = 24	FC	Temp	Turb	Cond	pH	DO	Flow
FC	1.00						
p-value	0.0000						
Temperature	0.69	1.00					
p-value	0.0003	0.0000					
Turbidity	-0.25	-0.20	1.00				
p-value	0.2385	0.3408	0.0000				
Conductivity	0.55	0.62	-0.63	1.00			
p-value	0.0056	0.0014	0.0014	0.0000			
pH	0.42	0.48	-0.22	0.60	1.00		
p-value	0.0417	0.0173	0.2886	0.0026	0.0000		
Dissolved oxygen	-0.67	-0.86	0.37	-0.66	-0.45	1.00	
p-value	0.0005	0.0000	0.0720	0.0006	0.0290	0.0000	
Flow	-0.53	-0.66	0.67	-0.92	-0.47	0.72	1.00
p-value	0.0081	0.0005	0.0004	0.0000	0.0209	0.0001	0.0000

Snow Creek at SNO/0.8

Sample size = 51	FC	Temp	Turb	Cond	pH	DO	Flow
FC	1.00						
p-value	0.0000						
Temperature	0.70	1.00					
p-value	0.0000	0.0000					
Turbidity	-0.40	-0.32	1.00				
p-value	0.0043	0.0241	0.0000				
Conductivity	0.54	0.33	-0.66	1.00			
p-value	0.0001	0.0172	0.0000	0.0000			
pH	0.33	0.40	-0.30	0.34	1.00		
p-value	0.0176	0.0035	0.0308	0.0137	0.0000		
Dissolved oxygen	-0.63	-0.94	0.26	-0.31	-0.39	1.00	
p-value	0.0000	0.0000	0.0631	0.0263	0.0056	0.0000	
Flow	-0.69	-0.51	0.71	-0.84	-0.47	0.48	1.00
p-value	0.0000	0.0002	0.0000	0.0000	0.0005	0.0005	0.0000

Some correlations between stream flow and other parameters are probably due to season. For example, there was a moderate inverse relationship (-0.51 and -0.66) between flow and temperature. Higher rainfall and lower temperatures occur together in winter.

Similarly, oxygen was positively correlated with flow (0.48 and 0.72). Oxygen is higher in winter because winter is colder and colder water holds more oxygen.

Regression analysis of 2017-19 data showed fecal coliform concentration to be positively correlated with temperature at seven of the eight downstream stations (Figures 13 and 14). Moderate correlations were observed at stations on Snow Creek, Salmon Creek, Andrews Creek, and Tucker Ditch (R^2 ranged from 0.35 to 0.61, p <0.03); weak correlations occurred at Houck Creek and Contractors Creek (R^2 0.23 and 0.26; p 0.06 and 0.03); very weak at Zerr Drain (R^2 0.09, p 0.25); and no correlation at Uncas Valley Ditch (R^2 0.00, p 0.97).

Effects of Temperature

Seven of the nine stations that failed the fecal coliform standard occurred during the warmer months of May through September (Table 1). Fecal coliform concentrations were generally inversely correlated to stream flow and positively correlated to temperature (Table 2). When stream flow is low, bacteria become concentrated in the water, but temperature also appears to contribute to the higher FC levels observed in summer.

Weak to moderate positive correlations with temperature occurred at seven of the eight downstream stations in 2017-19 (Figures 13 and 14). Analysis of data collected since 1993 at downstream stations on Salmon Creek and Snow Creek showed FC levels to be highest during the summer months (Figure 12). Fecal coliform concentrations in Chimacum Watershed streams were also highest during the warmer months (Gately et al. 2015).

Higher fecal coliform concentrations during summer months have been found in other studies. Wang et al. (2018) reported higher *E. coli* concentrations during summer's higher temperatures in Fall Creek, New York and associated it with greater microbial activity in summer.

Chen and Chang (2014) observed higher *E. coli* levels during summer in three western Oregon streams and attributed the higher levels to higher temperatures since *E. coli* is more likely to persist and grow in a warmer environment.

Clark and Norris (2000) reported that fecal coliform concentrations in Wyoming streams were generally higher from April through September than from October through March and that fecal coliform concentrations were positively correlated to temperature.

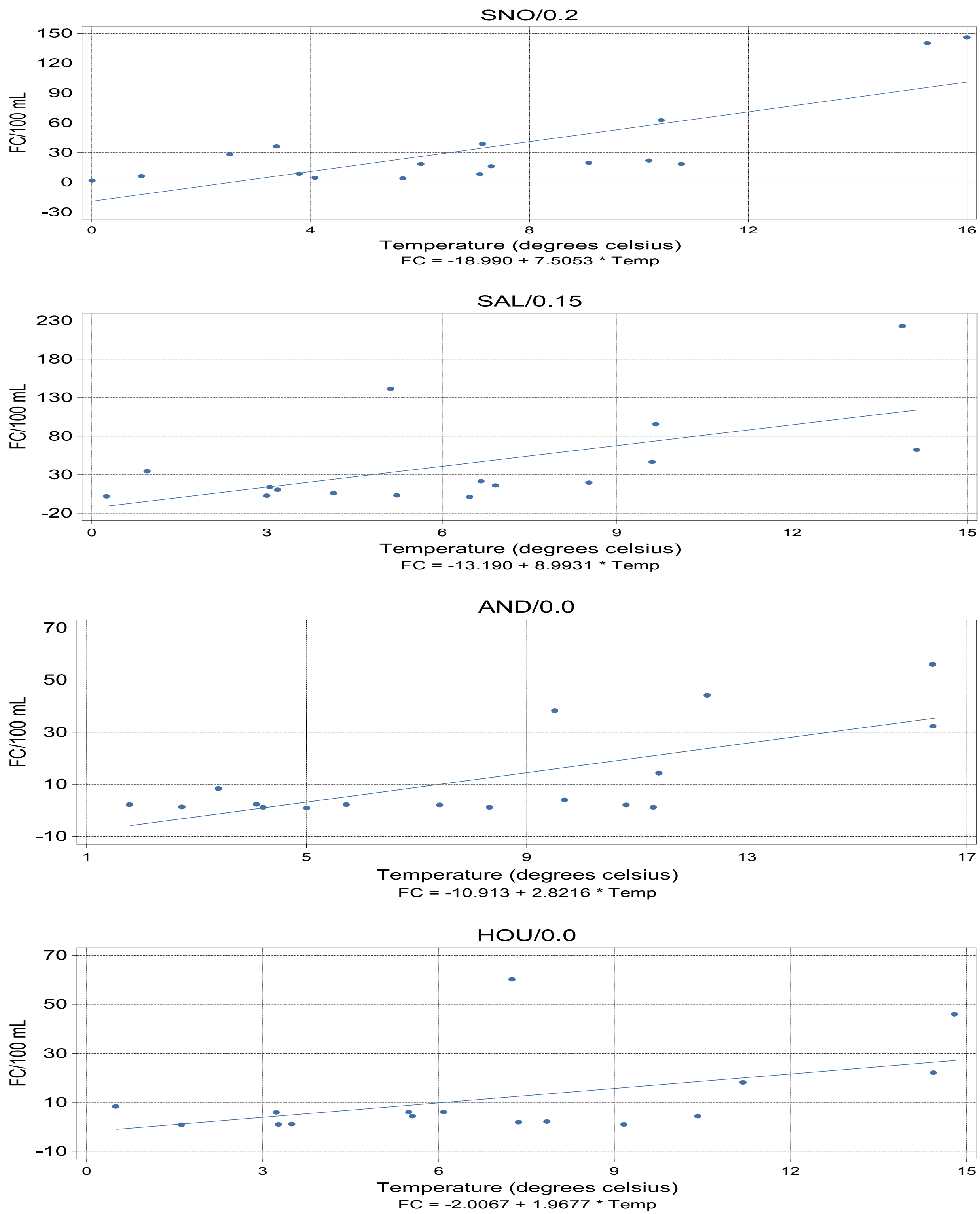


Figure 13. Regression of fecal coliform concentration on temperature at downstream stations on streams monitored in the Discovery Bay Watershed from November 2017 to April 2019.

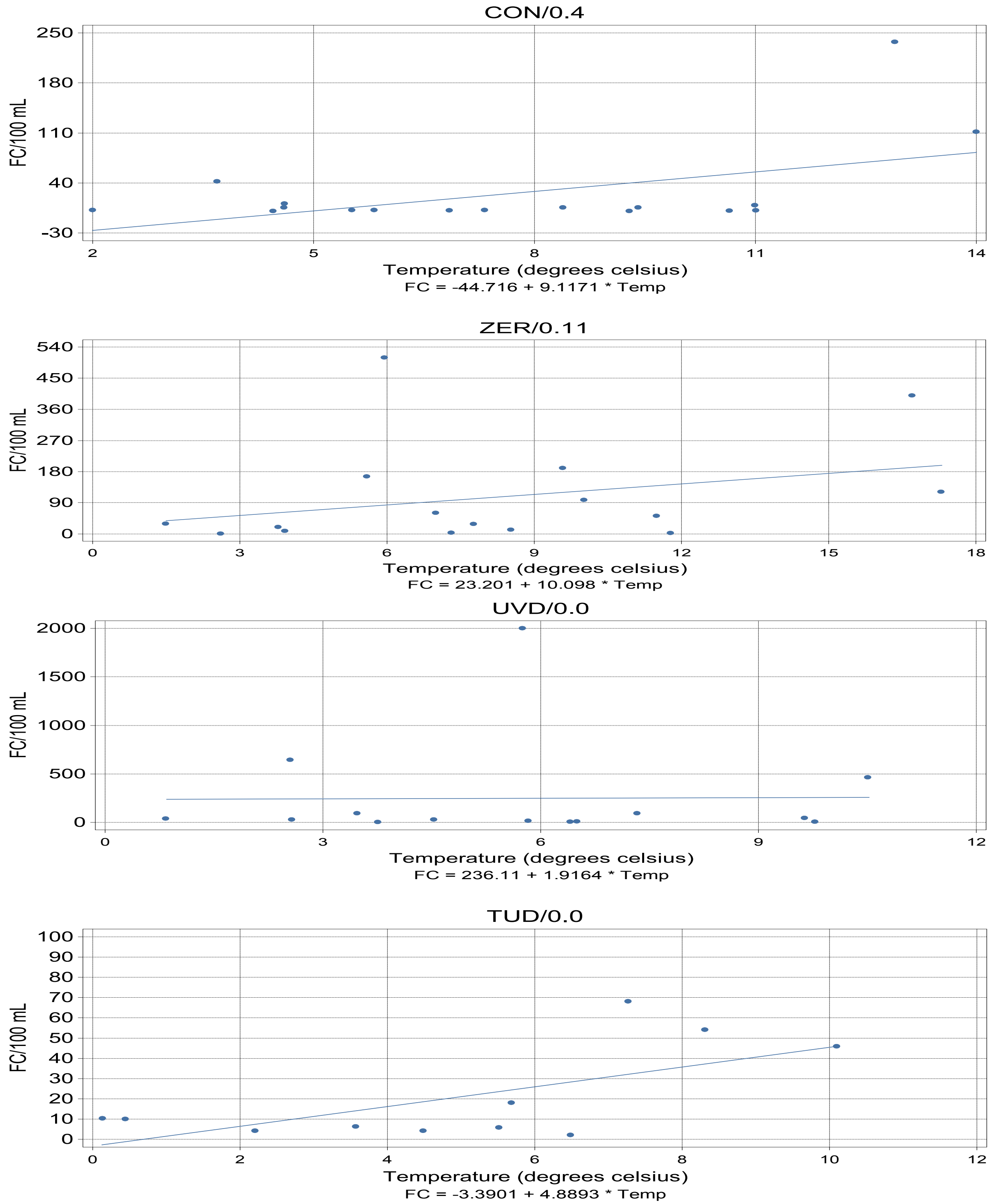


Figure 14. Regression of fecal coliform concentration on temperature at downstream stations on streams and ditches monitored in the Discovery Bay Watershed from November 2017 to April 2019.

Town (2001) reported a moderate positive correlation between temperature and fecal coliform concentration in Pennsylvania streams. Concentrations were higher when water temperatures were greater than about 15°C (usually from June to September) than they were when water temperatures were less than about 15°C (usually during March and April).

Hyer and Moyer (2003) reported that fecal coliform concentrations in three Virginia streams were highest in the summer and lowest in the winter.

Cho et al. (2016) compiled fecal coliform observations from four streams located in Massachusetts, North Carolina, Pennsylvania, and Korea. They observed high fecal coliform concentrations in summer and low concentrations in winter and attributed the seasonal differences to the fact that bacterial regrowth is dominant in summer, whereas bacteria are inactivated or dead in winter in both soil and surface water.

Pachepsky et al. (2011) conducted experiments on *E. coli* O157:H12 in the sediment of a Maryland stream and found that it survived better at 22.9 degrees C than at 14.5 degrees C.

Muirhead and Littlejohn (2009) and Soupir (2008), both cited by Cho et al. (2016), reported that *E. coli* in cow pies deposited in autumn and winter died off, but grew in spring and summer.

Fecal Coliform Loading

Fecal coliform loading, which takes into account stream flow as well as concentration, is shown in Figure 15. Of the four streams (Snow Creek, Salmon Creek, Contractors Creek, and Zerr Drain) that enter directly into Discovery Bay, Snow Creek and Salmon Creek contributed by far the largest amount of fecal coliform bacteria due to their much higher flows. Snow Creek's average loading (12 billion FC bacteria per day) was 1.6 times that of Salmon Creek's loading (7 billion FC bacteria per day). In the 2012-13 water-year, Snow Creek's average loading (37 billion FC per day) was more than twice that of Salmon Creek's average loading (15 billion per day). For comparison, Chimacum Creek's average loading in the 2011-12 water-year was 116 billion FC per day.

Fecal Coliform in Marine Water

Consumption of shellfish is the most likely pathway for humans to be exposed to potential pathogens in water polluted by human or animal wastes. Washington Department of Health (DOH) collects water samples a minimum of once every two months at 19 stations throughout Discovery Bay.

The state fecal coliform standard for marine water is different from that of fresh water. In marine water the GMV should not exceed 14 FC/100 mL and the estimated 90th percentile (10 percent of the samples) should not exceed 43 FC/100 mL.

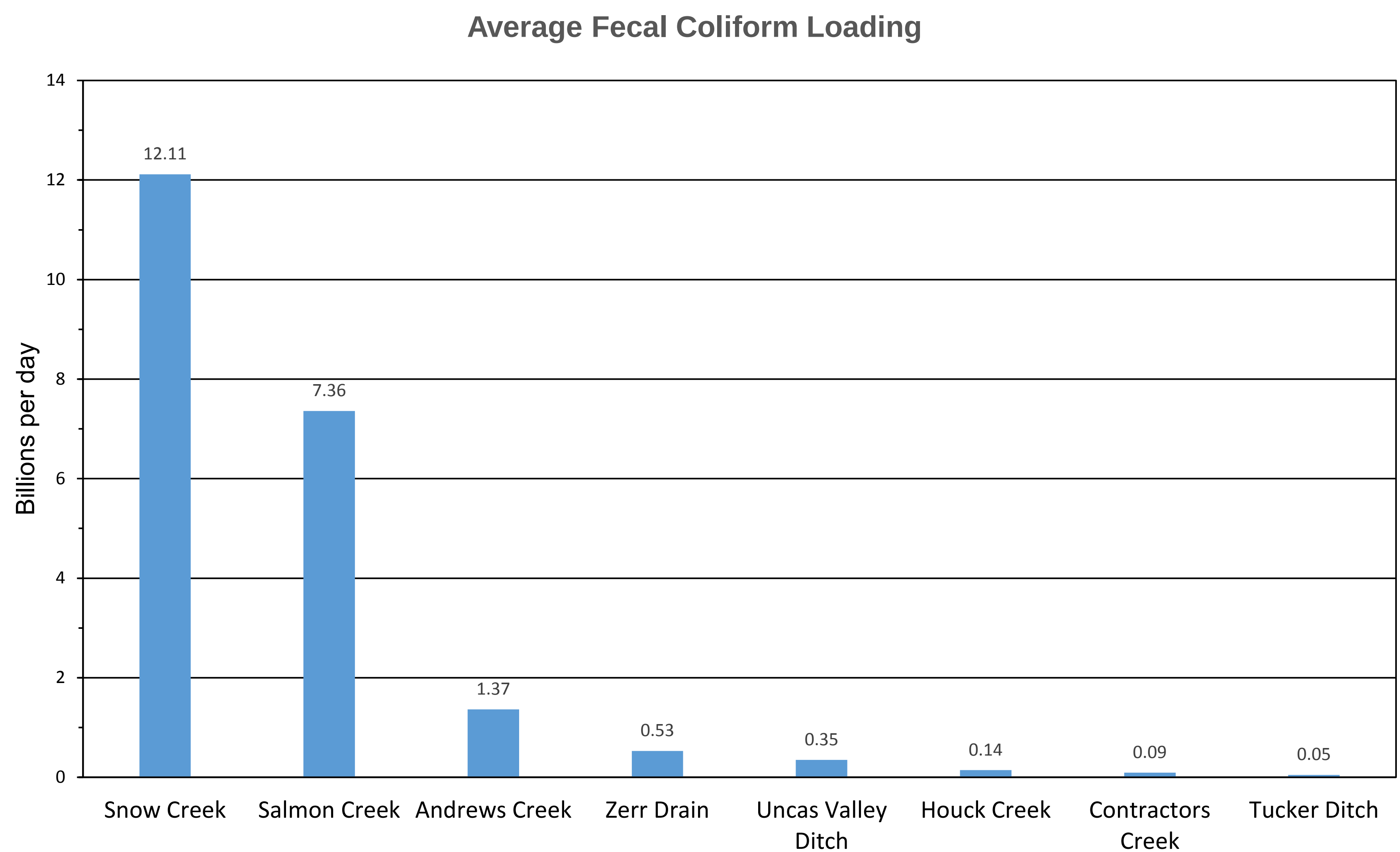


Figure 15. Average fecal coliform loading for streams in the Discovery Bay Watershed monitored mothly from November 2017 to April 2019 (except January 2019).

In 2006, station 48, the closet station to the mouths of Salmon Creek, Snow Creek, and Zerr Drain at that time, had a GMV of 6.2 FC/100mL and an estimated 90th percentile of 46 FC/100 mL. Thus, station 48 failed the standard. In DOH's 2019 report, station 48 passed the standard with a GMV of 2.3 FC/100 mL and an estimated 90th percentile of 5.0 FC/100 mL.

However, station 196, which is currently closest to the stream mouths, had the highest GMV (5.5 FC/100 mL) and the highest 90th percentile (33.2 FC/100 mL) of the 19 stations. All of the stations, including station 196, met both parts of the standard, but because the 90th percentile exceeded 30 FC/100 mL, DOH determined that "part of the Discovery Bay growing area is threatened with a downgrade in classification" (letter from DOH Manager Scott Berbells, April 10, 2019).

Analysis of data collected at station 196 from August 2015 to December 2018, showed the arithmetic FC mean of samples collected on an outgoing tide to be 17.3 FC/100/mL, compared to 11.1 FC/100 mL for samples collected on an incoming tide. The difference, however, was not statistically significant (p=0.30).

Regression analysis was used to determine if temperature and/or salinity was correlated to the fecal coliform level at station 196. Analysis of 102 samples collected from 2015 through 2018 showed a very weak inverse correlation between fecal coliform concentration and salinity (R^2=0.04, p=0.04). When samples collected on outgoing and incoming tides were analyzed separately, a stronger inverse correlation (R^2=0.34, p=0.01) was observed for samples collected on an incoming tide (Figure 16). Higher FC concentrations at lower salinity levels point to the freshwater streams as a contributing factor, but it is interesting that the correlation was stronger on an incoming tide than on an outgoing tide.

Regarding temperature, there was no correlation (R^2=0.0007, p=0.80) between fecal coliform and temperature when all samples were analyzed together. When samples were separated by outgoing and incoming tides, a very weak positive correlation (R^2=0.10, p=0.16) was observed for an outgoing tide (Figure 17).

Microbial Source Tracking

When fecal coliform concentrations are high, the question is always asked, "What is the source of the fecal coliform?" Since fecal coliform bacteria are in the intestinal tracts of all warm-blooded organisms, sources could be humans, livestock, pets, or wildlife. Fecal coliform analysis does not differentiate between these sources. However, since the advent of DNA testing, it is possible to identify the contaminant source.

DNA analysis, known as Microbial Source Tracking, is expensive—about $450 per sample. We have been fortunate to have the EPA Manchester lab In Port Orchard do

Fecal Coliform Concentration versus Salinity

At Marine Station 196

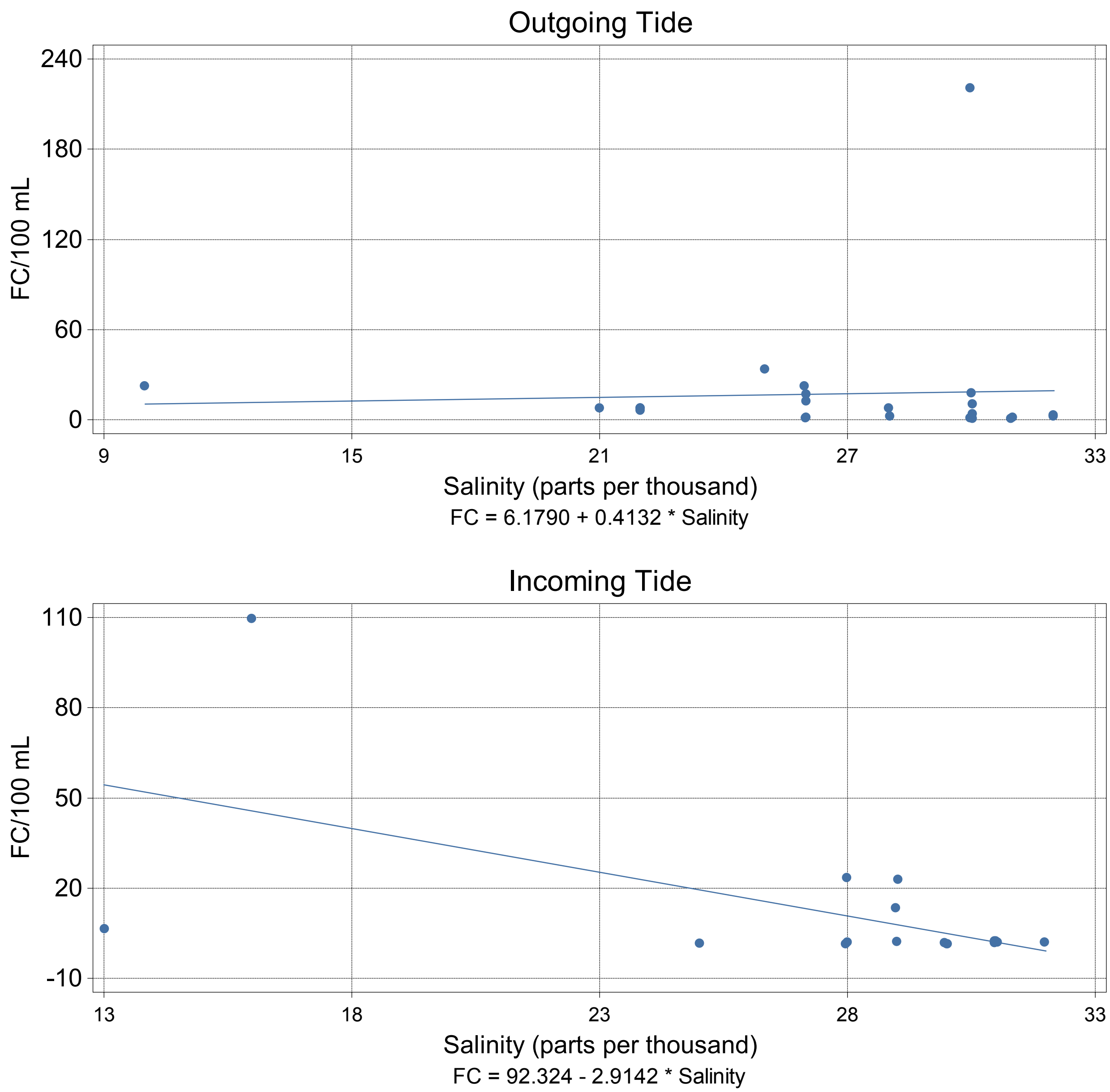
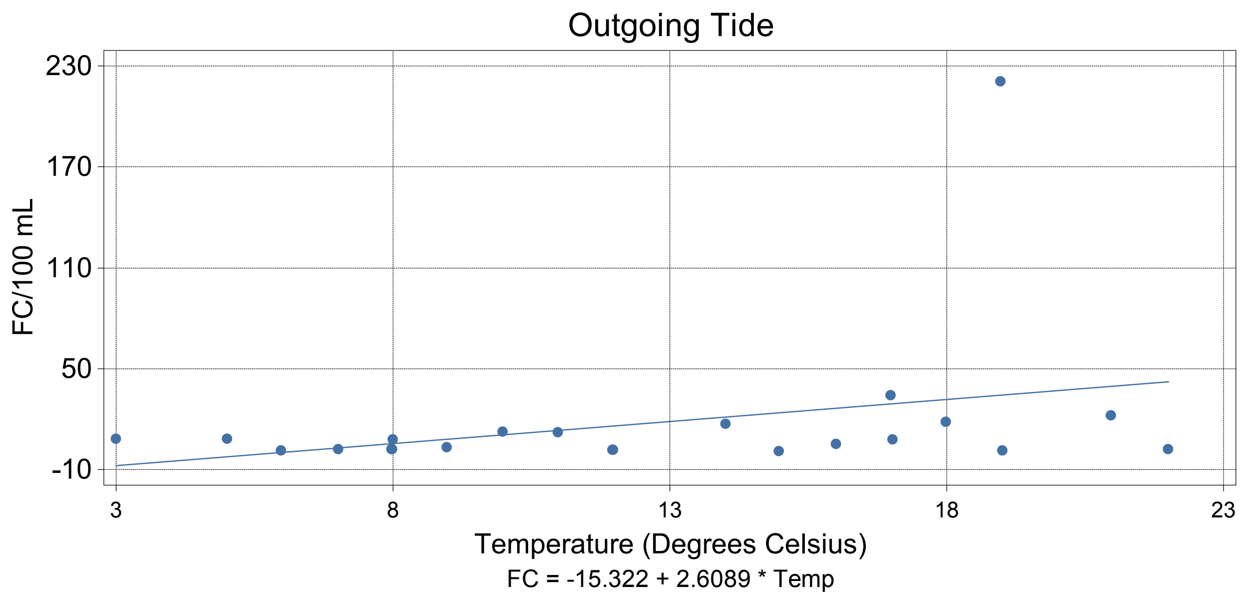


Figure 16. Regression of fecal coliform concentration on salinity at marine station 196 for samples collected on outgoing tides (R^2=0.002, p=0.83) and incoming tides (R^2=0.34, p=0.01) from August 2015 to December 2018. Data courtesy of Washington Department of Health.

Fecal Coliform Concentration versus Temperature

At Marine Station 196



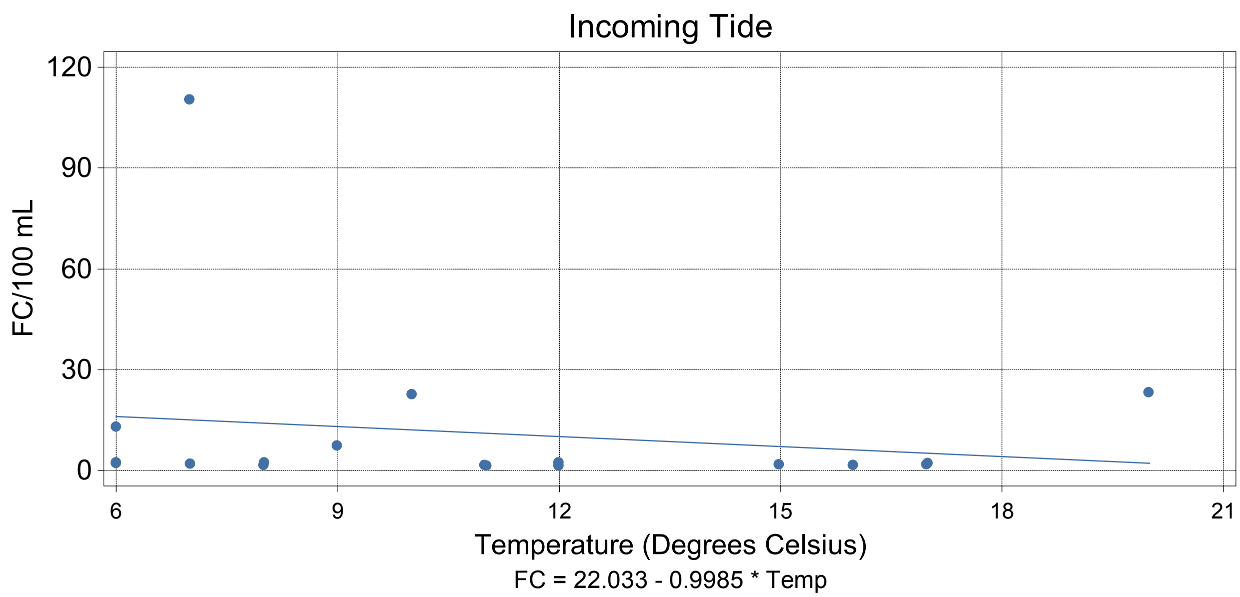


Figure 17. Regression of fecal coliform concentration on temperature at marine station 196 for samples collected on outgoing tides (R^2=0.10, p=0.16) and incoming tides (R^2=0.03, p=0.50) from August 2015 to December 2018. Data courtesy of Washington Department of Health.

the work for us at no charge. The EPA lab has conducted DNA analysis twice now in the Discovery Bay Watershed: once in 2012-13 and once in 2018-19.

EPA used different methods in the two time periods and it is important to understand each method in interpreting the results. In 2012-13, samples were first tested for "general" *Bacteroides* to determine if *any* kind of *Bacteroides* was present. "General" included *all* warm-blooded organisms. If none was found, testing ceased and the result was designated "absent." If "general" tested positive, the sample was analyzed for the presence of a "ruminant" biomarker and up to two "human" biomarkers. If the first "human" biomarker tested "negative," a second, different biomarker was tested. If either of the two biomarkers tested positive, the result was designated "positive." Only one biomarker was used for "ruminant." A ruminant is an animal with multiple stomachs which chews a cud, and includes cattle, sheep, goats, buffalo, elk, and deer.

Unlike fecal coliform analysis, there was no numerical count of the *Bacteroides* bacteria for comparison. Frequency of occurrence was used to evaluate *Bacteroides*. Frequency of occurrence is the number of positive outcomes divided by the total number of tests conducted at each monitoring station.

Of the 197 samples collected in 2011-12, 71% tested positive for "general" *Bacteroide*s; 13% tested positive for "human"; and 3% tested positive for "ruminant." Human *Bacteroides* was found in Andrews Creek, Houck Creek, Salmon Creek, Snow Creek, and Uncas Valley Ditch (Figure 18). Ruminant *Bacteroides* was found in Andrews Creek and Snow Creek. Neither human nor ruminant *Bacteroides* was found in Tucker Ditch in spite of general *Bacteroides* occurring in 100% of the samples collected at two of the three stations on Tucker Ditch and in 38% of the samples at the third station. Contractors Creek and Zerr drain were not analyzed in 2012-13.

When general *Bacteroides* was present but not human or ruminant *Bacteroides*, wildlife could have been responsible. However, it is also possible that human and/or ruminant *Bacteroides* was present, but at an insufficient number for an identification. This possibility became apparent in the analysis of lab duplicates taken from the same sample bottle. One of the duplicate pair showed the presence of human or ruminant and the other showed only general *Bacteroides*.

In 2018-19, EPA used a semi-quantitative method of DNA analysis. This method did not use general or ruminant biomarkers. Instead, two biomarkers specific for humans and two biomarkers specific for cattle were used. Biomarker HF 183, one of the two human biomarkers used in 2018-19, was also used in 2012-13.

For the Zerr Drain samples, in addition to the human and cattle biomarkers, one avian biomarker was also used. Ducks and geese commonly frequent a small pond immediately upstream from the monitoring station. Also, sea gulls frequent Discovery

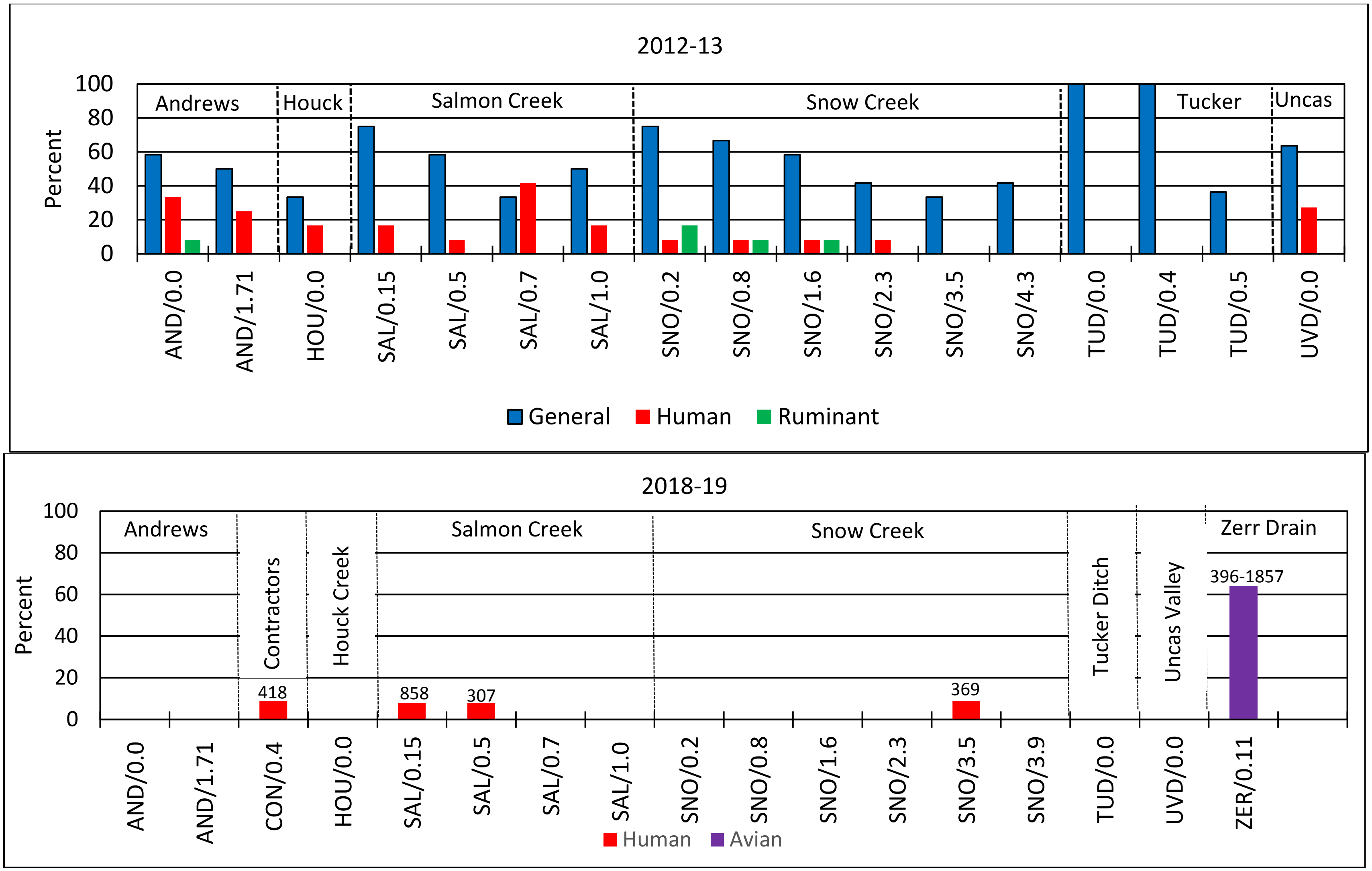


Figure 18. Frequency of occurrence of general, human, and ruminant *Bacteroides* in samples collected monthly in 2012-13 (top); and frequency of occurrence of human and avian (sampled only in Zerr Drain) *Bacteroides* in samples collected monthly in 2018-19 (bottom). No cattle Bacteroides occurred in 2018-19 samples. Quantification numbers are shown on top of bars. Refer to text for a description of the two methods used and a more complete explanation of each method.

Bay, and because Zerr Drain is an estuary, it could receive sea gull feces on incoming tides.

The MST method used in 2018-19 enumerated the number of copies made of each of the biomarkers. The quantification number (i.e., the number of biomarker copies) allows a comparison *only* with the same kind of biomarker (i.e., human to human, cattle to cattle, or avian to avian). It does not allow comparisons between different biomarkers (e.g., human to avian).

Of the 204 samples analyzed, only 11 samples had biomarkers that could be quantified. Human biomarkers occurred in four of the samples and avian biomarkers were present in seven (Figure 17). Two human biomarkers were from lower Salmon Creek on Fish and Wildlife property; one occurred on Snow Creek downstream of several homes located near the creek; and one occurred on Contractors Creek near Highway 101. No cattle biomarkers were found.

When a biomarker was not detected in a sample it was designated “ND” for non-detect. There was a total of 764 NDs in samples collected in 2018-19. If a biomarker was detected but the number of biomarker copies was “below the level of quantification,” it was designated “BLOQ” for “below level of quantification.” Forty-one biomarkers were designated BLOQ; thirty-seven of these were human biomarkers and four were avian. None were identified as cattle biomarkers. To avoid the risk of “false positives” due to “background noise,” BLOQs were treated as NDs. It is noteworthy, however, that no cattle biomarkers were identified as BLOQs.

Based on MST results, it appears that conditions improved in the Discovery Bay Watershed from 2012-13 to 2018-19, although this is not a strict comparison due to the different methods used. The presence of human biomarkers decreased from 13% in 2012-13 to 2% in 2018-19. Human biomarkers were present at 13 stations in 2012-13 compared to 4 stations in 2018-19. Ruminant biomarkers (potentially cattle) decreased from 3% in 2012-13 to 0% in 2018-19.

In 2012-13, ruminant biomarkers were identified in 3% of the samples. Biomarkers were present at four stations: three on Snow Creek and one on Andrews Creek. In 2018-19, no cattle biomarkers were found in any of the samples. However, since ruminant biomarkers were analyzed in 2012-13 and cattle biomarkers were analyzed in 2018-19, the results are not strictly comparable. The biomarkers identified as ruminant in 2012-13 could have been from other ruminants. Deer would be the most likely source because sheep, goats, and buffalo were not known to be present.

Analyzing for an avian biomarker in Zerr Drain samples proved to be beneficial. The avian biomarker was present in 7 of the 11 months monitored. The other 4 months also tested positive as avian “BLOQs.” This is good information because station ZER/0.11

was one of the stations that failed the fecal coliform standard (Table 1) and it had the second highest GMV of all 19 stations (Figure 8). Thus, birds appear to be a major contributor to the bacterial contamination in Zerr Drain. Furthermore, birds could be responsible for the “threatened” FC level observed at marine station 196.

Waterfowl have been shown to be responsible for high fecal coliform levels in a number of studies. Geohring et al. (1999, cited by Jamieson et al. 2002) reported that fecal coliform contamination occurred on study plots that had not received liquid dairy manure for two years and attributed it to geese, which were frequently observed on the field.

Standridge et al. (1979) attributed high fecal coliform levels resulting in beach closures in a recreational lake in Madison, Wisconsin to a permanent duck population of 100-200 Mallard ducks. Valiela et al. (1991) calculated that waterfowl (ducks, geese, and swans) contributed 82% of the fecal coliform loading to Buttermilk Bay, Massachusetts from January to March, but only 7% from July to September when the birds were sparse.

In 2012-13, of the 197 MST samples, 140 or 71% were classified “general,” but only 32 (16%) of these were identified as human and/or ruminant. The remaining 108 (55%) were unidentified. Another way of stating this is that only 22% of the “general” category were human and ruminant. The remaining 78% were most likely from other animals and/or birds.

Hyer and Moyer (2003) used RNA (ribonucleic acid) analysis to identify *E. coli* sources on three Virginia streams. The total number of different sources identified for the three streams ranged from 18 to 21. Sources identified in the Urban Watershed stream that were found in 5% or more of the 279 samples were, in decreasing order of occurrence: goose, human, dog, duck, cat, sea gull, and raccoon; in the Agricultural Watershed stream (n=285), sources were: cattle, poultry, human, dog, and cat; and in the mixed Urban/Agricultural Watershed stream (n=274), sources were: poultry, cattle, human, dog, horse, and deer. Other animal sources that occurred in less than 5% of the samples were: opossum, sheep, rodent, coyote, pig, crow, muskrat, swan, ground hog, fox, bear, goat, skunk, and beaver.

Closer to home in neighboring Clallam County, Woodruff et al. (2009) conducted two studies from 2006 to 2009 in the lower Dungeness Watershed. In the first study, four freshwater stations and two marine stations were sampled monthly for 13 months. In addition to water sampled at the marine stations, sediment and detrital algae were also sampled. From the 1,164 *E. coli* isolates, 92% were identified. In order of occurrence, the sources were: avian (19.6%), gull (12.5%), waterfowl (9.7%), raccoon (9.2%), unknown (7.3%), human (7.1%), rodent (6.3%), and dog (4.3%). When combined, birds represented 42% of the samples. Birds occurred in at least 85% of the sampling events at all freshwater and marine water stations and from at least 56% of marine sediment sampling events. Wildlife, including raccoons, rodents, deer, elk, beaver, otter, rabbit, and marine mammals, represented about 26% of the isolates. Domestic animals and farm animals each represented about 7%.

The EPA Manchester lab analyzed samples from the second study. They used the same method and the same biomarkers as in the 2012-13 Discovery Bay Watershed study. Forty-two stations in the lower Dungeness Watershed and bay were sampled three times from December 2008 to January 2009. Forty percent of the samples were “general”; 7% were “human”; and 7% were “ruminant.”

In September 2017, a wildlife video camera was trained at a beaver dam on Snow Creek at about RM 0.4. The following animals and birds were observed: deer, beaver, mink, raccoon, squirrel, ducks, dippers, and heron (the video may be viewed at https://www.youtube.com/watch?v=j6ixIKWs4Dw).

Bacterial pollution is a non-point pollution in more than one sense. Not only do bacteria enter the stream from a number of places, but they come from a variety of sources, categorized as human, livestock, pets, and wildlife. In our 2012-13 MST study, only 22% of the biomarkers were identified as human and/or ruminant; 78% were from other warm-blooded animals and/or birds.

In 2018-19, human biomarkers constituted only 2% of the samples and cattle 0%. In Zerr drain (the only site where avian biomarkers were analyzed), avian biomarkers were positively identified in 64% of the samples and categorized as avian “BLOQs” in the remaining 36%. In the Dungeness study avian biomarkers were identified in 42% of the samples; avian biomarkers were identified at all freshwater stations and at all marine stations; avian biomarkers were identified at 85% of the sampling events. Birds were prominent in the Virginia study. Three kinds of birds (herons, ducks, and dippers) were observed in the 27-day recorded video at a single location on Snow Creek.

Sediment—Fecal Coliform Sink

Numerous studies have shown that on a volume basis fecal coliform bacteria are much more numerous in the bottom sediment than in the overlying water (Stephenson and Rychert 1982; Skinner et al. 1984; Marino and Gannon 1991; Sherer et al. 1992; Howell et al. 1996; Davis et al. 2005).

Van Donsel and Geldreich (1971) reported that fecal coliform concentrations in the sediment were 100-1000 times greater than in the water column in various aquatic environments. Goyal et al. (1977) found that fecal coliforms were from 1 to 383 (median 10) times greater in sediment than in the water column. In an Arizona study, Crabill et al. (1999) reported fecal coliform counts averaged 2200 times greater in the sediment than in the water.

Grimes (1980) showed that dredging in the Upper Mississippi River caused bacterial levels to increase in the water column. Fecal coliform levels were 4 times greater immediately downstream from the dredge discharge pipe than in samples upstream from the dredge and fecal streptococcus was 50 times greater downstream from the dredge. Both fecal coliform and fecal streptococcus concentrations were correlated with turbidity levels at the downstream site.

Davis et al. (2005) reported that *E. coli* concentrations in Arkansas spring water increased rapidly during the rising limb of a storm hydrograph, peaked prior to or coincident with the peak of the storm pulse, and then declined rapidly, well before the recession of the storm hydrograph. They suggested that *E. coli* are associated with resuspension of sediment during the onset of turbulent flow.

Jamieson et al. (2005) seeded a 1.1 m^2 section of stream bed in Swan Creek (Ontario, Canada) with a traceable (nalidixic resistant) strain of *E. coli* and followed it downstream in a 1.7-km reach. In evaluating several storm events, they observed that the resuspension of the traceable *E. coli* occurred primarily on the rising limb of the hydrograph, implying that a finite supply of sediment-associated bacteria are available for resuspension during individual storm events.

In laboratory experiments, Gerba and Mcleod (1976) showed that *E. coli* survived longer in seawater with sediment than in seawater alone and attributed the longer survival to the greater organic content of the sediment compared to the seawater.

Goyal and Adams (1984) found *E. coli* and several other fecal bacteria in sediment and overlying water from a sewage sludge dumpsite 46 miles off the Delaware-Maryland coast *30 months* after cessation of sludge dumping.

In a comprehensive review of fecal coliform bacteria in sediments, Pachepsky and Shelton (2011) concluded that “freshwater and estuarine sediments are important microbial habitats that may be critical contributors to water contamination” and that there is a need for “better understanding ecological and hydrological factors that affect functioning of sediments as *E. coli* reservoirs.”

Struck (1988) reported that fecal coliform levels in the water column and bottom sediment correlated with rainfall and turbidity in Minter Creek, Washington.

Long term data (1993-2012) for all streams in the Chimacum Watershed grouped together showed a positive correlation between fecal coliform concentration and turbidity (Gately et al. 2015).

In this study, turbidity was inversely correlated with fecal coliform at the majority of stations (13 out of 20; Table 2); positive correlations occurred at 7 stations. Only three positive and three negative correlations were significant ($p<0.05$). The three positive correlations were on Andrews Creek, Houck Creek, and Tucker Ditch. The three negative correlations were all on Snow Creek.

There are two possible reasons why there are not more and stronger correlations between fecal coliform and turbidity. One is the effect of dilution during higher flows. Another is the effect of temperature, which may counter that of turbidity. Temperature was positively correlated with fecal coliform at all 20 stations with statistical significance ($p<0.01$) at 19 of them (Table 2).

In order to minimize the confounding effects of temperature, Spearman's rank was run on samples collected solely in the colder, wetter (higher turbidity) months of November through February at stations SAL/0.15 and SNO/0.2. However, even this produced only week, non-significant correlations for Salmon Creek (0.15, $p=0.34$, $n=41$) and Snow Creek (0.18 $p=0.18$, $n=56$).

Base Flow Conditions

We know that fecal coliform bacteria live and multiply in the bottom sediment and that they can be resuspended in the water column with the sediment. However, our data shows only week positive correlations with turbidity at a minority of the stations (Table 2). In fact, more stations had an *inverse* correlation with turbidly. Fecal coliform concentrations were highest during the base (low) flow months of summer (Figure 12). Is it possible for bacteria living in the bottom sediment to be resuspended during base flow conditions? Based on recent studies, the answer is *yes*.

Pachepsky et al. (2017) tracked *E. coli* and enterococci concentrations in a slug of water flowing down a 0.4-mile reach of a Maryland stream during July under base flow conditions. One side of the stream had a 260-ft. buffer of deciduous trees with corn fields outside of the buffer. Only chemical fertilizer was used on the corn fields. The other side of the stream had a deciduous tree buffer (>600 ft.) except for the upper 300 ft. of the reach in which the tree buffer was 130 ft. Just *upstream* of the experimental reach outside of a 130 ft. buffer was a corn field, which was fertilized with dairy cow manure. On each of three replicate experiments *E. coli* concentrations increased significantly from upstream to downstream. On July, 9 *E. coli* increased from 148 to 610 CFU/100 mL ($p=0.035$); on July 16, *E. coli* increased from 83 to 1,231 CFU/100 mL ($p=0.001$); and on July 22, *E. coli* increased from 462 to 1,187 CFU/100 mL ($p=0.001$). This increase in *E. coli* concentration occurred despite an increased flow at the downstream sample station which would, by dilution, tend to decrease the concentration.

The authors attributed the higher concentrations of *E. coli* at the downstream site to water flowing through pores in the bottom sediment, where it picked up *E. coli*, and then transported it into the overlying water column, a process known as hyporheic exchange. *E. coli* in sediment over the entire reach averaged 6,520 CFU/100 g dry weight and the release rate was estimated to range from 36 to 57 cells/m^2/s.

Jamieson et al. (2003) investigated *E. coli* in Thomas Brook, a small headwater stream in Berwick, Nova Scotia. Their research suggested that the release of sediment-borne *E. coli* into the overlying stream water occurred without the influence of sediment resuspension during base flow (i.e., low flow) conditions.

In low flow conditions, Piorkowski et al. (2014) estimated the contribution of sediment-borne *E. coli* to the water column using a library-dependent microbial source tracking approach that matched waterborne *E. coli* isolates to sediment *E. coli* populations. The authors concluded that the numbers of *E. coli* released via hyporheic exchange were comparable to the numbers released via sediment transport.

Stocker et al. (2016) monitored bacterial concentrations at inlets and outlets of reaches in two creeks under base flow conditions and demonstrated statistical differences between inlet and outlet concentrations, suggesting that sediments released substantial numbers of both *E.coli* and enterococci into the overlying water.

DNA fingerprinting studies performed in urban creeks by Brinkmeyer et al. (2015) also showed that sediment-borne *E. coli* can be transported into the water column during base flow conditions.

The assumption of the release of *E. coli* from sediment during base flow conditions has resulted in the improvement of the predictive accuracy of transport models (Ghimire and Deng 2013).

Park et al. (2016) conducted *E. coli* monitoring in Pennsylvania's Little Cove Creek to improve the model SWAT (Soil and Water Assessment Tool). They observed that *E. coli* was released from streambed sediments during baseflow conditions when no sediment resuspension was occurring. The researchers evaluated two potential mechanisms responsible for the *E. coli* release: passive transport due to groundwater flow and active transport due to chemotaxis, movement activated by a chemical stimuli such as nutrients. They found that factoring in active transport (chemotaxis) accounted for a 42% improvement to the model, compared to a 4% improvement due to passive (groundwater) transport. *They concluded that "release of E. coli from streambed sediments during baseflow periods is substantial and that water column E. coli concentrations are dependent on not only land management practices but also on in-stream processes."*

FC/*E. coli* concentrations in sediment have been reported to decrease with depth. Alm et al. (2003) observed a twofold decrease in *E. coli* content in beach sand with 5-cm increments of depth within the first 15 cm. Garzio (2009, reported in Pachepsky and Shelton 2011) observed a much steeper decline of *E. coli* in sediment in a rural creek in Maryland. *E. coli* decreased 1 order of magnitude from 1 cm to 2 cm and 2 orders of magnitude from 1 cm to 4 cm. Haller et al. (2009) observed a fast decline with depth in Lake Geneva, Switzerland where sediment *E. coli* concentrations decreased 1 order of magnitude per centimeter within the upper 5 cm of sediment.

Algae—Fecal Coliform Sink

McFeters et al. (1978) investigated an unpolluted, pristine mountain stream in Grand Teton National Park. In this small stream, which is an outlet to a high elevation lake, total coliform counts were consistently greater than 200 colonies/100 mL in midsummer. Concurrent with the increase in bacteria was the emergence of periphyton (benthic algae) on rocks in the stream. Further investigation in the laboratory using *E. coli* and *Klebsiella* led them to conclude that the bacteria were growing and multiplying on algal excretory products.

Carr et al. (2005) sampled periphyton and bacteria on rocks from riffles in 51 streams in Ontario and Quebec. The rocks bearing the periphyton and bacteria were then exposed to nutrient gradients of nitrogen and phosphorus. Contrary to their hypothesis that the periphyton and bacteria competed for nutrients, they suggested that the periphyton and bacteria generally coexist in a mutually dependent association that offers space and resources to sustain growth in both groups of organisms.

Ksoll et al. (2007) found that fecal coliform bacteria, including *E. coli*, were growing in periphyton communities on rocks along the shoreline of Lake Superior. Densities peaked at 1,400,000 colonies per square centimeter in late July. DNA analysis showed that most (68-99%) of the identifiable *E. coli* strains were from waterfowl. In accompanying laboratory experiments, *E. coli* rapidly occupied periphyton communities, persisted in them for several weeks, and released *E. coli* cells to the overlying water. At the end of the experiment, agitation of the water caused an abundance of the *E. coli* cells to be released from the periphyton into the overlying water, yielding a concentration of 500 colonies/100 mL.

Ksoll and his coworkers concluded, "…although many *E. coli* strains isolated from periphyton may have originated from waterfowl and sewage effluent, other strains appeared to be unique to the periphyton that we studied and may have developed self-sustaining populations in these communities. *E. coli* cells attached to periphyton, whether they are unique to these periphyton communities or not, can detach and contribute to fecal coliform numbers measured in coastal waters. The presence, persistence, and possible naturalization of *E. coli* in periphyton communities further confound the use of fecal coliform as a reliable indicator of *recent* fecal contamination of recreational waters."

Whitman et al. (2003) sampled *Cladophora*, a filamentous alga, from 10 beaches in Lake Michigan. *E. coli,* as well as enterococci, was found in up to 97% of the samples. Based on these findings the investigators concluded that algae "may be an important environmental source of indicator bacteria and call into question the reliability of *E. coli* and enterococci as indicators of water quality for freshwater recreational beaches."

Taking the previous results a step further, Byappanahalli et al. (2003) determined that *Cladophora* provides a suitable environment for indicator bacteria to persist for extended periods and to grow under natural conditions.

Mauro (2008) found *Cladophora* along Lake Erie beaches in Presque Island State Park, Pennsylvania to be associated with *Bacteroides* over space (i.e., different beaches) and time.

Englebert et al. (2008 A) studied *E. coli* in association with *Cladophora* off three Lake Michigan beaches. They found *E. coli* concentrations to be higher within Cladophora mats than in surrounding water and that there was a decreasing concentration gradient away from the *Cladophora* mats. In a laboratory study (Englebert et al. 2008 B), the same researchers compared the survival of *E. coli, Salmonella, and Shigella* placed in *Cladophora* mats. *E. coli* persisted for 45 days, whereas *Salmonella* could not be detected after 10 days and *Shigella* after only 2 days. They concluded that if this preferential survival for *E. coli* holds true in the environment then *E. coli* concentrations may be artificially high relative to associated pathogens from the same fecal discharge event and may overestimate the risk to public health.

Sediment and algae were present in all the streams studied in the Discovery Bay Watershed and could be sinks for fecal coliform bacteria. Uncas Valley Ditch, Zerr Drain, Houck Creek, Andrews Creek, and Contractors Creek, in particular, have reaches with slow moving water, silty bottoms, and prolific algae, making them ideal sinks for fecal coliform bacteria.

Bacteria Survivability

As shown in the previous sections, fecal coliform bacteria have the ability to survive and grow in bottom sediment and algae. They also have the ability to survive in upland soil, groundwater, and cow manure.

Fecal bacteria have been shown to survive greater than 120 days in soil (Kibbey et al. 1978) and at least 70 days in groundwater (Bitton et al. 1983). Gerba et al. (1975, cited by Jamieson et al. 2002) reported survival times of enteric bacteria in soil and groundwater ranged from 2 to 4 months. Filip et al. (1988, cited by Jamieson et al. 2002) examined the survivability of several organisms in simulated conditions of saturated soil and observed that most organisms tested for, including *E. coli*, survived for over 100 days at 10^{o}C.

Wang et al. (2004) reported that in laboratory experiments fecal coliform bacteria in dairy cow manure remained viable for over 3 months at any moisture level. Kress and

Gifford (1984) found that cattle manure still produced fecal coliform counts as high as 4,200 FC/100mL after 100 days.

Jawson et al. (1982) reported that fecal coliform levels exceeded the 200 FC/100 mL standard in many samples collected from a northeast Idaho stream more than a year after cattle were removed from the watershed.

Much less is known about the survivability of *Bacteroides* in the environment. *Bacteroides* are obligate anaerobes; they require an environment void of oxygen to survive. Based on literature reviewed by Balleste and Blanch (2010), culturable *Bacteroides* can survive from a few hours to a few days and reproduction is not possible. Survival is better in winter than in summer. Although *Bacteroides* is short-lived the DNA of *Bacteroides* remains detectable from days to weeks.

Kreader (1998) experimented with *Bacteroides distasonis* from human feces incubated in Ohio River water. The bacterium was detected by PCR for at least 2 weeks at 4^{o}C, but for only 4 to 5 days at 14^{o}C, 1 to 2 days at 24^{o}C, and 1 day at 30^{o}C. Predators shortened survival time, especially in warmer water. Kreader stated that predators eliminate *Bacteroides* DNA whether the *Bacteroides* are dead or alive.

The lower survivability of *Bacteroides* compared to that of fecal coliform bacteria may account for the lower frequency of occurrence of *Bacteroides* in our study.

Groundwater, Preferential Flow, and Upland Sources

MST results in the Discovery Bay studies of 2012-13 and 2018-19, and in the 2011-12 Chimacum study (Gately et al. 2015) showed human fecal sources were more prevalent than ruminant and cattle fecal sources. Given the unmistakable odor of surfacing septage effluent, it is unlikely that the human *Bacteroides* entered the streams on the surface, but more likely made its way to the streams in subsurface flow.

In the 1970s, on-site waste disposal systems (OSWDS) ranked highest in total volume of wastewater discharged directly into the groundwater and were also the most frequently reported source of groundwater contamination (Geraghty and Miller 1978).

In a properly functioning OSWDS, fecal organisms are filtered and/or adsorbed by the soil adjacent to the drainfield trenches (Viraraghavan and Warnock 1976). However, improper site selection and/or poor installation can result in the subsurface escape of fecal organisms from the treatment zone (McCoy and Hagedorn 1979). A seasonally high water table can inundate the soil adjacent to the drainfield trenches and cause rapid movement of water and organisms away from the drainfield with little filtering or adsorption (Rahe et al. 1978). Coarse soils adjacent to the drainfield can contribute to the movement (Stolt and Reneau (1991).

In the absence of artificial drainage, it is believed that "preferential flow" through macropores in undisturbed soil is the primary method of bacterial transport (Jamieson et al. 2002). Macropores result from burrowing animals, earthworms, insects, plant root holes, etc.

Stolt and Reneau (1991) reviewed over 500 publications to evaluate the cause and effect relationships between OSWDS and ground and surface water pollution. They found that Virginia OSWDS were polluting ground and surface water with bacteria, viruses, and nitrogen. OSWDS had the greatest potential to pollute if they occurred in high density areas or if they were placed in soils with high water tables and/or coarse textures. When OSWDS were located in areas with shallow aquifers, bacterial pollution was considerable.

DeWalle and Schaff (1980) examined well records and water samples covering a 30-year period for an area underlain with glacial deposits near Tacoma, Washington. The population of the area was 242,000 with 100,000 of the residents on OSWDS. As many as 35% of the wells were contaminated with coliform bacteria.

Sandhu et al. (1979) examined levels of total coliforms, fecal streptococci, and *E. coli* in water samples from 460 wells in South Carolina. Fecal streptococci and *E. coli* were found in 75% and 43% of the wells, respectively. *E. coli* levels decreased as the distance between OSWDS and the wells increased.

Lusk et al. (2011) stated that the most commonly recommended means of reducing bacterial transport from septic systems is to increase distances from the drainfield to the groundwater, thus increasing the chances for removal of pathogens and reducing the chances of pathogen transport to the groundwater.

Reneau et al. (1975) examined levels of bacteria in ground and surface waters in a small (80 hectare) watershed in Virginia. Soils in the watershed were divided into three groups based on their suitability for OSWDS; 17% were suitable, 41% marginal, and 42% unsuitable. The OSWDS in marginal soil failed during periods of high precipitation. All of the OSWDS in the unsuitable soils failed. Water samples collected from ground and surface waters near failing OSWDS had high numbers of total and fecal coliform bacteria. Bacteria concentrations decreased with increasing distance from the OSWDS.

As with fecal bacteria from human sources, fecal bacteria from animal sources can be transported through the soil into groundwater and surface water. Howell et al. (1996) reported on the effects of cattle grazing in two Kentucky watersheds, both with deep, well-drained soils. Before grazing occurred near a spring, fecal coliform levels in the spring water exceeded the EPA standard of 200 FC/100mL in 29% of the samples. After cattle began grazing the surrounding pasture, 80% of the samples exceeded the standard.

The survival and growth of fecal coliform bacteria in stream sediment, algae, soil, and manure; the capability of bacteria to infiltrate groundwater and be transported to surface water; and the variety of fecal sources, including livestock, human, pet, and wildlife, all make it a challenge to meet the water quality standard.

These factors also make it difficult to demonstrate improvements resulting from Best Management Practices. As Wilkes and his co-authors (2013) stated, “Clearly, for systems impacted by multiple sources of fecal contamination, the mitigation benefits of a BMP could potentially be offset or clouded by other fecal pollution sources.”

Temperature

Temperature is one of the most important environmental influences on salmonid biology. The ambient water temperature determines the salmon’s internal temperature and therefore influences feeding rate, growth, metabolism, development of embryos and alevins (sac-fry), and timing of life history events such as upstream migration of adults, spawning, and downstream migration of smolts. Sub-lethal temperatures can effectively block migration, reduce growth, affect reproduction, inhibit smoltification, and cause stress and disease (Carter 2006).

Preferred temperatures for Coho rearing and growth have been reported as 12-14°C (Brett 1952; MacDonald et al.1991) and as 10-12°C (Konecki et al. 1995).

Washington State Department of Ecology (2002) reviewed the literature on three types of temperature studies to determine the temperature which, if exceeded, may result in adult and juvenile salmonid mortality: constant temperature studies, fluctuating temperature studies, and field studies. From this information they calculated the 7-day average of the daily maximum temperatures (7-DADMax) for the protection of salmonids. The 7-DADMax temperatures for these studies were as follows: constant temperature studies, 22.64°C; fluctuating temperature studies, 23.05°C and field studies, 22.18°C.

USEPA (1999) reported that temperatures in the range of 22-24°C totally eliminates salmonids from an area. USEPA (2003) Region 10 designated 16°C as the 7-DADMax temperature that should not be exceeded.

Temperature criteria for streams are listed in Table 200 (1) (c) of WAC 173-201A. The temperature standard is based on the 7-day average of the daily maximum temperatures (7-DADMax). Streams entering Discovery Bay are categorized as “core summer salmonid habitat,” which calls for a 7-DADMax of 16°C. Additional criteria, listed in Ecology publication 06-10-038 (revised January 2011) apply to Salmon Creek, Snow Creek, and Andrews Creek. In these streams the 7-DADMax should not exceed 13°C from September 1 to July 1. Ecology added the 13°C 7-DADMax standard in 2006 for the purpose of protecting the developing embryos of early spawning salmon such as Summer Chum.

In 2019, Salmon Creek failed the 7-DADMax-16ºC standard at 2 of the 3 stations monitored; Snow Creek failed at 5 of 5 stations; and Andrews Creek failed at 5 out of 5 stations (Figure 19, Table 4). Houck Creek failed at its downstream station and Uncas Valley Ditch passed at its downstream station.

Salmon, Snow, and Andrews creeks failed the 7-DADMax-13ºC standard at all the stations monitored. The 7-DADMax-13ºC standard does not apply to Houck Creek or Uncas Valley Ditch.

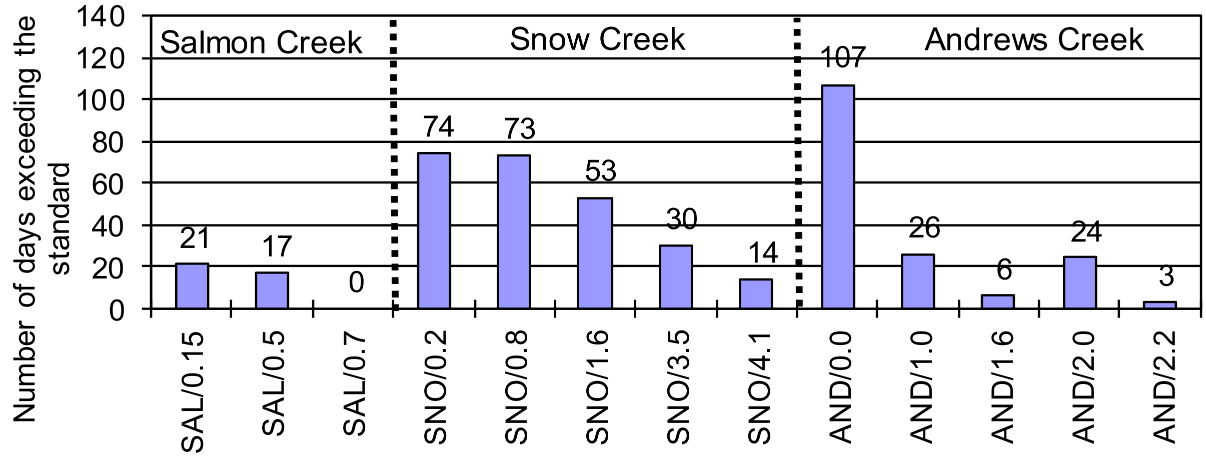
Uncas Valley Ditch had no days exceeding the 7-DADMax-16ºC standard. It had the amazingly low average maximum high daily temperature of 11.8 ºC for July and August (Table 4). Appendix Figure C-15 show no daily fluctuations as is normal (see other temperature graphs in Appendix C). The reason for this is that the logger was placed too far down into the soft sediment where the temperature was not affected by the usual changes between night and day.

Temperature in Salmon, Snow, and Andrews creeks generally increased from upstream to downstream (Figure 20). In 2019, at Salmon Creek's downstream station SAL/0.15, the 7-DADMax 16ºC standard was exceeded on 21 days and its 13ºC 7-DADMax standard was exceeded on at least 48 days. Snow Creek's downstream station exceeded the 16ºC and 13ºC standards on 74 days and 39 days (minimum), respectively (Table 4).

Because Andrews Creek flows through Crocker Lake, its downstream temperature is affected more by the surface temperature of Crocker Lake than by the temperature of Andrews Creek upstream from the lake. Andrews Creek enters the lake about 0.5 miles away from where it exits the lake. In 2019, downstream station AND/0.0 exceeded the 16 ºC standard on 107 days and the 13ºC standard was exceeded on a minimum of 46 days (Figure 19, Table 4). In comparison, station AND/1.0, upstream from Crocker Lake, exceeded the 16ºC standard on only 26 days and the 13ºC on a minimum of 37 days. In 2019, the average of the maximum daily highs for July and August was 2.0ºC higher near the mouth of Andrews Creek (AND/0.0) than it was upstream from Crocker Lake at station AND/1.0.

In 2003, a major restoration project began on lower Salmon Creek on 103 acres of land purchased by Washington Department of Fish and Wildlife (Figures 21 and 22). A new 3,500 ft.-long channel complete with meanders and large woody debris was constructed. Soon afterwards, North Olympic Salmon Coalition (NOSC) planted a variety of trees and shrubs along both banks. Then in the spring of 2006, under the Conservation Reserve Enhanced Program, 180-foot buffers on both sides of the

16°C 7-DADMax Standard



13°C 7-DADMax Standard

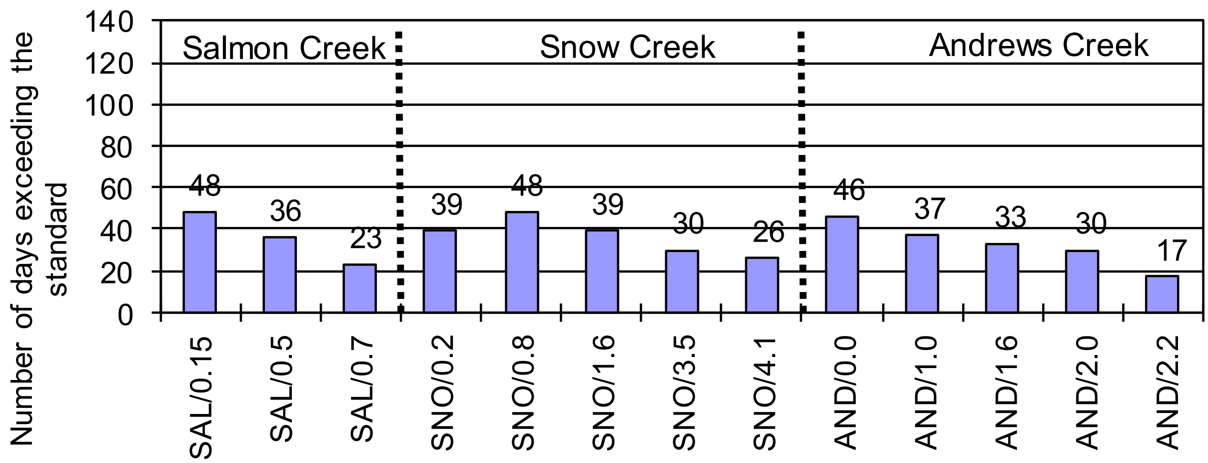


Figure 19. Number of days exceeding the 7-DADMax 16° C standard (top) and 7-DADMax 13° C standard (bottom) from May 1 to October 7, 2019 in Salmon Creek and from June 1 to October 7, 2019 in Snow Creek and Andrews Creek. The number of exceedances applying to the 7-DADMax 13° C standard is a minimum because the data loggers were deployed for only part of the applicable period from September 1 to July 1.

Table 4. Temperature data obtained from temperature data loggers deployed in the Discovery Bay watershed in 2019. The state standard requires that the 7-DADMax not exceed 16^o Celsius at any time and not exceed 13^o Celsius from September 1 to July 1.

Station	No. of Days 7-DADMax>16^o Celsius	No. of Days 7-DADMax>13^o Celsius from September 1 to July 1[1]	Average Maximum Daily High Temperature for July and August Combined	Temperature Data Logger Started Recording	Temperature Data Logger Stopped Recording
SAL/0.15	21	48	15.4	01-May-19	07-Oct-19
SAL/0.5	17	36	15.2	01-May-19	07-Oct-19
SAL/0.7	0	23	14.5	01-May-19	07-Oct-19
SNO/0.2	74	39	17.1	01-Jun-19	07-Oct-19
SNO/0.8	73	48	17.1	01-Jun-19	08-Oct-19
SNO/1.6	53	39	16.4	01-Jun-19	07-Oct-19
SNO/3.5	30	30	15.4	01-Jun-19	07-Oct-19
SNO/4.1	14	26	15.1	01-Jun-19	07-Oct-19
AND/0.0	107	46	17.7	01-Jun-19	07-Oct-19
AND/1.0	26	37	15.7	01-Jun-19	07-Oct-19
AND/1.6	6	33	15.3	01-Jun-19	07-Oct-19
AND/2.0	24	30	15.4	01-Jun-19	07-Oct-19
AND/2.2	3	17	14.8	01-Jun-19	07-Oct-19
HOU/0.0	16	69	15.6	01-May-19	08-Oct-19
UVD/0.0	0	0	11.8	01-May-19	08-Oct-19

[1] Number of days are a minimum because the data logger was not deployed during the entire time period.

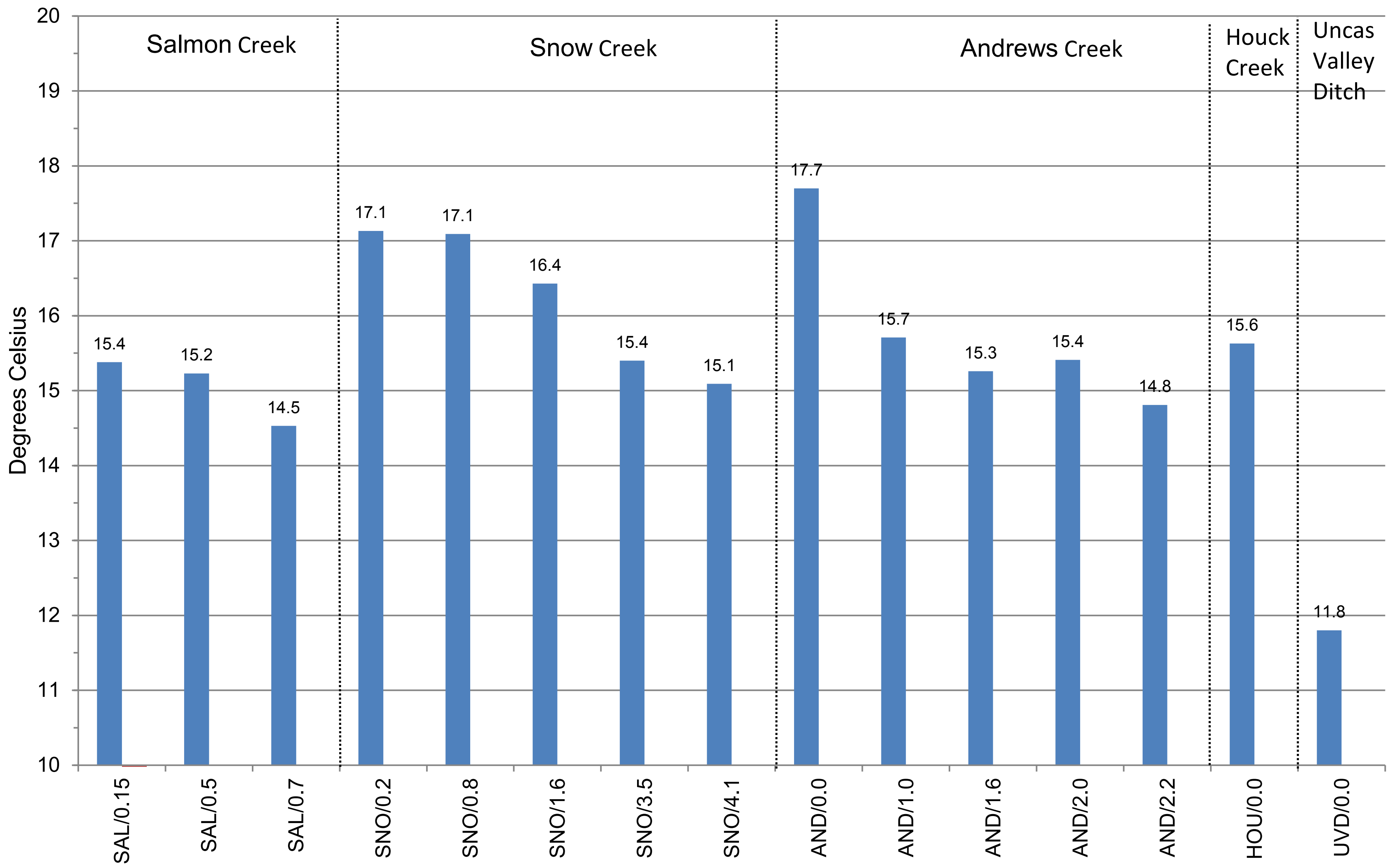


Figure 20. Average maximum high daily temperatures for July and August 2019 at temperature logger stations in the Discovery Bay Watershed.

Figure 21. Aerial photo showing Salmon Creek's new channel constructed in 2003.

A new channel is excavated.

Gravel is added to the channel.

Large woody debris is placed in the channel.

The new channel is ready for water!

Figure 22. Photos taken in 2003 showing the construction of Salmon Creek's new channel.

channel were planted with a variety of 18,000 trees and shrubs. The new channel received its first flow of water on June 23, 2004, approximately 60 days before the Summer Chum returned.

Stream temperature in the new channel has decreased slightly since the restoration project (Figure 23). Since water temperature is affected by air temperature and air temperature varies from year to year, comparisons need to take air temperature into account in assessing temperature trends. For this reason, air temperatures measured in Quilcene are shown on the graph. Also for comparison purposes, upstream station SAL/0.7 is shown as a control. Station SAL/0.7 is a good control because Salmon Creek flows through forested land upstream from this station and the stream channel is well shaded.

Prior to the Washington Department of Fish and Wildlife (WDFW) restoration project, downstream station SAL/0.1 exhibited an increasing temperature trend from 2000 to 2003 at a rate similar to that of upstream control station SAL/0.7 (Figure 23). Air temperature in Quilcene also increased during this period. In contrast, from 2005 to 2019 as trees planted in the 2003-04 CREP project grew, temperature at downstream station SAL/0.15 showed a slight decreasing trend when upstream control SAL/0.7 was increasing as was the air temperature in Quilcene.

From 1999 to 2016, Snow Creek's downstream temperature exhibited a slightly increasing trend, similar to that of upstream control stations SNO/4.1, SNO/4.3, and SNO/4.4 and to the air temperature trend at Quilcene (Figure 24).

Andrews Creek flows through Crocker Lake before entering Snow Creek at RM 3.5. Due to the influence of Crocker Lake, two downstream stations are compared to upstream control station AND/2.2 and to the air temperature in Quilcene (Figure 25). From 2000 to 2019, control station AND/2.2 showed a slightly increasing trend as did the air temperature in Quilcene. Station AND/1.0, upstream of Crocker Lake, also had a slightly increasing trend, whereas the trend at AND/0.0 at the mouth was flat, neither increasing nor decreasing.

At first glance, it may appear that all is not well when 13 out of 15 (87%) stations failed the 16°C 7-DADMax temperature standard. However, this is not the case. It is good to have a goal to shoot for, but all is not lost when the goal is not met as our fish trapping data points out. Andrews Creek, downstream from Crocker Lake, was the warmest reach monitored in the Discovery Bay Watershed in 2019. From June 1 to October 1, the temperature standard was met on only 12 days (see Appendix Figure C-1). The average of the daily high temperatures for July and August was 17.7 °C (Table 4). In spite of this, we observed dense schools of Coho fry in shallow pools in this reach on August 6 and 7, 2019, when temperature highs were 18.3 °C and 17.9 °C respectively.

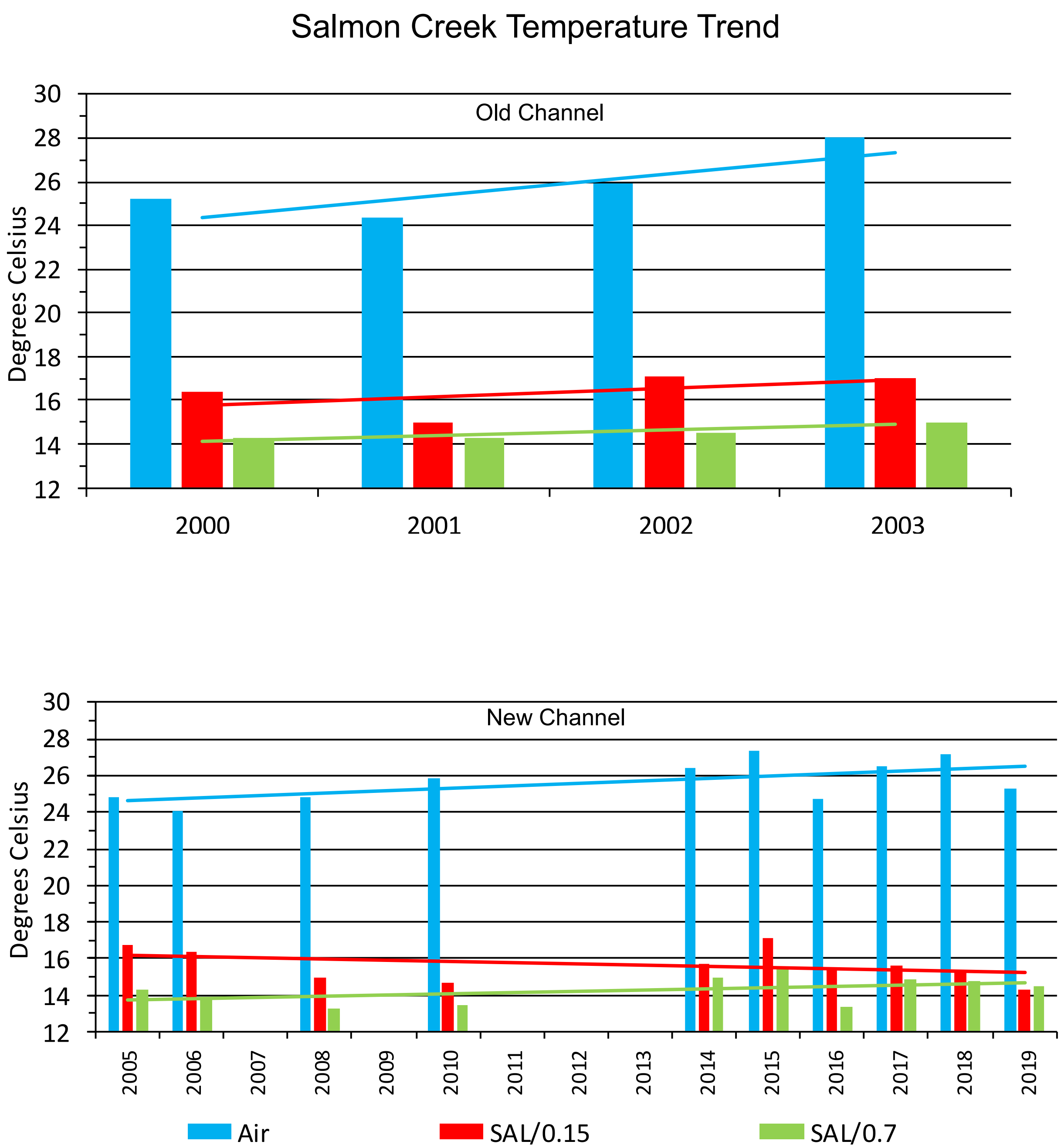


Figure 23. Comparison of the temperature trend at Salmon Creek downstream station SAL/0.15 to the trend at the forested, upstream control station SAL/0.7 and to the air temperature in Quilcene. Temperatures shown are averages of the daily maximum high temperatures for July and August. Stream flow was switched from the old channel to the new channel in June 2004.

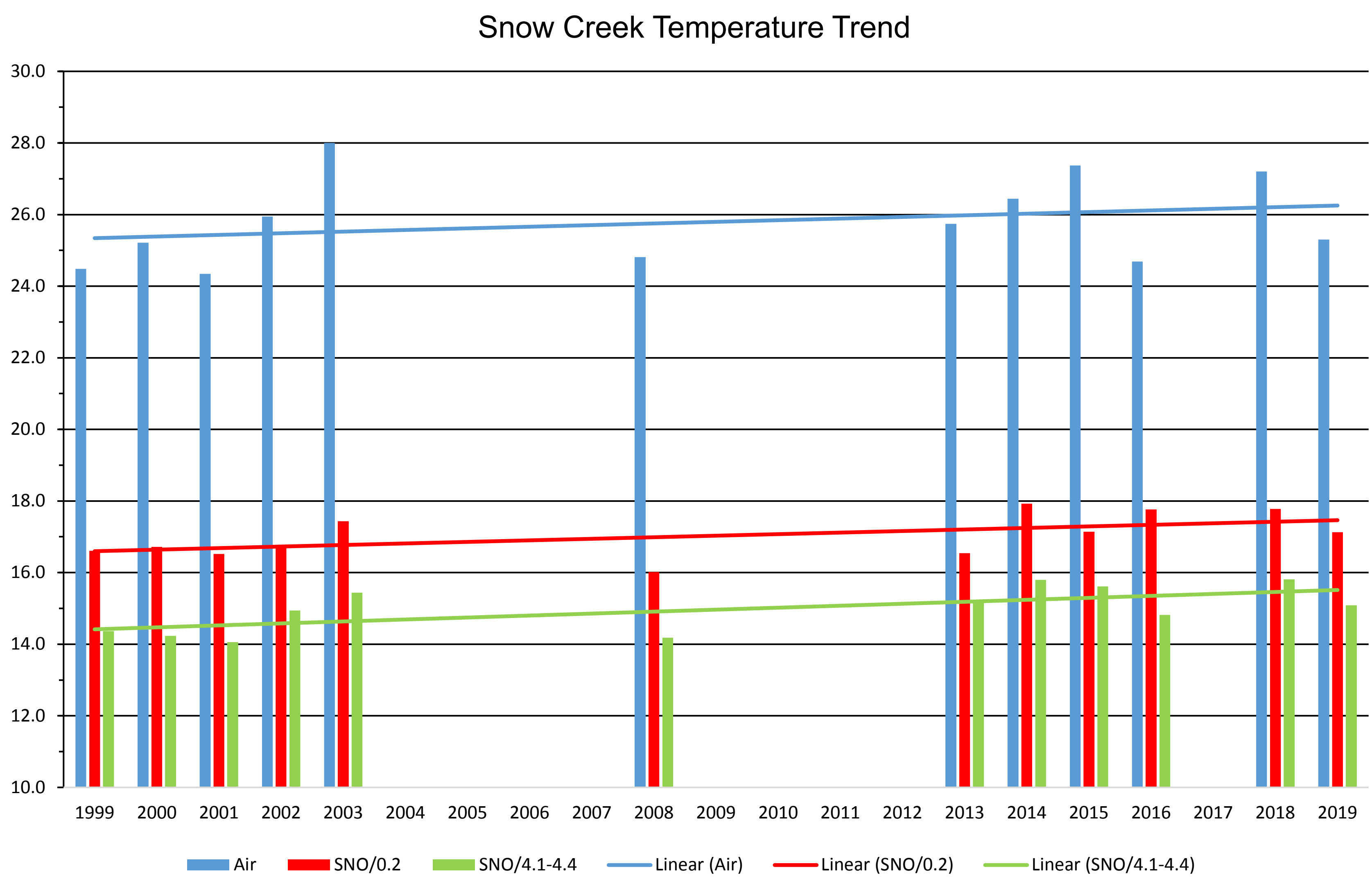


Figure 24. Comparison of the temperature trend at Snow Creek downstream station SNO/0.2 to the trend at the forested, upstream control stations SNO/4.1-4.4 and to the air temperature in Quilcene. Temperatures shown are averages of the daily

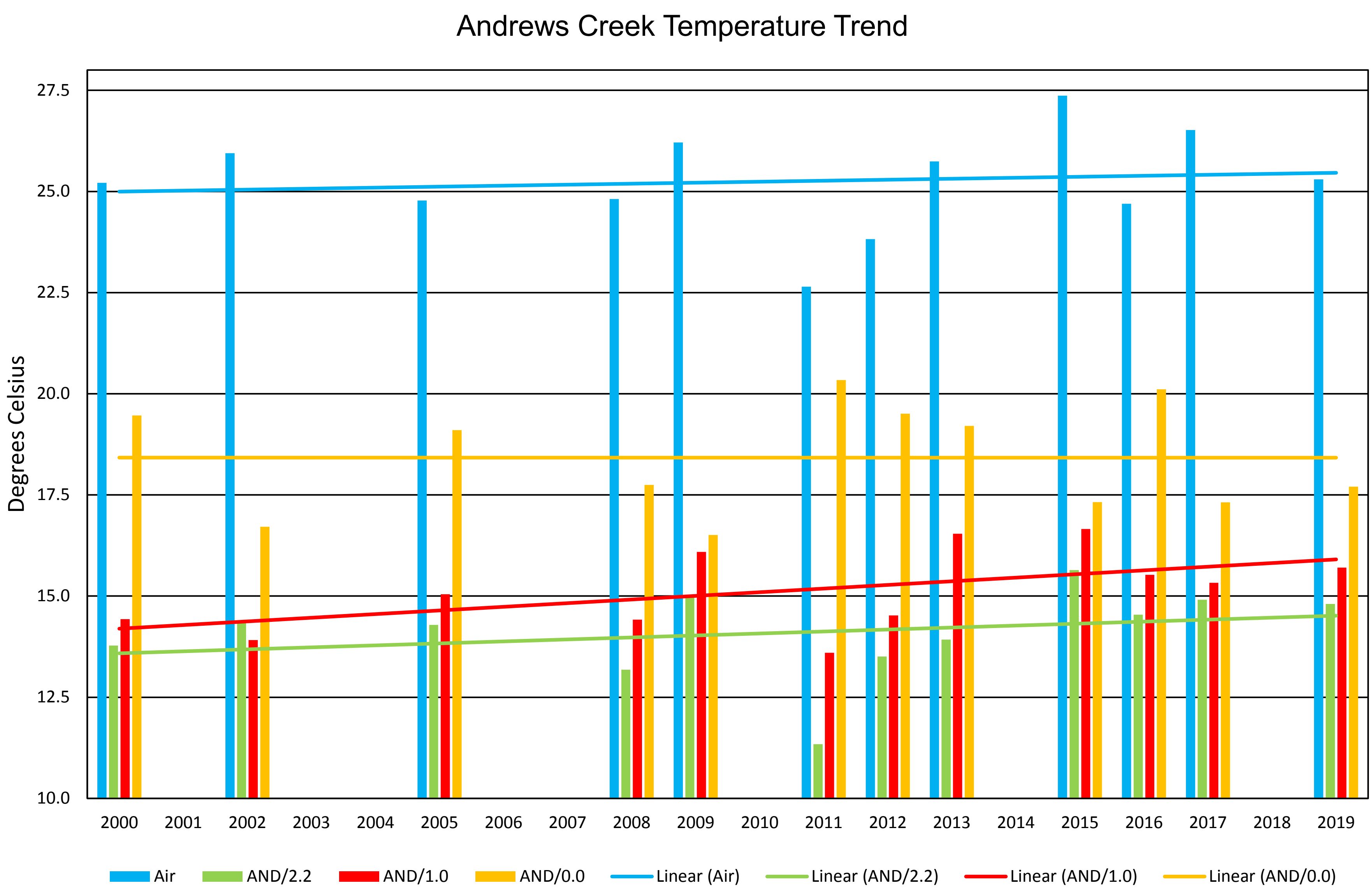


Figure 25. Comparison of the temperature trends at Andrews Creek downstream stations AND/0.0 and AND/1.0 to the trend at forested, upstream control station AND/2.2 and to the air temperature trend in Quilcene. Temperatures shown are averages of the daily maximum high temperatures for July and August combined.

Table 4. Temperature data obtained from temperature data loggers deployed in the Discovery Bay watershed in 2019. The state standard requires that the 7-DADMax not exceed 16° Celsius at any time and not exceed 13° Celsius from September 1 to July 1.

Station	No. of Days 7-DADMax>16° Celsius	No. of Days 7-DADMax>13° Celsius from September 1 to July 1[1]	Average Maximum Daily High Temperature for July and August Combined	Temperature Data Logger Started Recording	Temperature Data Logger Stopped Recording
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SNO/3.5	30	30	15.4	01-Jun-19	07-Oct-19
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AND/1.6	6	33	15.3	01-Jun-19	07-Oct-19
AND/2.0	24	30	15.4	01-Jun-19	07-Oct-19
AND/2.2	3	17	14.8	01-Jun-19	07-Oct-19
HOU/0.0	16	69	15.6	01-May-19	08-Oct-19
UVD/0.0	0	0	11.8	01-May-19	08-Oct-19

[1] Number of days are a minimum because the data logger was not deployed during the entire time period.

Fish trapping on these dates yielded an average catch of 23 Coho (1.5-2 in. long) per trap, a very high catch rate. These Coho fry had access to Snow Creek only 600 feet downstream, where the 7-DADMax was 16.8 ºC and 16.6 ºC on the same days (see Appendix Figure C-14).

Since fish are cold-blooded, their metabolism increases as water temperature increases. As long as fish are not stressed and food is abundant, fish may benefit from a little warmer water by increased growth and condition factor (weight-length relationship). This was what Roegner and Teel (2014) concluded from their study of juvenile Chinook in the Columbia River.

Roegner and Teel studied the condition factor of 5,536 juvenile Chinook Salmon, captured in different seasons in the lower Columbia River in relation to water temperature ranging from 4.2ºC to 23.5ºC. Contrary to their hypothesis that the condition factor would decline during periods of high temperature, the condition factor actually increased during summer when temperatures ranged from 19ºC to 23.5ºC. Other studies have shown that positive growth can be maintained at temperatures above 19ºC if oxygen and food rations are sufficiently high (Brett et al. 1982; Clarke and Shelbourn 1986; Marine and Cech 2004). Furthermore, Roegner and Teel surmised that some stocks may be relatively tolerant of—or even benefit from—temperatures above 19ºC due to genetic adaption.

Higher metabolism and increased growth of salmonids in freshwater has been shown to improve their growth and survival in marine water. Ward and Slaney (1988) found that marine survival of Steelhead reared in the Keogh River, British Columbia was correlated with smolt length and weight. Thompson and Beauchamp (2014) found that the marine survival of Skagit River Steelhead appeared to be related to a higher growth rate set in an early freshwater stage which resulted in larger smolts. Holtby et al. (1990) studied the marine survival of Coho Salmon from Carnation Creek, British Columbia over a 17-year period. Although they attributed marine survival to variable ocean conditions (i.e. upwelling off the northwest coast of Vancouver Island), they noted that large smolts survived better in years when marine survival was relatively poor.

Thus, water temperature a little warmer than the standard may be beneficial.

Temperature profiles for the 15 stations monitored in the 2019 water-year are shown in Appendix C.

Surface Water Dissolved Oxygen

Dissolved oxygen (DO) is one of the most important indicators of water quality. It is essential for the survival of fish and the macroinvertebrates which fish feed on.

Water becomes aerated as it comes in contact with the atmosphere. The steeper the stream's gradient, the greater is the aeration; more aeration occurs in riffles than in pools.

When water holds the maximum amount of dissolved oxygen (DO) possible under "normal" conditions, it is said to be 100% saturated. Warm water has a lower saturation level than cold water and therefore cannot hold as much oxygen as cold water. For instance, the saturation level of 20°C water is 9.1 mg/L, compared to 11.3 mg/L for 10°C water.

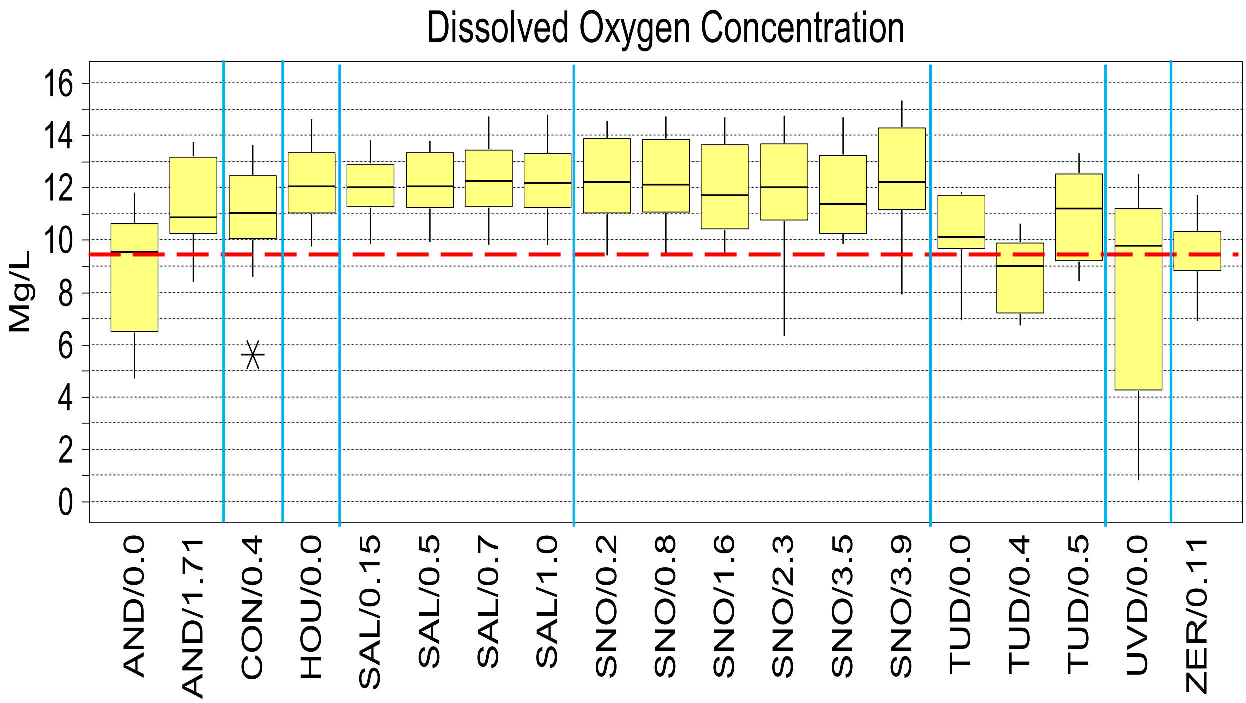
Aquatic plants release dissolved oxygen into the water by photosynthesis and on sunny days water in which there is excessive vegetation can become supersaturated (>100%) with dissolved oxygen. When plants die, their decomposition removes oxygen, causing the DO concentration to decrease.

The Washington DO standard for "core summer salmonid habitat" is a 1-day minimum of 9.5 mg/L (WAC chapter 173-201A).

USEPA (1986) produced the following sliding scale relating salmonid production (biomass per area per time) to various DO levels:

DO Concentration (mg/L)	Effect On Salmon and Trout
8	No production impairment
6	Slight production impairment
5	Moderate production impairment
4	Severe production impairment
3	Limit to avoid acute mortality

In the monthly monitoring conducted from November 2017 to April 2019, 10 of the 19 stations failed the state standard (Figure 26). The DO concentration at four of the failed stations was above the 8 mg/L "no production impairment level." Four other failures occurred at stations on Tucker Ditch and Uncas Valley Ditch. Both of these ditches dry up during the summer, but it is likely that the lower reaches of these ditches to Salmon Creek serve as refugia for salmonids during periods of high flow. DO levels were high in the ditches during the high-flow winter months. Juvenile Coho have been trapped in lower Uncas Valley Ditch in the past.



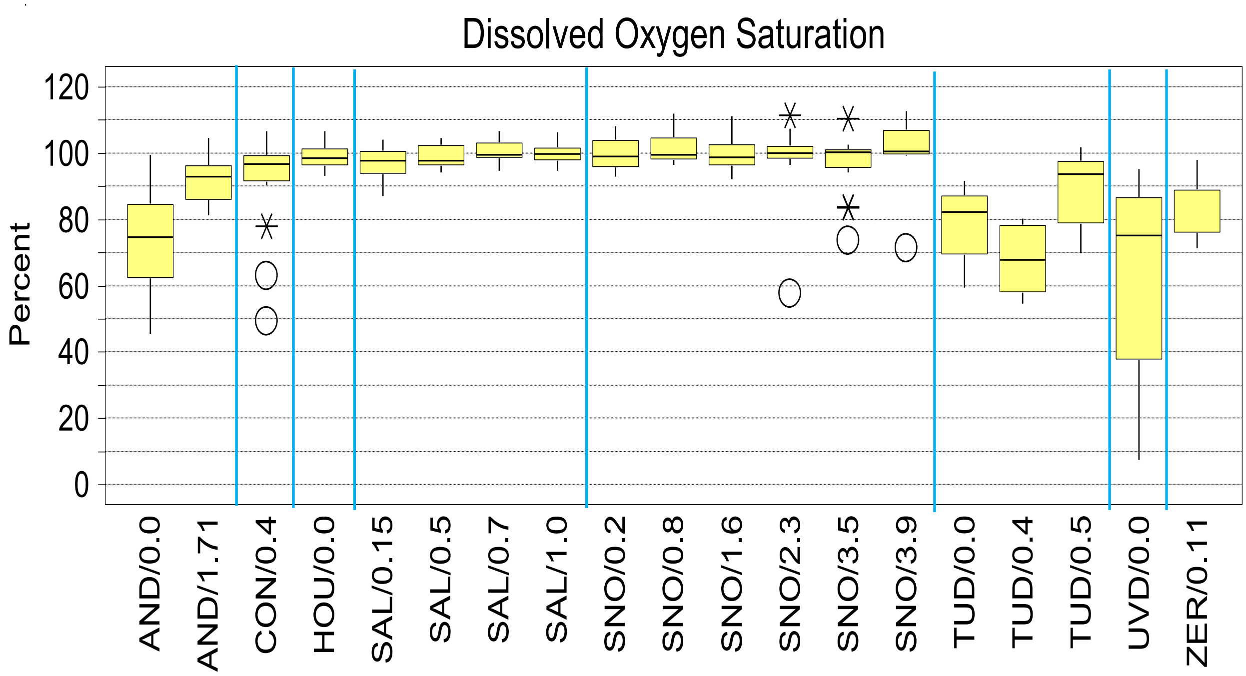


Figure 26. Dissolved oxygen concentration (top) and saturation (bottom) at stations in the Discovery Bay Watershed monitored monthly from November 2017 to April 2019 (except January 2019). The state standard requires that the dissolved oxygen concentration not be less than 9.5 mg/L (dashed line). For an explanation of the “box and whiskers,” refer to “statistics” in the “methods” section.

The DO concentration in lower Andrews Creek, downstream from Crocker Lake (the same reach with high temperatures described in the last section), historically has had low dissolved oxygen levels. In July 2018, DO measured 4.7 mg/L. This reach is fed by anaerobic groundwater, which is apparent by a coating of brown ferric hydroxide on the stream bottom. Dissolved ferrous iron in the groundwater precipitates out as ferric hydroxide when it comes in contact with oxygen. This reaction consumes dissolved oxygen.

Decaying canary grass and aquatic vegetation in the channel probably also contributed to the low dissolved oxygen. A cursory sampling of macroinvertebrates on August 7, 2019 when the Coho fry were trapped revealed predominantly scuds, leeches, and sow bugs, all indicators of poor water quality. Despite this, a high density of Coho fry were present. These juvenile Coho could have originated in the reach where they were trapped or they could have come from nearby Snow Creek, only 600 feet downstream.

As with the temperature standard, salmonids can survive when the dissolved oxygen standard is not met. However, as the EPA chart shows, production (and fish length) decrease as DO decreases below 8 mg/L. Because survival is related to fish length and because intragravel dissolved oxygen (see following section) is dependent on surface dissolved oxygen, it is always best that surface dissolved oxygen be as high as possible.

Intragravel Dissolved Oxygen

Intragravel dissolved oxygen (IGDO) refers to the dissolved oxygen in the subsurface flow (i.e., the DO in the water flowing through the gravel). Developing salmonid eggs and alevins as well as macroinvertebrates (e.g., stoneflies, mayflies, caddisflies) depend upon an adequate supply of oxygen (USEPA 1986). Requirements for salmonid eggs and alevins are the same as those for adults; no impairment occurs above 8 mg/L and acute mortality occurs below 3 mg/L (see chart in Dissolved Oxygen section for intermediate levels of impairment). It is sediment or fines within the gravel that limits the flow of oxygen-bearing water to the eggs, alevins, and macroinvertebrates.

In the 1980s, Summer Chum Salmon experienced a severe drop in abundance in Hood Canal and Strait of Juan de Fuca streams (Ames et al. 2000). This critical situation resulted in the National Marine Fisheries Service listing the Summer Chum as “threatened” under the Endangered Species Act. Habitat degradation was one of the factors believed responsible for the general decline in Summer Chum. Because juvenile Chum spend about 95 percent of their freshwater stage in the gravel, an adequate level of dissolved oxygen in the gravel is crucial to their survival.

When the new channel was constructed for Salmon Creek on WDFW property (Figures 21 and 22), we expected there would be a lot of fines in the sediment. The question was, how long would it take for the fines to be flushed out and for the gravel to become suitable for spawning and egg incubation? Intragravel dissolved oxygen monitoring answered this question. Fortuitously, the Conservation District had begun monitoring IGDO in Salmon Creek in 2001. Thus, we had 3 years of baseline data for the reach being replaced. Also, when we began monitoring IGDO in the new channel in 2004, we monitored the reach immediately upstream from the new channel to serve as an additional control. However, this upstream control reach was not a “pristine” control because it had been relocated to its current location probably about the early 1900s. Also, cattle were fording the creek immediately upstream from the control reach, potentially causing erosion with fines moving downstream. In the fall of 2008, a cattle bridge was constructed, and cattle were fenced from the creek (Figure 27).

Not surprisingly, IGDO levels in the new channel in 2004 were very low (average 2.3 mg/L) during that first fall and winter, only a few months after the first flow of water (Figure 28). None of the “redds” maintained a DO concentration above the EPA critical survival level of 3.0 mg/L from September through March. However, by 2007, only three years later, IGDO levels in the new channel averaged 8.1 mg/L, approximating both the pre-construction average level and the upstream control average. From 2007 to 2009, the percentage of “redds” with DO greater than 3.0 mg/L ranged from 71% to 84% only slightly less than the upstream control reach range (78% - 95%) and slightly greater than the range for the original channel (50% - 83%).

Another way of evaluating intragravel dissolved oxygen is to compare intragravel DO to surface water DO. Under perfect conditions the intragravel DO would be 100% of the surface DO. Average ratios of intra-gravel DO to surface DO in the new channel for the first three years (2004-2006) ranged from 22% to 53%, compared to the much higher range of 55% to 79% for the upstream control reach (Figure 28). However, for the next three years (2007-2009) new channel ratios ranged from 61% to 76%, approximating the range for the upstream control reach (66% to 80%) and the pre-construction range (58% to 73%).

Thus, it took three years for Salmon Creek’s new channel to be purged of enough fines for IGDO to recover to pre-construction levels. From October 2004 to September 2007 Salmon Creek experienced nine high flows (three each year), ranging from 50 cfs to 115 cfs. It is likely that periodic high flows are what purge fines from the riffles.

Besides its importance to developing salmonid eggs and alevins, an adequate supply of dissolved oxygen is also important to the macroinvertebrates inhabiting the gravel substrate. Macroinvertebrates such as stoneflies, mayflies, and caddisflies are an important food source for salmonids and other fishes.

Macroinvertebrates are used as an indicator of water quality. The number and kinds of macroinvertebrates are used to calculate a Benthic Index of Biotic Integrity (B-IBI). The higher the B-IBI, the heathier the stream is. Because macroinvertebrates require dissolved oxygen, IGDO concentration is a major determining factor of the B-IBI.

Livestock Bridge on Salmon Creek

at approximately RM 0.7

Figure 27. Livestock bridge, solar-powered watering tank, and fencing, built in the fall of 2008, prevented cattle from accessing 800 ft. of Salmon Creek.

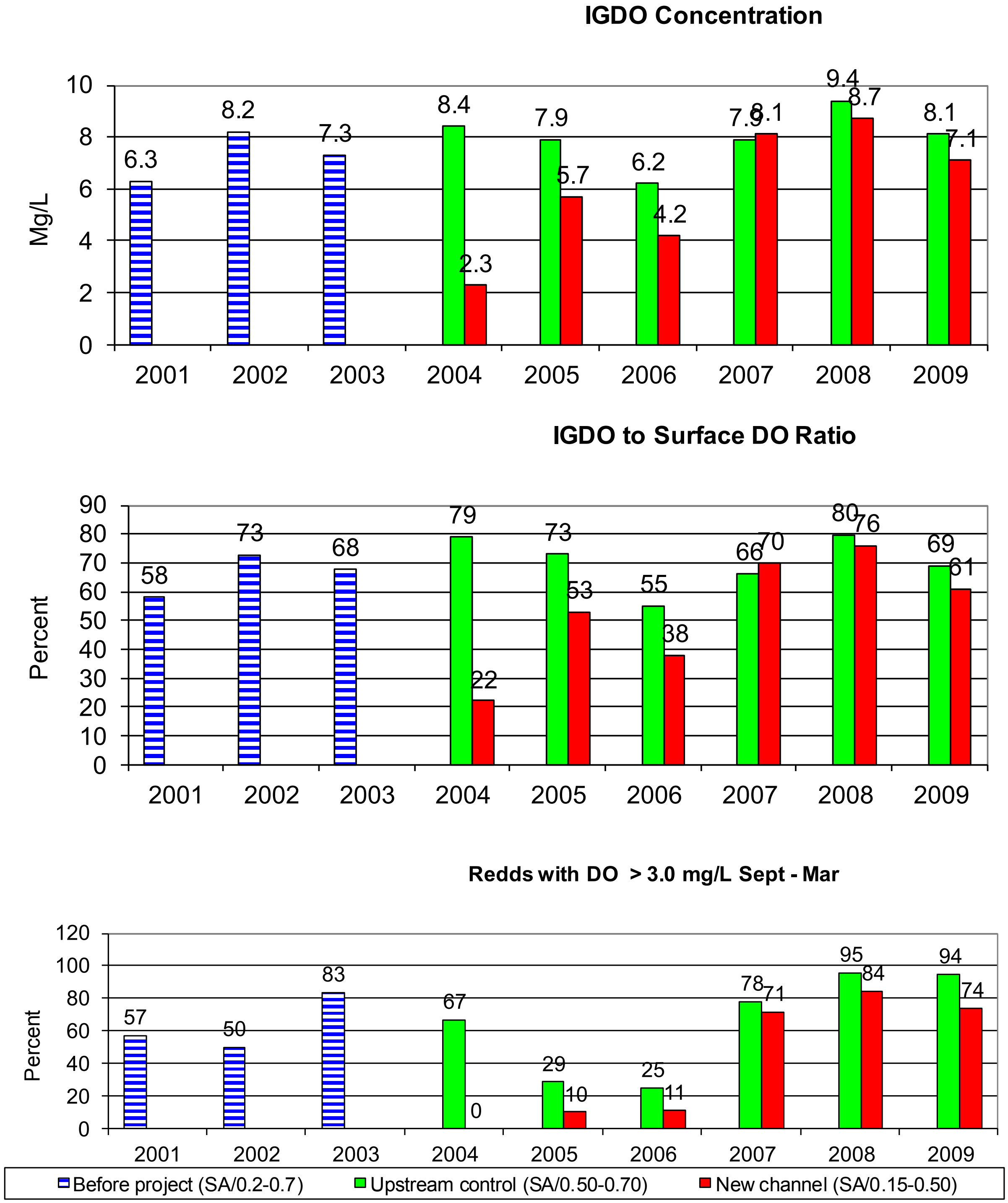


Figure 28. Salmon Creek average intragravel dissolved oxygen concentrations (top), average intragravel DO to surface DO ratios (middle), and percentage of redds with DO greater than 3.0 mg/L from September through March for the original channel before the project began, the upstream control reach, and the excavated new channel.

NOSC collected macroinvertebrates in Salmon Creek's new channel and in an upstream control channel from 2004 to 2008 (NOSC undated report; NOSC unpublished data). The B-IBI for the new channel in 2004, its first year with water, was only 16, meriting a rating of "very poor" (Figure 29). In 2005 it increased to 22 for a rating of "poor" and in 2006 it increased to 34 for a rating of "fair." (Category ratings such as "poor" and "fair" were obtained from the University of Washington.) The upstream control channel had a B-IBI ranging from 30 to 36 for a "fair" rating for all 5 years. Thus, macroinvertebrates recovered in two years, one year prior to the recovery of IGDO. Based on regression analysis of B-IBI on IGDO using data collected from 2004 to 2008 from Salmon Creek's new channel and the upstream control reach, B-IBI was highly correlated ($p=0.0000$) to the intragravel dissolved oxygen level (Figure 30).

IGDO and B-IBI data were used to evaluate an erosion abatement project on Houck Creek, a tributary to Salmon Creek (Figure 5). In the 1960s Houck Creek was rerouted over a steep bank about 100 feet upstream from its confluence with Salmon Creek at RM 1.0. Over the years erosion carved a deep gully in the bank as tens of thousands of cubic yards of soil washed into Salmon Creek and onto the Summer Chum spawning grounds. To stem the erosion, in August 2002 JCCD and NOSC worked together to have 1000 cubic yards of large crushed rock placed in the gully (Figure 31). Additionally, a half-round culvert section was placed at the top of the bank and extended over the rock to prevent more erosion of the bank.

Although we have no pre-construction data, we do have several post-construction years of IGDO data (2002-2007) and B-IBI data (2003-2005) on Salmon Creek, upstream and downstream of its confluence with Houck Creek. Downstream IGDO concentrations (range 8.1-10.4 mg/L) were similar to upstream concentrations (range 8.6-10.4 mg/L; (Figure 32). Similarly, IGDO to surface DO ratios downstream of Houck Creek (range 73%-87%) were similar to upstream ratios (range 77%-91%). The percentage of "redds" with DO concentrations greater than 3.0 mg/L ranged from 80% to 100% for both upstream and downstream reaches. Upstream and downstream B-IBIs were also similar; three-year B-IBI averages for both reaches received ratings of "fair" (NOSC unpublished data).

Much variation in IGDO concentration occurred within the same reach, not only between different riffles, but within the same riffle. IGDO levels in "redds" only a few feet apart often differed greatly. Also, within the *same* "redd," IGDO levels often varied from one month to the next (Figure 33).

Survival of eggs and alevins requires acceptable IGDO levels throughout the *entire* incubation period from September to March. This means that, at a minimum, the IGDO level must be maintained above 3 mg/L, the acute mortality level. As Figure 33 shows, IGDO levels within individual "redds" were extremely dynamic with DO in one "redd" fluctuating from near 8 mg/L to near 0 mg/L in one season.

The depth that the eggs are buried can make a difference in the IGDO concentration. In an experiment conducted in Chimacum Creek, one air-stone was placed 2 inches above

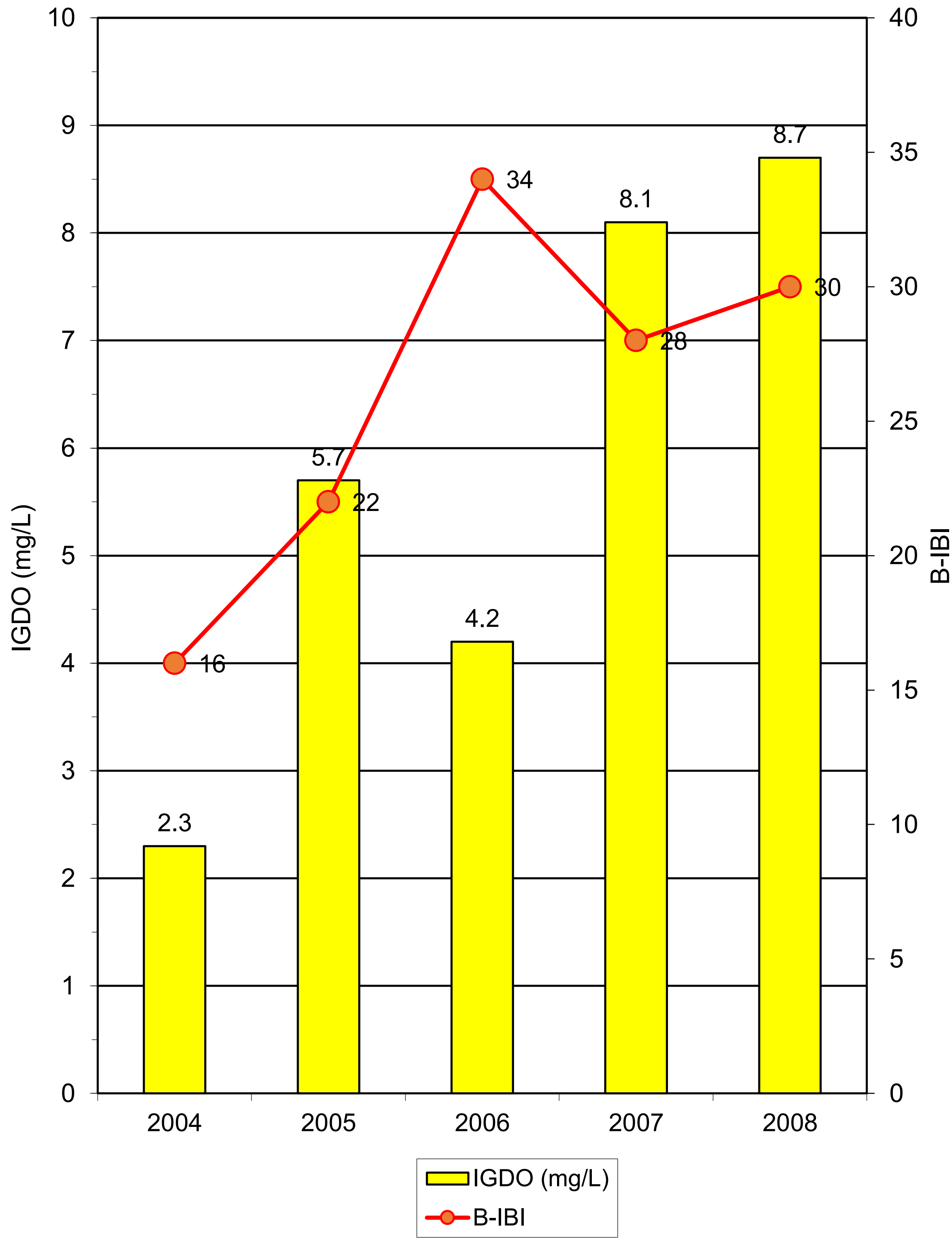


Figure 29. Comparison of average intragravel dissolved oxygen levels in Salmon Creek's new channel to the Benthic Index for Biotic Integrity index from 2004 to 2008. Water began flowing in the new channel on June 23, 2004.

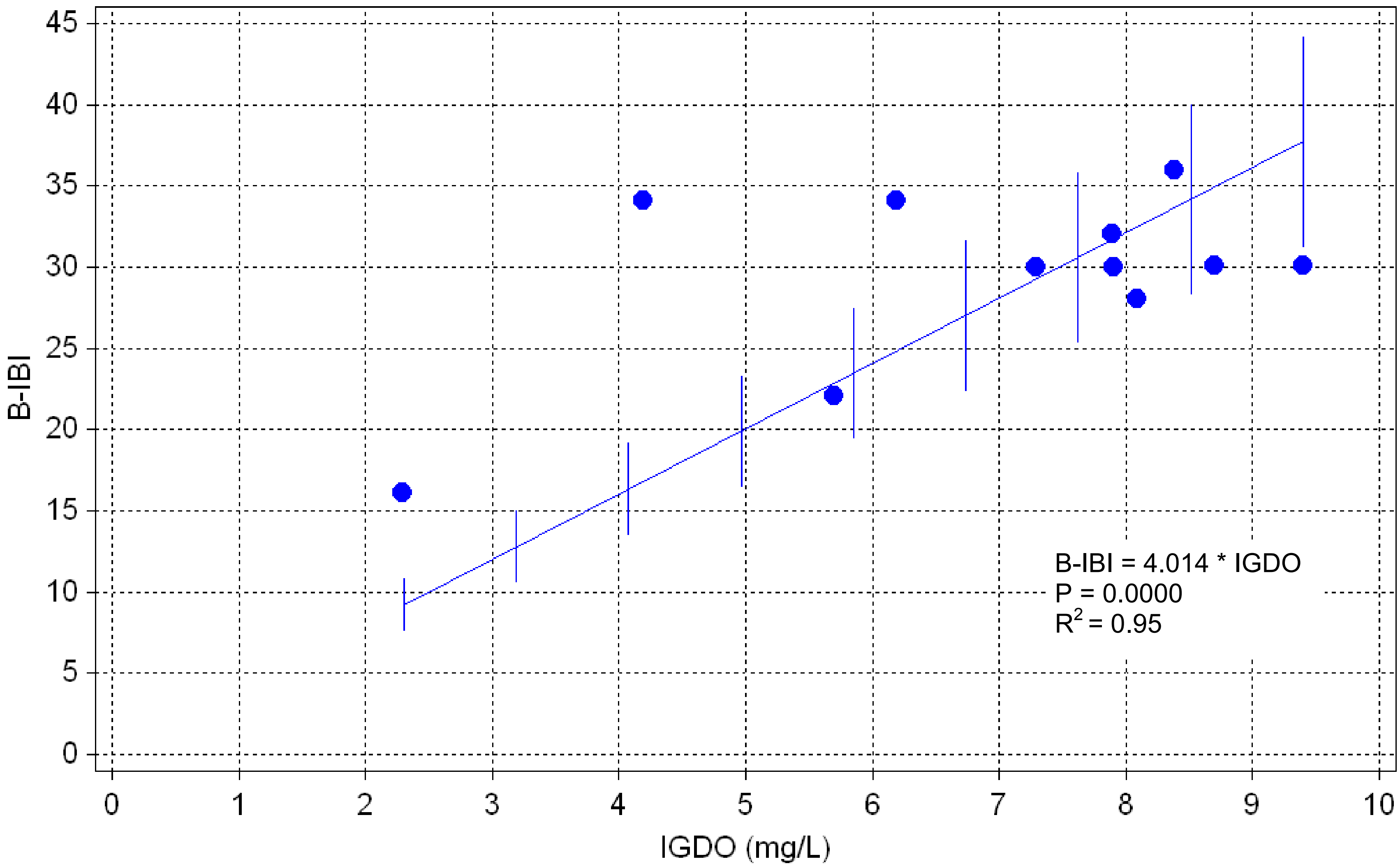


Figure 30. Regression of the benthic index of biotic integrity (B-IBI) on the intragravel dissolved oxygen concentration for data collected from Salmon Creek's new channel and upstream control reach from 2004 to 2008. Vertical bars represent 95 percent confidence limits.

High flows - view of Houck culvert.

Houck Creek Stabilization Project

After the rock was placed in the gully, North Olympic Salmon Coalition (NOSC) volunteers constructed several rock check dams between the toe of the fill and Salmon Creek. Willow stakes and grass seed were planted on exposed slopes not covered by rock.

Figure 31. In August 2002, 1000 cubic yards of rock were placed in the gulley which Houck Creek eroded when it was re-routed in the 1960's. A half-round culvert was placed at the top to prevent head-cutting.

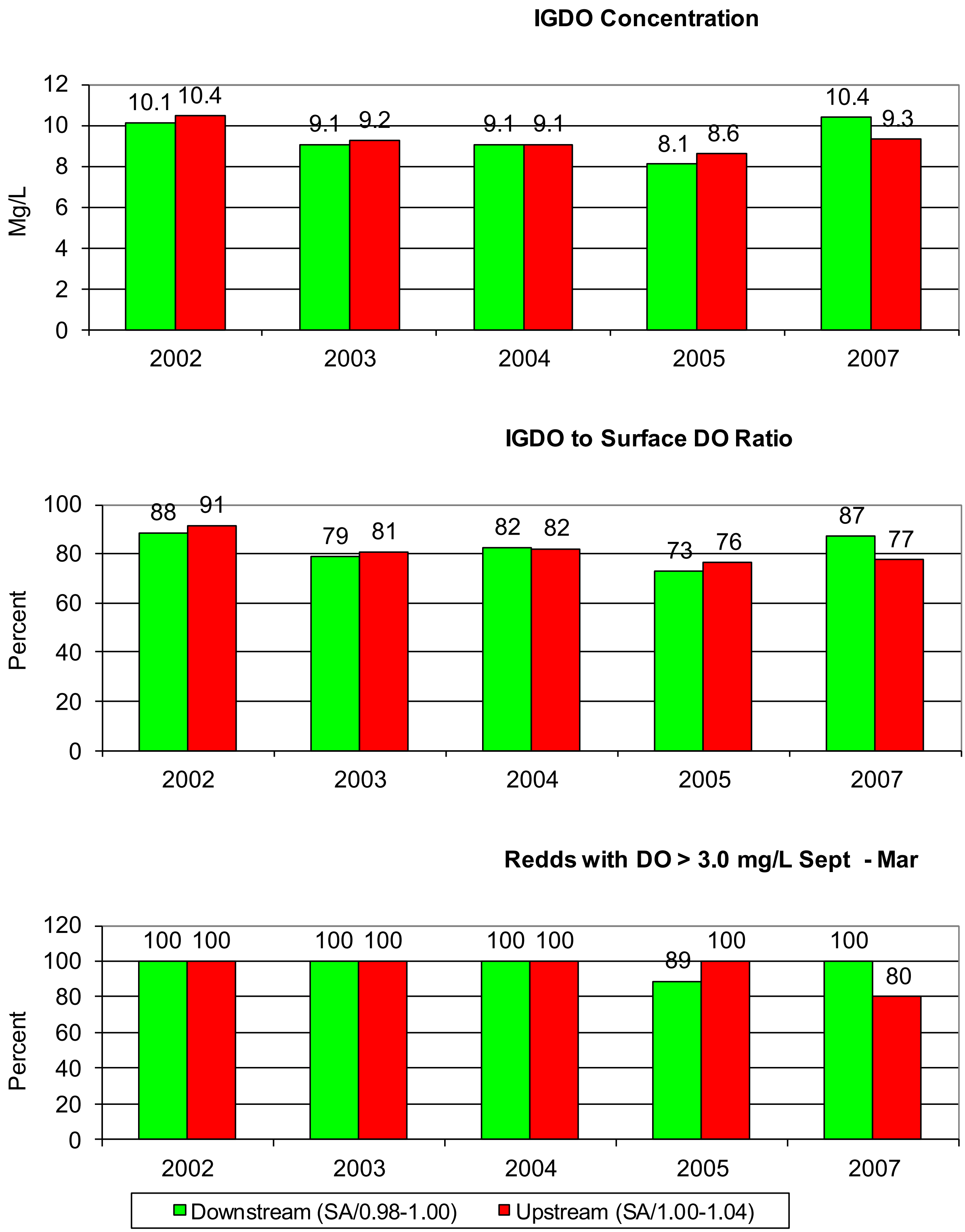


Figure 32. Salmon Creek average intragravel dissolved oxygen concentrations (top), average intragravel DO to surface DO ratios (middle), and percentage of redds with DO greater than 3.0 mg/L from September through March for the reach immediately downstream from Houck Creek and the reach immediately upstream from Houck Creek.

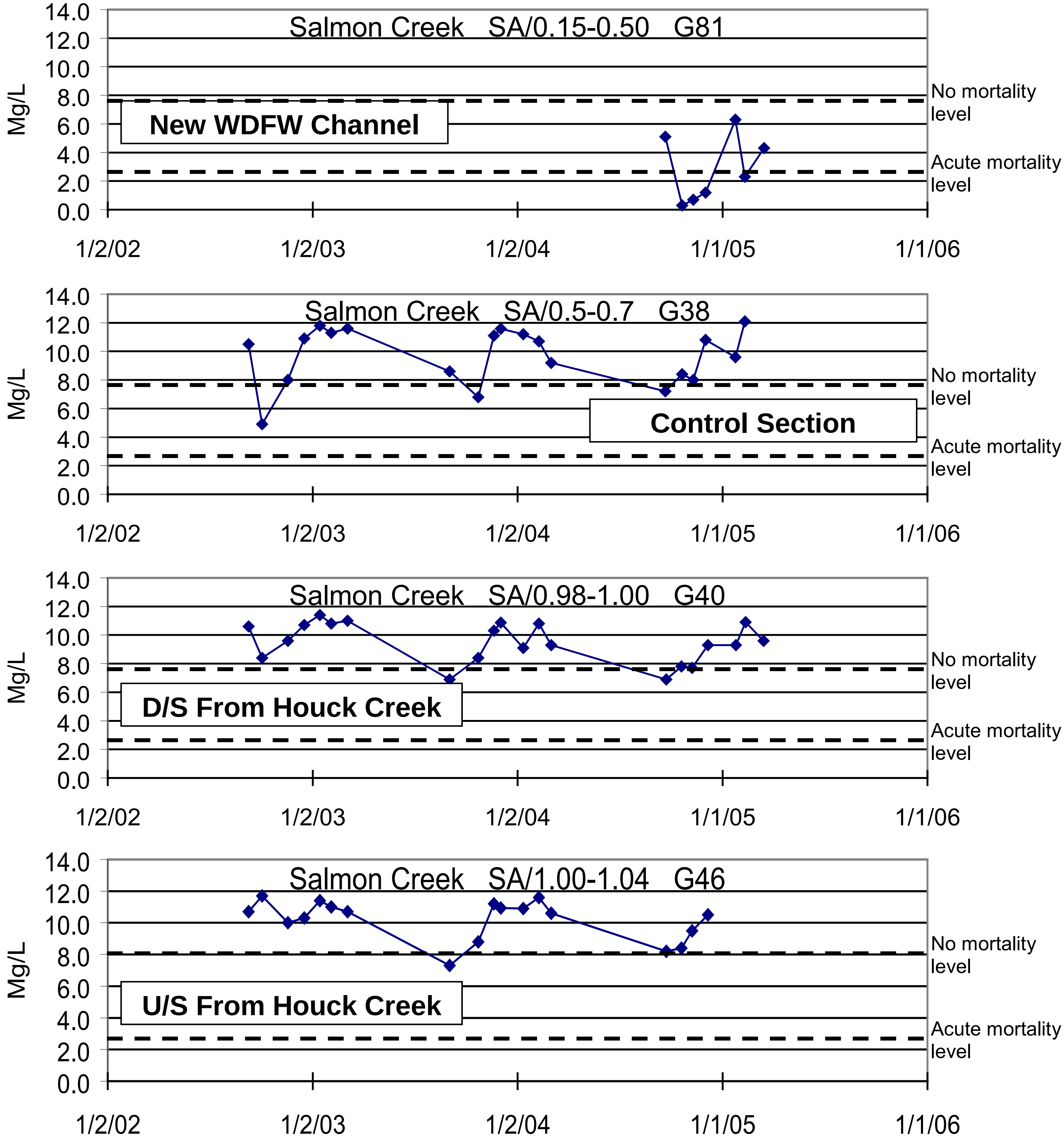


Figure 33. Intragravel dissolved oxygen levels at four simulated redd sites on Salmon Creek where dissolved oxygen was measured monthly during the summer chum egg incubation period (Sept.–Mar.) over the course of several years. EPA(1986) guidelines state that acute mortality occurs below 3 mg/L, some production impairment occurs between 3 mg/l and 8 mg/L, and no impairment occurs above 8 mg/L.

the other. The IGDO concentration was greater closer to the surface (Gately et al. 2015).

In 12 years of monitoring IGDO with over 3,000 measurements, only rarely did we observe IGDO levels greater than surface DO levels. When we did, the difference was usually less than 0.2 mg/L and probably due to analytical error. We have never observed a correlation between intragravel DO and surface DO.

Various studies (Shumway et al. 1964, Bjornn and Reiser 1991, Malcolm et al. 2003) on the relationship between the IGDO concentration and egg/alevin survival show that survival is directly related to the IGDO concentration. As Chapman (1988) put it, "*Any* decremental reduction in dissolved oxygen levels from saturation probably reduces survival to emergence or post-emergent survival.

Turbidity, Suspended Solids, and Sediment

Egg and Alevin Survival

In the previous section the importance of an adequate flow of oxygen-bearing water to salmonid eggs, alevins, and macroinvertebrates was discussed. It is "fines" plugging the pores in the spawning gravel that causes low intragravel dissolved oxygen.
"Fines" caused by erosion is a common problem. In a 1996 survey of 47 states managing coldwater fisheries, 34 states (72%) indicated that "erosion or sediment" was an obstacle to maintaining self-sustaining trout populations (Epifanio 2000).

"Fines" move downstream in two ways. Particles less than 0.1 mm in size are usually transported in the water column. Material greater than 1.0 mm is usually transported as bedload along the stream bottom. Material of intermediate size (0.1-1.0 mm) could be transported either way, depending on stream velocity and hydraulics (MacDonald et al. 1991).

In past years, JCCD used two methods to measure suspended material. Total suspended solids (TSS) was measured by weighing the suspended material. It was expressed in mg/L. Turbidity was measured by a nephelometric method which measures the light reflected by the suspended material. The unit of measurement is the nephelometric turbidity unit or NTU. The gravimetric (weight) method is labor intensive; the nephelometric method is quick and easy. The state standard is based on turbidity. In recent years JCCD has used only the turbidity method.

The standard requires that turbidity does not exceed 5 NTU over background turbidity when the background turbidity is 50 NTU or less. When the background turbidity is greater than 50 NTU, turbidity should not be more than 10% above the background level. Turbidity measurements are not as precise as other water quality measurements because the reading is constantly changing as the suspended matter settles out.

Generally, several samples are analyzed before determining if the standard has been violated.

Turbidity measurements taken monthly from November 2017 to April 2019 ranged from 0.6 NTU to 42 NTU (Figure 34). The highest levels occurred in Uncas Valley Ditch (42 NTU) and Contractors Creek (39 NTU). Both drainages were exposed to sunlight in places and had excessive vegetation in the channel. Decaying vegetation can cause high turbidity levels. Whether fines in the gravel are inorganic or organic from decaying vegetation, both can plug gravel pores, limiting flow and causing egg and/or alevin mortality. Uncas Valley Ditch at UVD/0.0 always appears turbid even with little flow. Suspended material in this ditch is extremely fine and never completely settles out.

Measuring the percentage of “fines” in the gravel is another way to assess gravel quality. To determine the percentage of “fines,” bottom sediment is collected with a McNeil sampler, a cylinder-like device pressed into the bottom substrate. Sediment is collected and then passed through a series of different size sieves, separating the sediment into groups of different sizes. Each group is then placed in a graduated cylinder, partially filled with water. The volume of water displaced by the sediment is equal to the volume of sediment. The sediment passing through the last sieve, measuring 0.85 mm, is designated the “fines.” The percentage of fines is the volume of fines divided by the volume of the entire sediment sample multiplied by 100.

In 1994, sediment samples were collected with a McNeil sampler in Snow Creek and Salmon Creek. Fourteen samples collected in the lower half-mile of Snow Creek (from Highway 101 upstream) averaged 18% “fines” (WDFW and PNPTT 2000). Concurrent sampling at 14 sites on 1.1 miles of Salmon Creek (from Highway 101 upstream) yielded an average of 15.1% “fines” (Bernthol and Rot 2001).

Levels of “fines” (averages) in unimpacted streams were reported as follows: Olympic National Forest streams, 6.4% (Cederholm and Reid 1987); Hoh River tributaries, 10.9% (Hatten 1991); South Fork Hoh River, 11.4% and main Hoh River, 14.5% (Cederholm 1991); and Southeast Alaska streams, 9.5% (Edington 1984) and 9.7% (Sheridan et al. 1984). Peterson et al. (1992) suggested that when “fines” exceed 11%, causes for their presence should be thoroughly investigated. Thus, it appears that in 1994, spawning gravel in Salmon Creek (15.1% fines) and Snow Creek (18% fines) was degraded.

Chimacum Creek, sampled in 1996 with a McNeil sampler was also degraded by fines. Three reaches were sampled: two downstream of Irondale Road and one just upstream of the road. From downstream to upstream, the percentages of fines were 16%, 18%, and 22% (Gately et al. 2015).

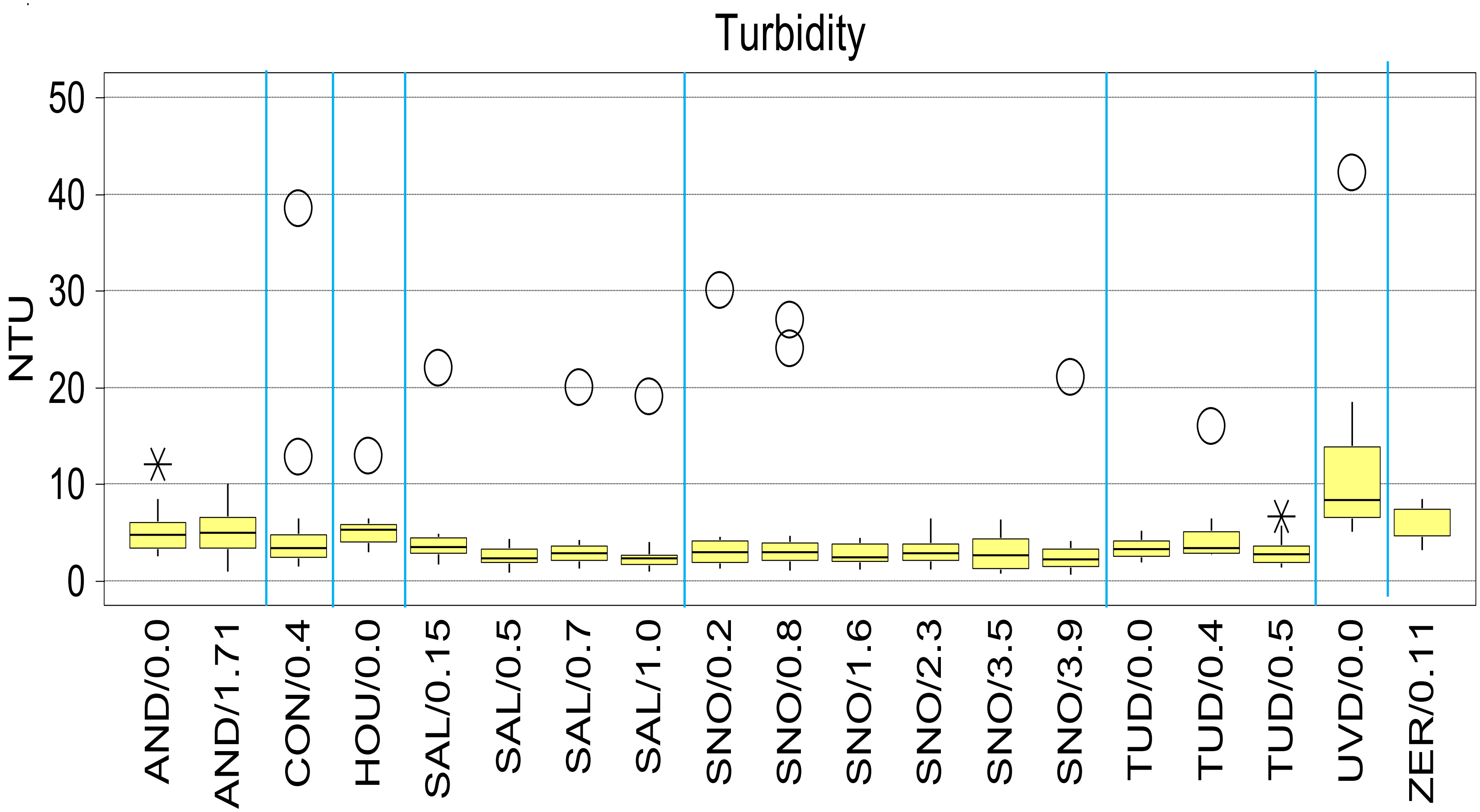


Figure 34. Turbidity measurements taken monthly at stations in the Discovery Bay Watershed from November 2017 to April 2019 (except January 2019). For an explanation of the "box and whiskers," refer to "statistics" in the "methods" section.

Almost all of the JCCD's water quality monitoring has been "ambient" monitoring; monitoring dates were scheduled in advance and monitoring was conducted rain or shine. However in 1994, JCCD targeted rain events and monitored both TSS and turbidity (Gately 2001). That year, Snow Creek's average TSS loading was about 100 times greater than Salmon Creek's average loading. Ninety-nine percent of this loading occurred on two days when flows were extremely high: 181 cfs in November and 245 cfs in December. On November 30, when TSS measured 486 mg/L and turbidity was 460 NTU, Snow Creek's loading was an astronomical 475,000 pounds per day. On December 21, when TSS measured 284 mg/L and turbidity was 280 NTU, TSS loading was 376,000 pounds per day. Measurements at upstream and downstream stations indicated that erosion was occurring between stations SNO/4.4 at Snow Creek Ranch (Highway 101) and SNO/7.0 at Snow Creek Road. Forest management was and still is the predominant land use upstream of RM 4.4 at Snow Creek Road.

In a 1991 survey by Jones and Stokes Associates (1991), 12 slope failures were identified on Snow Creek upstream of RM 4.4 at Snow Creek Ranch. Seven of these may have occurred naturally prior to 1957 and were considered to be healing. Five were believed to have occurred after 1980 and were considered active. Four of these were associated with logging roads and one with a landing site.

The following year, Nelson et al. (1992) surveyed the same area and cited several timber harvesting related causes of erosion including: ineffective waterbars on logging roads, slumping (mass wasting of soil), debris torrents, and debris jams and associated bank undercutting. Based on information on stand age, road density, soils, slope, and precipitation, they estimated average annual sediment loading to be 0.50 acre-feet/square mile, about twice the estimated background level.

In 1994 and early 1995, Washington Department of Natural Resources (DNR) personnel and Jobs for the Environment crew investigated the Roderick clearcut area (Sec 10, T28N, R2W) in the Snow Creek Basin upstream from Snow Creek Ranch. They found erosion coming from logging roads and steep side slopes (Figure 35). They revegetated the side slopes and decommissioned (i.e., allowed to return to a natural, forested condition) about five miles of logging spur roads. To reduce road associated erosion, they removed culverts, installed waterbars, and planted trees and grass (Michel 1995).

In 2018, NOSC contracted Natural Systems Design to conduct an in-depth assessment of the Snow Creek Watershed (Katz et al. 2020). The assessment included a sediment budget and geomorphic, hydraulic, and habitat characterizations. The investigators observed that hill-slope inputs such as landslides appeared to be inactive and stabilized. Sediment input from slides was estimated to be 810 cubic yards/year or 22%

Figure 35. Eroded logging road and slope failure occurring in the upper Snow Creek Watershed (Sec 10, T28N, R2W) between stations SNO/4.4 (Snow Creek Ranch) and station SNO/7.0 (Snow Creek Road. Photographs taken in January 1995.

of the total 3,750-cubic yards/year sediment budget. Sediment coming from 39 miles of forest roads was estimated to be 1,200 cubic yards/year or 32% of the budget. Bank erosion contributed the greatest amount, an estimated 1,740 cubic yards/year or 46% of the sediment budget.

Katz and his coauthors attributed the degradation of Snow Creek that began in the early 1900s to several factors: logging, land clearing, flood plain reduction, bank armoring, in-stream wood removal, channelization, and the introduction of invasive species. The combination of these practices caused down-cutting of the stream channel. Down-cutting occurred in the early 1900s and a second episode is occurring presently, mainly upstream from West Uncas Valley Road at RM 1.5. Downstream of RM 1.5, the channel is aggrading (up-building). Additionally, the estuary and delta in Discovery Bay are aggrading. The lack of flood plain and minimal amount of wood in the channel has transformed the creek from a low-energy depositional system to a high-energy erosive system. Egg and alevin mortality is occurring from both redd scouring and siltation.

Andrews Creek, a tributary to Snow Creek, also experienced erosion in the upper watershed in the past. On December 21, 1994 the TSS level (53 mg/L) at station AND/2.2 on Boulton Road was 4.4 times greater than the level at upstream station AND/3.8 on Snow Creek Road. Nelson et al. (1992) reported that, between the two roads, Andrews Creek flows through a steep-walled, wooded ravine, which appeared to be very unstable. They observed many slides and areas of bank erosion as well as much sediment (sand and gravel) in the stream channel. Logging had occurred up to the edge of the ravine in several areas, but apparently had not occurred in the ravine itself. The team attributed the unstable slopes to the steepness of the ravine and its unconsolidated soils. Based on these conditions, Nelson and his team predicted that sediment transport from this section of stream would continue for many years.

Prior to the bank stabilization project on Houck Creek (Figure31), turbidity measurements were 2-3 times greater downstream of the eroding bank on Houck Creek than they were upstream (Figure 36). After the project, measurements were about the same.

However, high turbidity at station HOU/0.02, upstream of the bank stabilization project, prompted additional monitoring in the upper Houck Creek watershed, where forest management was, and still is, the land use. On March 14, 2003, immediately following a substantial rain event, a number of stations on Houck Creek, East Houck Creek, and several of their tributaries were monitored along with three stations on Salmon Creek. Turbidity at station HOU/0.0, at the mouth of Houck Creek, measured 148 NTU (Figure 36). Turbidity at station SAL/1.0 on Salmon Creek, just upstream from its confluence with Houck Creek, was 22 NTU compared to 35 NTU at station SAL/0.7, three-tenths of a mile downstream. Turbidity at station HOU/0.02, upstream of the bank stabilization

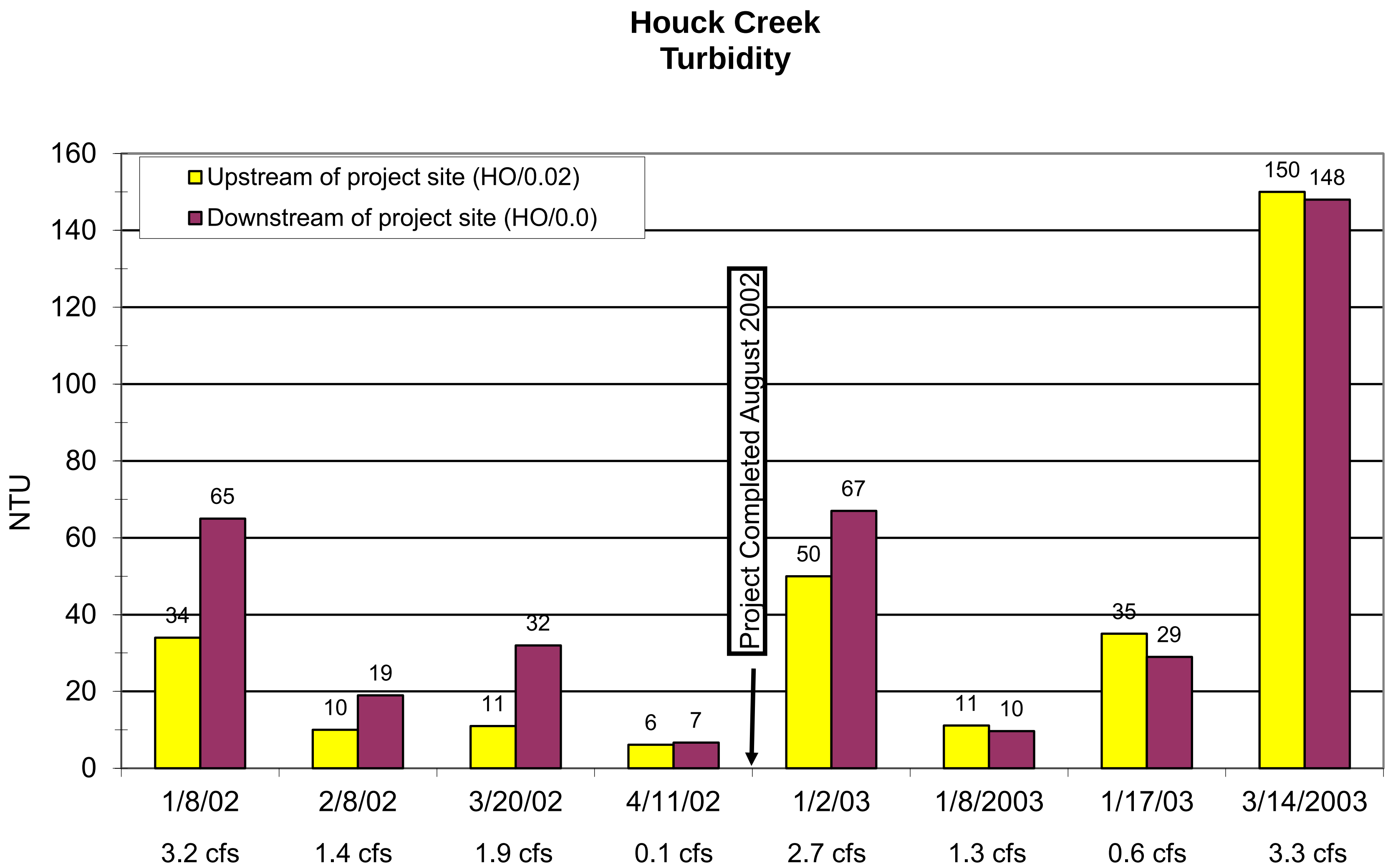


Figure 36. Turbidy measurements taken upstream and downstream and before and after an erosion abatement project on Houck Creek. Houck Creek stream flows are shown below sample dates.

M:\JCCD Share\Water Quality\Reports - water quality\Disco Bay Comprehensive report\Figures, final\Figure 36_Houck Creek culvert-turbidity.xls project, was 150 NTU, indicating the erosion was not coming from the project site but from farther upstream.

Additional monitoring in the upper watershed indicated that logging roads were major contributors of sediment to Houck Creek and East Houck Creek (Figure 37; Table 5). A high sediment source of East Houck Creek was traced to a ditch alongside the B2000 road. The ditch entered East Houck Creek on the upstream side of the B2000 road (station EHO/DITCH/B4000-01). The turbidity level of the ditch water was 660 NTU compared to 49 NTU at East Houck Creek station EHO/1.7 (sampled immediately upstream of the confluence with the ditch). A similar observation was made where a Houck Creek tributary passed under the B2000 road at culvert 11. Turbidity in the ditch water was 195 NTU (station HOU/Ditch/B2000-11) compared to 12 NTU in the tributary stream at station HOU/Trib/B2000-11 (sampled immediately upstream of the confluence with the ditch). Logging roads are often a major source of sediment entering streams (Adams and Ringer 1994).

Sediment coming from logging activities in the upper Houck Creek basin has led to another problem. For years a pond on Houck Creek acted as a sediment basin. The pond is now filled with sediment causing water to overflow its bank and revert to the stream channel it occupied prior to its diversion in the 1960s. This unfenced historical channel flows through a horse pasture before emptying into Uncas Valley Ditch, which flows into Salmon Creek.

Salmon Growth

Salmonids are sight feeders and turbidity may depress the growth of salmonids. Sweka and Hartman (2001) videotaped brook trout feeding in an artificial stream and measured the distance that a trout would react to a prey (live housefly larvae) under varying turbidity levels ranging from 0 NTU to 43 NTU. Reaction distance decreased curvilinearly as turbidity increased. At <1 NTU reaction distance was about 30 inches; at 43 NTU it was 3.5 inches. The greatest change in reaction distance per unit change in turbidity occurred at the lowest levels of turbidity (0-15 NTU).

Martin et al. (2019) investigated the growth rate and food consumption of juvenile Coho in relation to natural turbidity levels in Pudding Creek, a coastal stream in northern California. The researchers observed that overwinter growth rate and food consumption varied in relation to the duration and magnitude of turbidity and temperature. Growth rate and food consumption were positively associated with low-to-moderate turbidity exposures (>3NTU to >20 NTU) and negatively associated with elevated turbidity exposures (>55 NTU to >150 NTU). However, they said that the associations were based on the net effect of not only turbidity, but also temperature and other factors such as fish movement between reaches and residency time in different reaches.

pH

pH is a measure of the water's acidity (pH < 7), neutrality (pH = 7), or basicity (pH > 7). The scale of measurement is logarithmic. Thus, a 1-unit difference represents a 10-fold change in the hydrogen ion concentration; a 2-unit difference represents a 100-fold

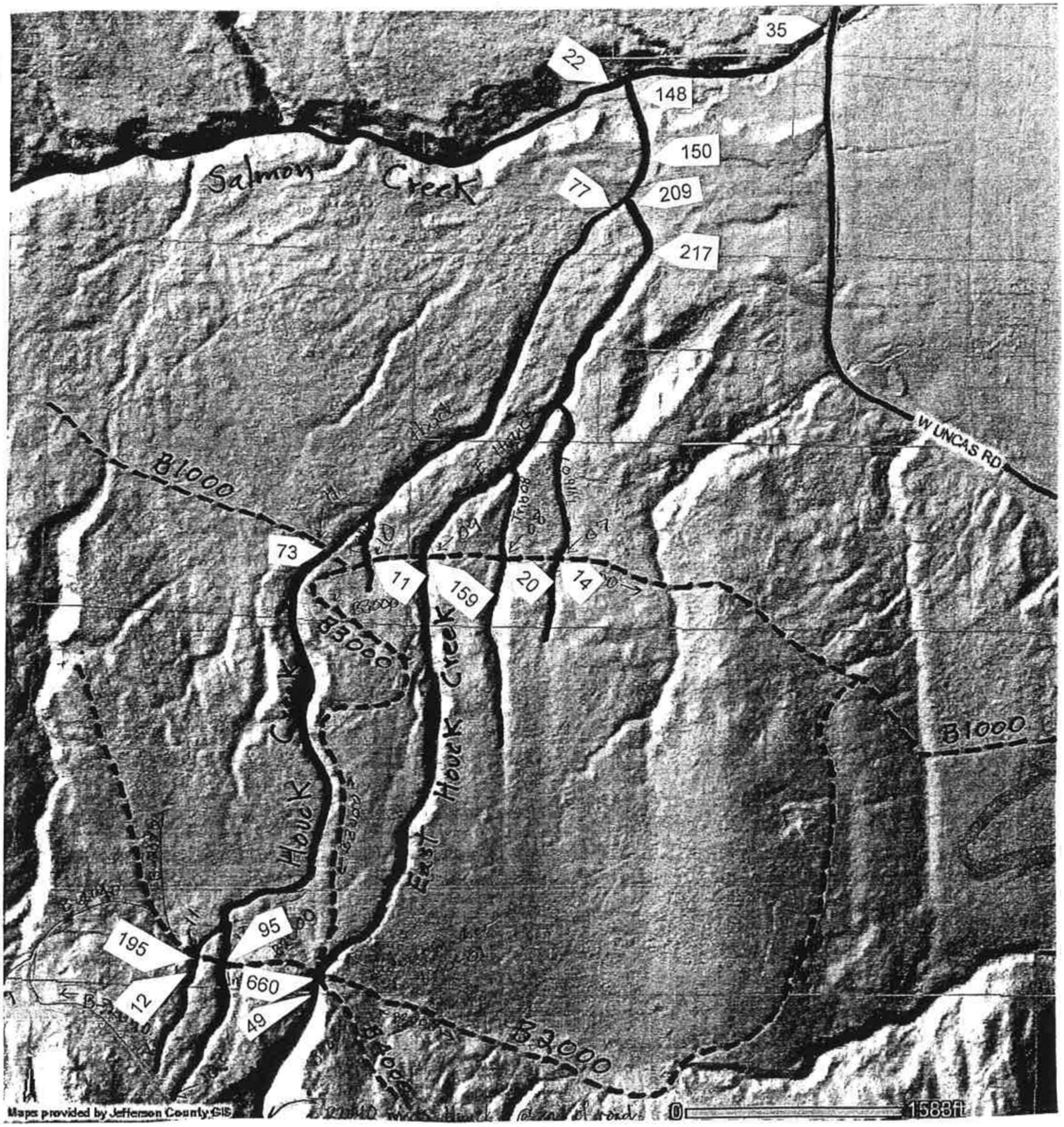


Figure 37. Map showing Salmon Creek, Houck Creek, and East Houck Creek and turbidity measurements (NTU) taken at various places on March 14, 2003 following a rain event. Descriptions of sample locations are given in Table 5.

Table 5. Turbidity and total suspended solids (TSS) measurements taken on Houck Creek and Salmon Creek on March 14, 2003 after a substantial rain event.

Stream	Station	Time	Turbidity (NTU)	TSS (mg/L)	Station Decription
Salmon Creek	SA/0.1	1115	35	49	Larrance pasture, just upstream from estuary
Salmon Creek	SA/0.7	1130	35	53	West Uncas Road
Salmon Creek	SA/1.0	1158	22	34	Upstream from confluence with Houck Creek
Salmon Creek	SA/2.7	1345	9	14	B-1000 road bridge
Houck Creek	HOU/0.0	1155	148	210	Near mouth
Houck Creek	HOU/0.02	1145	150	211	Upstream of bank stabilization project
Houck Creek	HOU/0.1	1210	77	125	Upstream from Confluence with East Houck Creek
Houck Creek	HOU/0.9	1330	73	93	B1000 road - culvert 11
Houck Creek	HOU/1.8	1500	95	190	B2000 road - culvert 10
Houck Creek Tributary	HOU/Ditch/B2000-11	1445	195	83	Mouth of B2000 road ditch at culvert 11
Houck Creek Tributary	HOU/Trib/B1000-	1325	11	6	B1000 road - culvert 10; RB tributary to Houck Creek
Houck Creek Tributary	HOU/Trib/B2000-11	1445	12	12	B2000 - culvert 11(upstream of ditch); LB tributary to Houck Creek; confluence at RM 1.7
East Houck Creek	EHO/0.0	1205	209	363	Mouth of East Houck Creek
East Houck Creek	EHO/0.2	1230	217	343	In woods, upstream of old (~1960) channelization project
East Houck Creek	EHO/0.9	1320	159	279	B1000 road - culvert 9
East Houck Creek	EHO/1.7	1415	49	67	B4000 road - culvert 01
East Houck Creek Tributary	EHO/Ditch/B4000-01	1415	660	488	B4000 road - culvert 01;mouth of B2000 road ditch
East Houck Creek Tributary	EHO/Trib/B1000-7	1305	14	8	B1000 road - culvert 7; RB tributary; confluence at RM 0.4
East Houck Creek Tributary	EHO/Trib/B1000-8	1315	20	15	B1000 road - culvert 8; RB tributary; confluence at RM 0.6

change, etc. The state standard requires that the pH be within the range of 6.5 to 8.5. In 2017-19, most pH measurements for Salmon Creek and Snow Creek stations were basic, between 7.0 and 8.0 most of the time (Figure 38). Whereas, Tucker Ditch station TUD/0.4, Uncas Valley Ditch, and the downstream station on Andrews Creek were usually slightly acidic. These same stations experienced low dissolved oxygen measurements due to low gradients, low flows, and much decaying organic material. Carbon dioxide levels are typically higher when dissolved oxygen levels are low and this would account for the acidic measurements at these stations.

Conductivity

Conductivity refers to the ability of a substance (e.g., water) to conduct an electric current. The unit of measurement for conductivity is the mho, which is the reciprocal of the ohm, the unit of measurement for resistance (i.e. mho=1/ohm). The more dissolved ions in the water, the higher the conductivity. Conductivity is affected primarily by the geology of the watershed through which the stream and contributing groundwater flow.

Because an increase in water temperature causes an increase in conductivity, for the purpose of comparison, measurements are adjusted to a common temperature of 25^oC. Distilled water has a conductivity in the range of 0.5 to 3 µmhos/cm. The conductivity range for potable water in the United States is 30-1500 µmho/cm (MacDonald et al*.* 1991). Most Pacific Northwest streams have conductivities near the low end of this range. There is no state standard for conductivity, and except for unusual circumstances, conductivity is seldom deleterious to fish.

Conductivity does help characterize the water. To a limited degree in fresh water, it indicates the fertility of the water; low conductivity measurements are typical of nutrient-poor water. Low conductivity is characteristic of waterbodies at high elevations with shallow soil overlying bedrock. Conductivity typically increases as elevation decreases and soil depth increases.

Conductivity for all streams monitored ranged between 50 µmho/cm and 380 µmho/cm (Figure 39). Median conductivity levels for Snow Creek were about 100 µmho/cm compared to 185 µmho/cm for Salmon Creek. Approximate median levels (in µmho/cm) for the tributary streams and ditches were: Andrews Creek, 75; Uncas Valley Ditch, 150; Houck Creek, 155; Tucker Ditch, 160; and Contractors Creek, 190. There was little change in median levels from upstream to downstream in the lower one mile of Salmon Creek and lower four miles of Snow Creek. In contrast, Chimacum Creek's main stem and east fork increased about 100 µmho/cm from upstream to downstream (Gately et al. 2015).

Conductivity in Zerr Drain ranged from 969 µmho/cm to 7,874 µmho/cm with a median Level of 2,420 µmho/cm. Zerr drain is an estuary and its high conductivity due to the

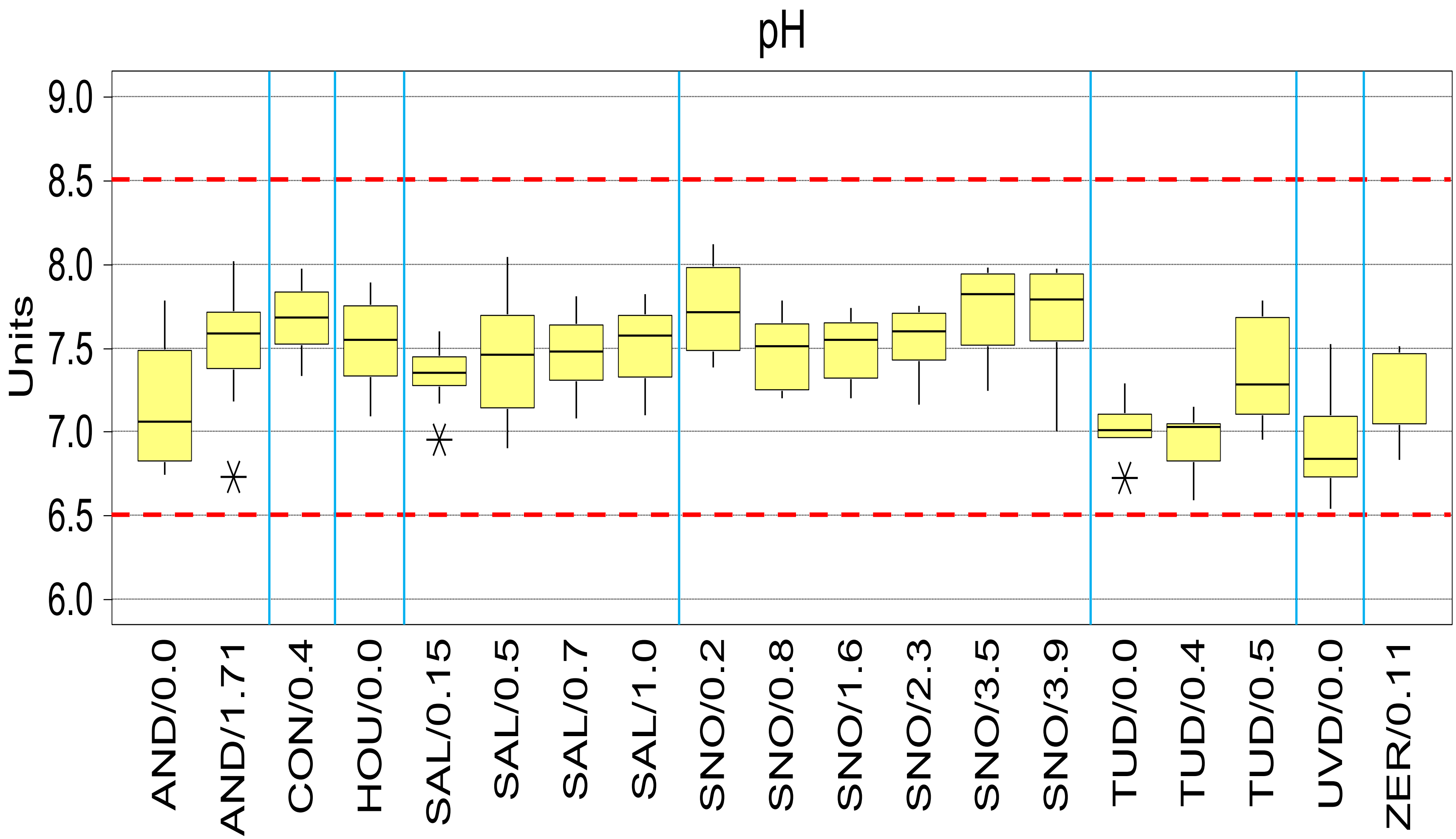


Figure 38. pH measurements taken monthly in the Discovery Bay Watershed from November 2017 to April 2019 (except January 2019). To pass the state standard, values need to be between the dashed lines. For an explanation of the “box and whiskers,” refer to “statistics” in the “methods” section.

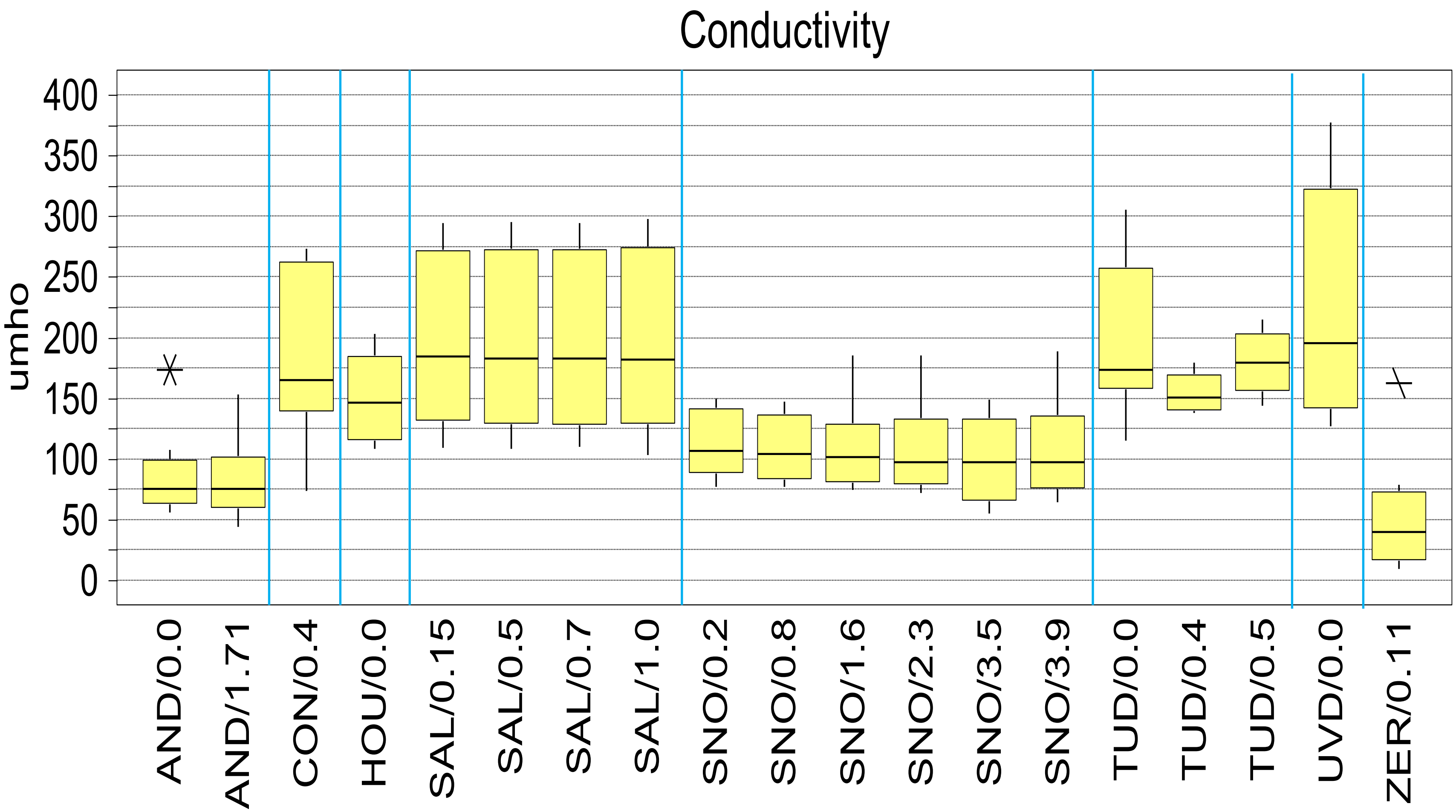


Figure 39. Conductivity measurements taken monthly in the Discovery Bay Watershed from November 2017 to April 2019 (except January 2019). Estuarine station ZER/0.11 is shown at 1/100 of the actual values. For an explanation of the "box and whiskers," refer to "statistics" in the "methods" section.

salt water mixing on incoming tides.

Nitrogen

Nitrogen in the form of nitrate (NO_3) is an important nutrient for plants and algae. Most researchers believe that nitrogen is the limiting factor to plant and algae production in salt water, although some believe that phosphorus could be the limiting factor, or that it could be a combination of both, or that it changes with the season (Howarth 1988). Whether it be nitrogen or phosphorus, fresh water or salt water, it is best to limit the amount of both nutrients entering any waterbody.

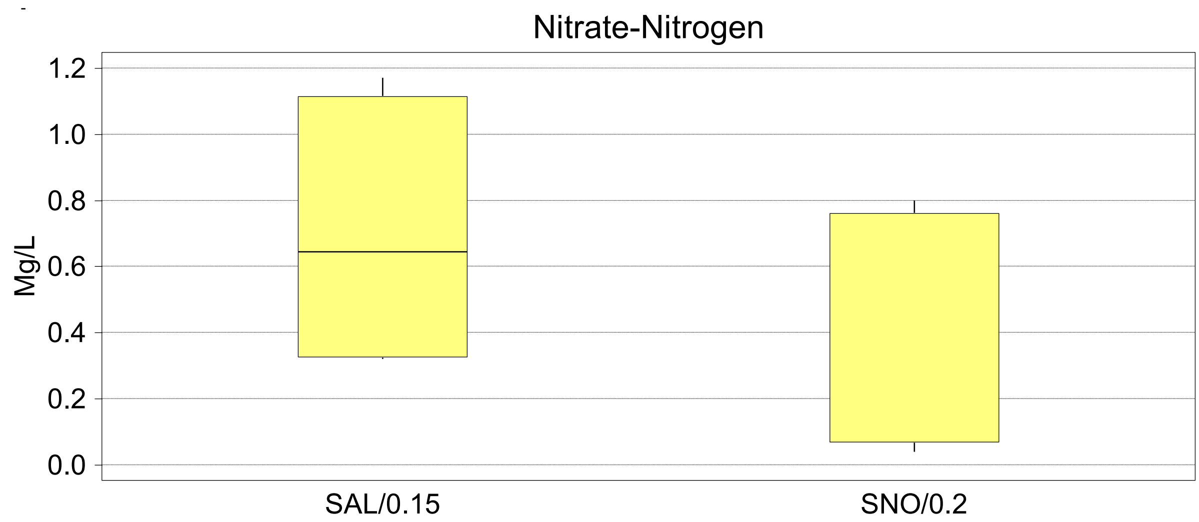
In recent years, algal blooms have increased dramatically in lakes and coastal areas of the United States as well as throughout the world (Gilbert et al. 2005). More frequent toxic algal blooms have increased the risk of illness from shellfish consumption in Washington State (Trainer and Hardy 2015).

In salt water, an algal bloom is commonly called “red tide,” but more formally a “harmful algal bloom” or “HAB.” Toxic algae can become concentrated in shellfish which can cause sickness or death to consumers. About 100 algal species are known to produce toxins. (Farabegoli et al. 2018)

Algal blooms, whether toxic or not, may cause fish kills. When algae die, they sink to the bottom where bacterial decomposition causes a reduction in dissolved oxygen. When an upwelling occurs, the oxygen-depleted bottom water is brought to the surface and fish trapped in the oxygen-deficient water die. In recent years, excessive nitrogen has been associated with fish kills in Hood Canal (Cope and Roberts 2013). Similar situations occur periodically in the Gulf of Mexico (Rabalais et al. 2001) and Chesapeake Bay (Breitburg 1992).

Nitrate-nitrogen can be a problem in groundwater. Because nitrates readily dissolve in water, they can percolate through the soil in groundwater and contaminate wells. In excessive concentrations, nitrates can cause methemoglobinemia (blue baby syndrome), which can be fatal. For this reason EPA standards require nitrate-nitrogen levels to be less than 10 mg/L nation-wide.

From 2017 to 2019, nitrate-nitrogen was sampled four times at downstream stations on Salmon Creek and Snow Creek. Concentrations ranged from 0.1 mg/L to 1.2 mg/L with Salmon Creek’s concentrations slightly higher than Snow Creek’s (Figure 40). Examination of 958 measurements taken in the Discovery Bay Watershed since 1998 revealed most measurements ranging from 0.0 mg/L to 1.5 mg/L (Figure 41). Houck Creek had the highest median concentration (1.0 mg/L and the highest overall concentration (3.3 mg/L).



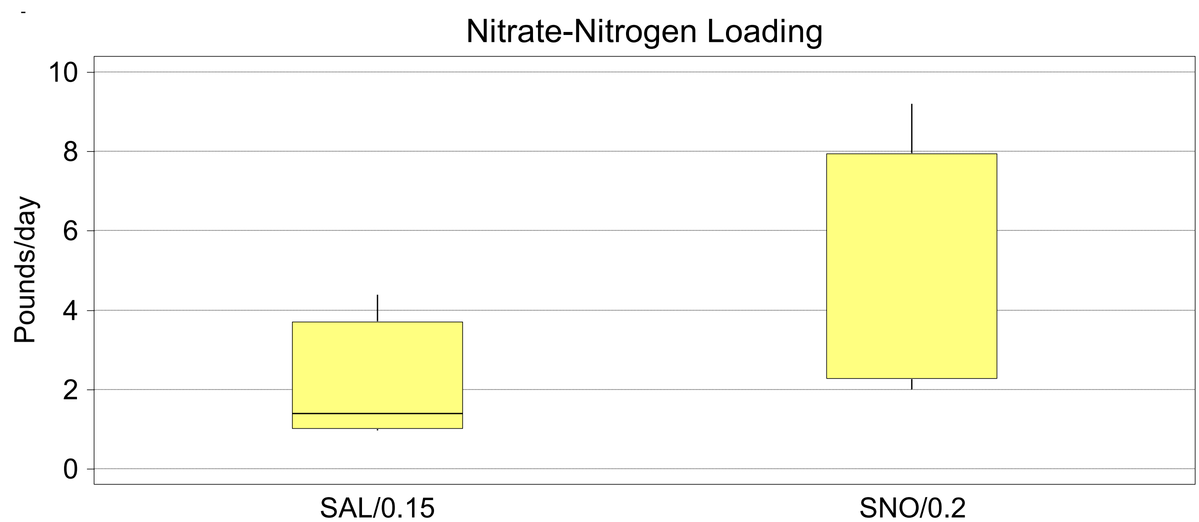
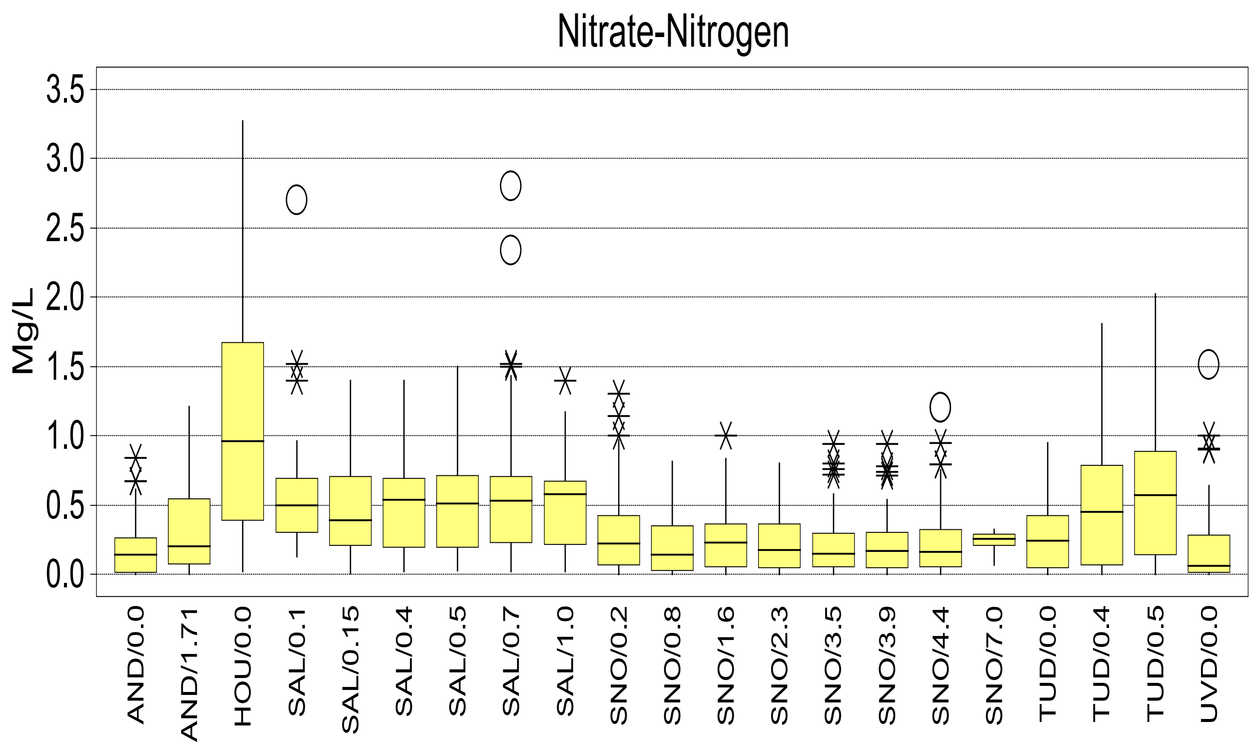


Figure 40. Nitrate-nitrogen concentration (top) and loading (bottom) measured quarterly in the Discovery Bay Watershed from November 2017 to October 2018. For an explanation of the "box and whiskers," refer to "statistics" in the "methods" section.



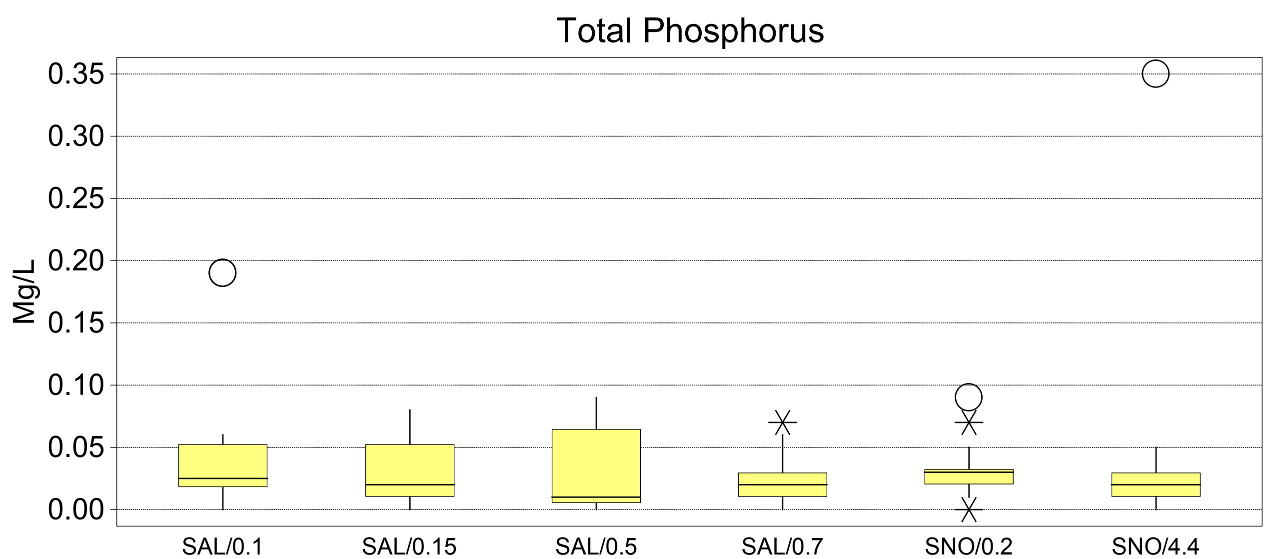


Figure 41. Nitrate-nitrogen and total phosphorus concentrations at stations in the Discovery Bay Watershed monitored since 1998. For an explanation of the "box and whiskers," refer to "statistics" in the "methods" section.

Stations in the Chimacum Watershed sampled in 2007-08 had similar median concentrations, but more measurements above 1.5 mg/L, the highest being 6.5 mg/L (Gately et al. 2015). Nine rivers flowing into Hood Canal, sampled from 1960 to 2002, had median concentrations ranging from 0.04 mg/L to 0.37 mg/L with a maximum of 0.7 mg/L (Paulson et al. 2006).

Nitrate-nitrogen loadings based on four measurements made in 2017-18 are shown in Figure 40. Salmon Creek's loading ranged from 1 pound/day to 5 pounds/day. Due to higher flows in Snow Creek, Snow Creek's loading ranged from 2 pounds/day to 9 pounds/day. For comparison, Chimacum Creek's loadings in the 2007-08 water year ranged from 2 pounds/day in September to 1,564 pounds/day in December, when stream flow (66 cfs) and concentration (4.2 mg/L) were both high (Gately et al. 2015). Paulson et al. (2006) reported loadings for several Jefferson County streams. Average daily loadings, expressed as pounds per day were as follows: Spencer Creek, 4; Tarboo Creek, 14; Thorndyke Creek, 16; Little Quilcene River, 51; Big Quilcene River, 100; Duckabush River, 126; and Dosewallips River, 301.

Sources of nitrogen include soils, organic fertilizer (manure), inorganic fertilizer (chemicals), septic drainfields, automobile exhaust, fossil fuel combustion, and atmospheric nitrogen (through denitrification). Based on a literature review, Carpenter et al. (1998) concluded that agriculture and urban activity, including industry, were major nonpoint sources of both nitrogen and phosphorus.

Although efforts to control nutrient loadings to coastal waters have traditionally focused on agricultural lands, there is an increased awareness of nitrogen loadings coming from residential and urbanized lands (Reay 2004). Studies in New England indicate that effluent from residential septic systems is a significant, and in many cases, dominant nitrogen source to coastal embayments (Valiela and Costa 1988; Giblin and Gaines 1990; Weiskel and Howes 1991; Valiela et al. 1997; all cited by Reay, 2004).

In on-site septic systems, most of the nitrogen in septic waste passes into the groundwater. In the anaerobic septic tank, organic nitrogen is converted to soluble ammonium-nitrogen. In the aerobic drainfield, soluble ammonium nitrogen is oxidized to soluble nitrate-nitrogen (Wilhelm et al. 1994), which then enters the groundwater (Reay 2004). Since nitrate-nitrogen is dissolved, it will be carried down-gradient in the groundwater and will eventually enter a stream, lake, or salt water; and if it is within the photic zone, it will be absorbed by plants or algae.

Only in recent years has it been realized that on-site septic systems are a nitrate-nitrogen source to groundwater and surface water. Washington Department of Health in conjunction with the University of Washington are experimenting with septic designs to remove nitrate-nitrogen.

Excessive fertilizer is another potential source of nitrate-nitrogen. Farmers and gardeners should take care not to apply more fertilizer than plants can absorb during the growing season.

Phosphorus

Like nitrogen, phosphorus is an important nutrient for plants. Phosphorus is an element and exists in several forms, both organic and inorganic. Inorganic phosphorus is bound up as minerals in rocks and is not readily available. Organic phosphorus is contained in plant and animal tissue, waste solids, and other organic matter.

Inorganic orthophosphate (PO4), also known as soluble reactive phosphorus (SRP) is the form that is readily taken up by plants and algae. Because of this rapid uptake, there is usually not enough orthophosphate left in the water to indicate a problem. For this reason, JCCD has chosen to monitor total phosphorus, which includes all forms of phosphorus.

Phosphorus is usually the limiting factor to plants and algae in fresh water and can cause eutrophication in lakes. Excessive phosphorus can cause fish kills in fresh water, similar to the way nitrate-nitrogen causes fish kills in salt water. Fish kills in the Great Lakes in the 1960s were caused by phosphorus in laundry detergents making their way through treatment plants into the lakes. Laws now limit the amount of phosphorus allowed in detergents. There is no state standard for phosphorus in streams. In lakes, Ecology's "action level" for total phosphorus (TP) is 0.02 mg/L.

Unlike nitrate-nitrogen, which percolates through soil in the groundwater, orthophosphate-phosphorus generally binds to soil particles and would not enter waterbodies except through soil erosion. However, in sandy soils with high water tables or in older septic drainfields where phosphate adsorption capacity has become limited, phosphorus contamination of groundwater from septic effluent can occur (Harman et al. 1996).

Total phosphorus (TP) was sampled four times at downstream stations on Salmon Creek and Snow Creek from 2017 to 2018. Concentrations in the two creeks ranged from 0.01mg/L to 0.07 mg/L with Snow Creek concentrations being slightly greater than Salmon Creek's (Figure 42). Examination of 134 total phosphorus measurements taken throughout the Discovery Bay Watershed since 1998 revealed most measurements ranging from 0.0 mg/L to 0.1 mg/L with medians for both streams at about 0.02 mg/L (Figure 41). TP concentrations in Chimacum Creek's main stem and east fork also ranged from 0.0 mg/L to 0.1 mg/L

TP loading in Salmon Creek ranged from 1.0 pound per day to 4.5 pounds per day compared to Snow Creek's higher range of 2.0 pounds per day to 9.1 pounds per day (Figure 42). Salmon Creek's median loading was 1.4 pounds per day and Snow Creek's was 3.6 pounds per day. For comparison, TP loading for Chimacum Creek ranged from

0 to 30 pounds per day with a median of 3 pounds per day (Gately 2015). *Average* daily loadings (median not available) for the Duckabush River and Dosewallips River were 27 and 33 pounds per day respectively (Embrey and Inkpen 1998).

Excess phosphorus may contribute to harmful algae blooms in lakes. Crocker Lake, the only lake in the Discovery Bay Watershed, has been tested for HABs by Jefferson County Environmental Health. Two of four kinds of toxin have been detected: anatoxin-a and microcystin. Anatoxin-a was detected in 2011, 2012, 2018, and 2019, but only exceeded the “recreational guidance” criteria in 2018. Microcystin was detected below “recreational guidance” criteria in 2011 and 2018. Cylindrospermopsin and saxitoxin were not detected in water samples collected in 2018, the only year tested for these toxins. (Washington State Toxic Algae website https://www.nwtoxicalgae.org/)

Fishes

Fishes inhabiting Discovery Bay streams include Coho Salmon, Chum Salmon, Steelhead (Rainbow Trout), Cutthroat Trout, Eastern Brook Trout (Andrews Creek), Sculpin, Three-spine Stickleback (*Gasterosteus aculeatus*), and Western Brook Lamprey (*Lampetra richardsoni*) (JCCD data).

As part of the Salmon Creek Estuary Project, NOSC conducted fyke netting in Salmon Creek’s estuary from February to May each year from 2009 to 2013. Of the 8,522 fish caught, 47 percent were juvenile Chum Salmon, 46 percent Staghorn Sculpin (*Leptocottus armatus*), and 5.5 percent Shiner Surfperch (*Cymatogaster aggregata*); in decreasing order of abundance, the remaining 1.5 percent were made up of Pacific Herring (*Clupea pallasii*), juvenile Pink Salmon (*Oncorhynchus gorbuscha*), juvenile Coho Salmon, Threespine Stickleback, Surf Smelt (*Hypomesus pretiosus*), Pacific Sardine (*Sardinops sagax*), and Pacific Sanddab (*Citharichthys sordidus*) (Sarah Doyle, personal communication, August 2018).

Nelson et al. (1992) reported the following fishes to inhabit Discovery Bay: Coho Salmon, Chum Salmon, Steelhead (Rainbow Trout), Cutthroat Trout, White Sturgeon, Yelloweye Rockfish, Yellowtale Rockfish, Copper Rockfish, Quillback Rockfish, Rock Sole, English Sloe, Starry Flounder, Pacific True Cod, Ling Cod, Surf Perch, Striped Perch, Herring, Sand Lance, and Smelt.

Trends

Table 6 shows fish data for Salmon Creek and Snow Creek provided by Washington Department of Fish and Wildlife. Overall, Summer Chum returning to Salmon Creek have increased since 2001 with a maximum of 6,846 fish returning in 2015 (Figure 43). A supplementation project (1992 to 2003), in which some Salmon Creek fish were artificially spawned, incubated in the WDFW Dungeness hatchery, and released, proved

Table 6. Snow Creek and Salmon Creek fish data.[1, 2, 3, 4] Courtesy of the Washington Department of Fish and Wildlife.

	Chum			Coho			Steelhead		Chinook			Pink			Sockeye		Cutthroat	Eulachon	Bluegill	Brown Bullhead	Pacific Lamprey
Year	Salmon Cr		Snow Cr	Salmon Cr	Snow Cr		Snow Cr		Salmon Cr		Snow Cr	Salmon Cr		Snow Cr	Salmon Cr	Snow Cr	Snow Cr	Salmon Cr	Snow Cr	Snow Cr	Snow Cr
	adults	fry	adults	redds	adults	smolt	adults	smolt	adults	fry	adults	adults	fry	adults	adults	adults	smolt				adults
1970																					
1971	249																				
1972	970																				
1973	636																				
1974	512		818																		
1975	755		340																		
1976	521		608		486																
1977	701		538		1357		106														
1978	1664		629		601	5201	140	1510			2			1							5
1979	458		133		367	9156	78	960			1			1							
1980	3074		709		709	9090	120	1461													8
1981	439		242			8344	128	1659						1							
1982	1386		766			7048	109	1866													
1983	731		154		432	7700	52	1367													
1984	828		384		326	1871	131	1192													
1985	151		20		36	6947	154	2233													
1986	582		213		432	10113	61	557													
1987	1062		465		681	641	72	2003													
1988	1915		723		17	6296	71	582													
1989	194		21		73	6915	29	1844													
1990	245		33		104	448	12	1438													
1991	172		12		4	4300	34	1251													
1992	433		21		11	4787	51	2238													
1993	452		11		111	117	30	1629													
1994	161		2		0	495	41	1704													
1995	591		25		106	3657	45	320													
1996	894		160		239	3	139	2169									56				
1997	834		67		7	779	73	1253									20				7
1998	1134		27		62	599	63	838									31				
1999	499		30	6	95		58										0				
2000	846		30		45	5897	192	1383									56				
2001	2638		154	33	419	7670	56	2526									23				
2002	5517		532	54	561	5438	28	2474									27				
2003	5653		304	46	352	32434	91	2787									75				1
2004	6021		396	206	1998	13724	40	565									17				
2005	6142		832	34	1508	10731	15	1187									50				
2006	4894		598		1012	18924	24	711									18				
2007	1274		439		993	25471	35	990									57				
2008	1568	65496	172	9	538	16916	8	298		0			1				36	1			
2009	1237	78164	229		2644	20633	16	441		0			0				53	0			
2010	2740	28943	524		1090	32243	10	870		0			0				184	4			
2011	2279	42850	342		1680	27210	34	954		0			21				94	0			
2012	2318	124045	496		2916	8454	21	242		38			0				56	0			
2013	2746	209783	574	10	807	40037	50	2279	13	0	0	24	1	2	0	0	135	0			
2014	2460	318733	483	4	2797	43177	8	864	2	71	0	0	1959	0	1	0	104	0			
2015	6846	19792	971	10	1325	16053	24	1359	22	0	0	12	0	2	0	0	163	3			
2016	3154	15175	636	18	1377	15350	13	303	10	2	3	1	0	0	1	0	84	5	1068	2	1
2017	711	107211	68	4	1112	15110	39	1389	11	44	0	12	1	2	0	0	111	6	429	467	4
2018	742	43858	191	12	1392	26685	29	785	5	57	2	0	379	0	0	0	88	11	10	197	23
2019	1868	131338	365	11	466	21894	43	1101		0			300				138	15	5	7	2

1. Data collected by WDFW at Snow Creek weir (year-round) and Salmon Creek adult and outmigrant traps (seasonal) with the exception of Salmon Creek coho which are estimates from stream survey redd counts.
2. Salmon Creek summer chum supplementation program 1992-2003 (adults from that program returned through 2007). Snow Creek coho supplementation program 1998-2003 (adults from that program returned through 2006).
3. Salmon Creek summer chum eggs were transferred to Chimacum Creek for reintroduction program 1996-2003.
4. Salmon Creek redd counts were not always complete due to weather, stream flow, land owner permission, etc. They should be considered minimums and are not comparable.

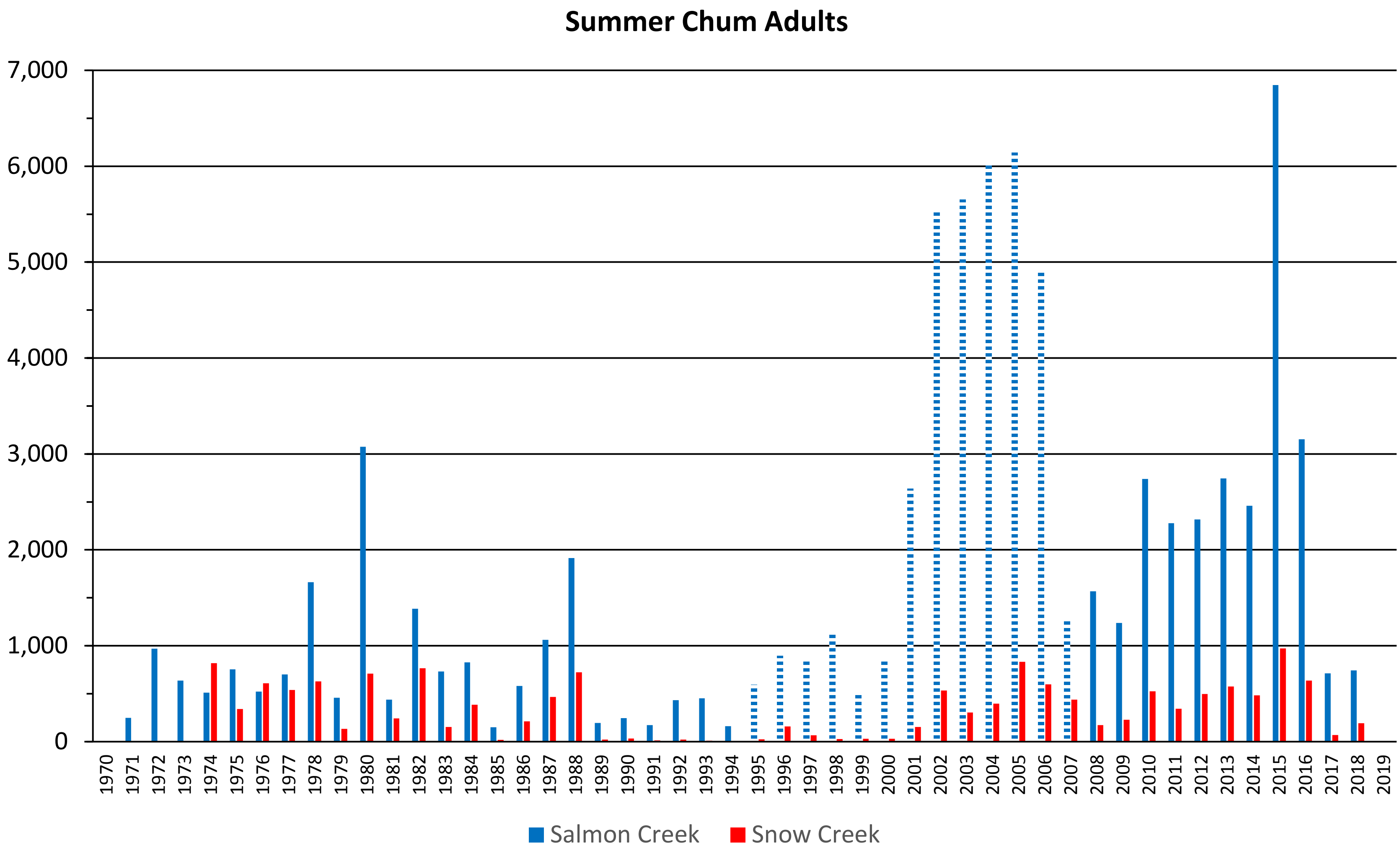


Figure 43. Number of Summer Chum Adult Salmon counted at the Salmon Creek fish trap (RM 0.2) and Snow Creek weir (RM 0.8). A suplementation program (hatcher-raised Chum) occurred on Salmon Creek from 1992 to 2003 with adults returning from 1995 through 2007. The dashed blue bars represent years when some returning Chum were hatchery-raised.

successful. Except for 2017 and 2018, numbers of returning Chum were generally higher after the supplementation project than before.

During the last seven years of the supplementation project, some of the Chum incubated at the Dungeness hatchery were released into Chimacum Creek. These fish led to the successful reintroduction of Summer Chum in Chimacum Creek (See Gately et al. 2015 for details).

In Snow Creek, Summer Chum returns have shown no trend and have remained below 1,000 since 1974 (Figure 43).

Coho returns to Snow Creek declined from 1,357 returns in 1977 to only 17 fish in 1988 and remained low (<250) through 2000. A supplementation project conducted from 1998 to 2003 boosted returns considerably from 2004 to the present with a maximum of 2,916 Coho returning in 2012.

Chum returns to Snow Creek are based on redd counts. Due to high stream flow, lack of landowner permission and other factors, stream reaches were not surveyed the same every year so redd counts should be considetred minimums. Since 1999, counts ranged from 4 to 206 (Table 6, Figure 44). .

Snow Creek Steelhead returns, counted at the weir, reached a maximum of 192 fish in 2000 (Table 6, Figure 45). Returns were substantially less since 2004 with a high of 50 fish in 2013.

A small number of Chinook (*Oncorhynchus tshawytscha*), Pink, and Sockeye Salmon (*Oncorhynchus nerka*), and Pacific Lamprey (*Entosphenus tridentatus*) have also been trapped in Salmon and/or Snow creeks (Table 6).

Eulachon (*Thaleichthys pacificus*), also called candle fish, have been trapped at the Salmon Creek weir from 2008 to 2019; their numbers ranged from 0 to 15 (Table 6). These anadromous fish grow to about 9 inches and spawn in a river; a 7-inch female lays about 25,000 eggs. The 0.03-0.04-inch diameter eggs have double membranes. The outer membrane ruptures quickly, exposing a sticky inner membrane which anchors to sand grains on the river bottom (Hart 1973).

Since 2016, Bluegill (*Lepomis macrochirus*), and brown bullhead (*Ameiurus nebulosus*) have been trapped at the Snow Creek weir: 1,068 bluegill in 2016 and 467 bullhead in 2015 with declining numbers each year since then (Table 6). The bluegill and brown bullhead probably came from Crocker Lake. Both species normally inhabit lakes and most likely came from Crocker Lake via Andrews Creek. In 1998, Crocker Lake was treated with rotenone to exterminate Northern Pike (*Esox Lucius*), which had been illegally introduced.

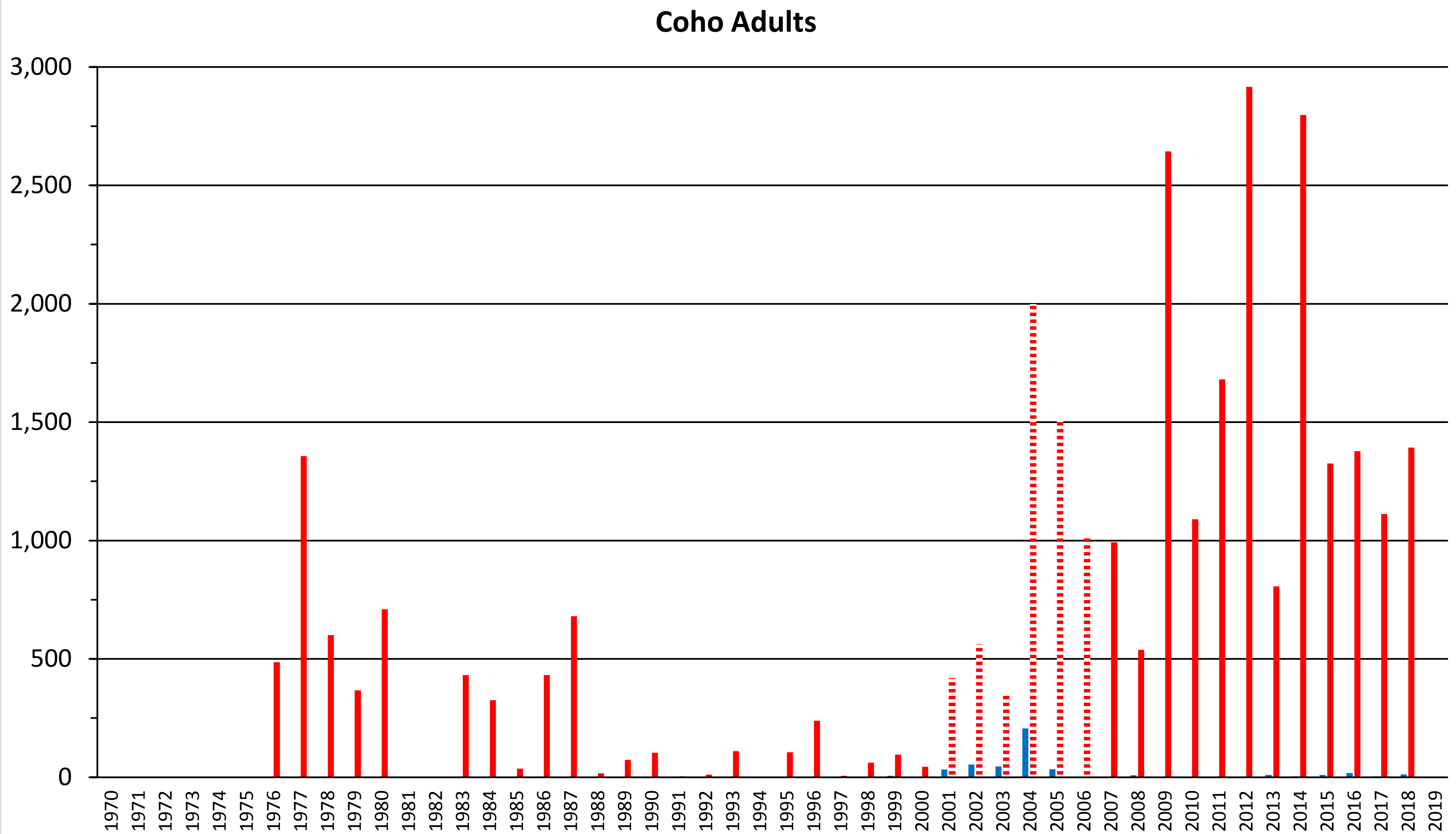


Figure 44. Number of Coho Salmon redds counted in Salmon Creek and number of adult Coho Salmon counted at the Snow Creek weir (RM 0.8). A suplementation program occurred on Snow Creek from 1998 to 2003 with adults returning from 2001 through 2006.

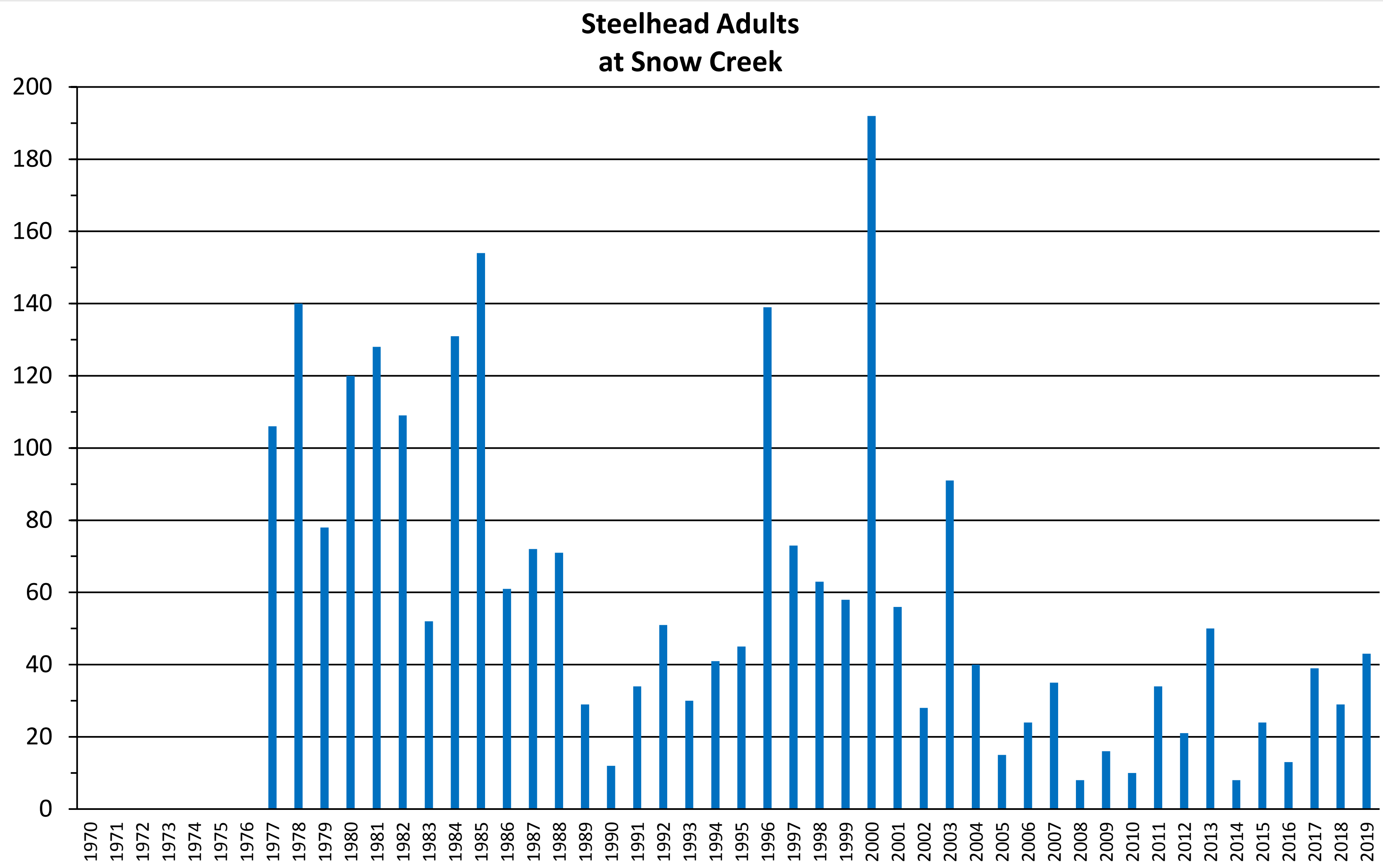


Figure 45. Number of adult Steelhead counted at the Snow Creek weir (RM 0.8).

Juvenile salmon trapping in Salmon Creek's new channel, constructed on WDFW property in 2003 (see Figures 21 and 22), showed an increasing trend for juvenile Coho in all seasons except July-August (Figure 46). In the upstream control, juvenile Coho exhibited an increasing trend in all seasons except October-December (Figure 47)

Two habitat restoration projects were conducted on Andrews Creek. The first extended from Crocker Lake upstream almost to Highway 101. A large section of this reach was unshaded, choked with canary grass, and low in dissolved oxygen (see Restoration Section for details). Very few salmon were caught prior to completion of the project in 1995. After removing sediment and canary grass from the channel, planting trees, and fencing it from horses, juvenile Coho exhibited a rising trend (Figure 48).

Prior to 1995, Andrews Creek ran in a ditch alongside Highway 101 for almost one-half mile. The ditch was full of canary grass and dissolved oxygen was low. In 1995, the Washington Department of Transportation moved the channel away from the road, fitted the new channel with meanders and two sediment basins, placed large-woody-debris in the channel, and planted the banks with a variety of trees and shrubs (see Restoration Section for details). Trapping from 1996 to 2011 showed an increasing trend for juvenile Coho (Figure 49).

Freshwater Limiting Factors

Of the parameters analyzed, it does not appear that temperature, surface dissolved oxygen, or pH are limiting salmon production. What does appear as possibly limiting production is intragravel dissolved oxygen. Because surface DO, the source of intragravel DO, is adequate, it is not DO itself that is the problem. The problem is fines in the gravel that prevent the flow of oxygenated water from reaching the redds. Eggs and alevins require a *continuous* supply of *adequate* oxygen for several months. As was previously shown (Intragravel Dissolved Oxygen Section), intragravel DO concentrations in monitored "redds" in Salmon Creek was extremely variable (Figure 33), sometimes dropping below the acute mortality level of 3 mg/L.

In the past, logging activity in the upper basins of Snow Creek, Salmon Creek, Andrews Creek, and Houck Creek have resulted in high turbidity and high total suspended solids (Turbidity, Suspended Solids, and Sediment Section). Based on a 2018-19 assessment, sediment is still a problem in Snow Creek, especially downstream of RM 1.5 where the channel is aggrading (Katz et al. 2020). Upstream of RM 1.5, where down-cutting is occurring, salmon mortality is likely occurring in redds due to the scouring.

Regarding the sedimentation of redds, it is encouraging to know that even an excessive amount of fines can, in time, be flushed from the gravel as was demonstrated on Salmon Creek's new channel (Figures 21, 22, and 28).

Salmon Creek – WDFW Restoration Reach - SAL/0.1-0.5

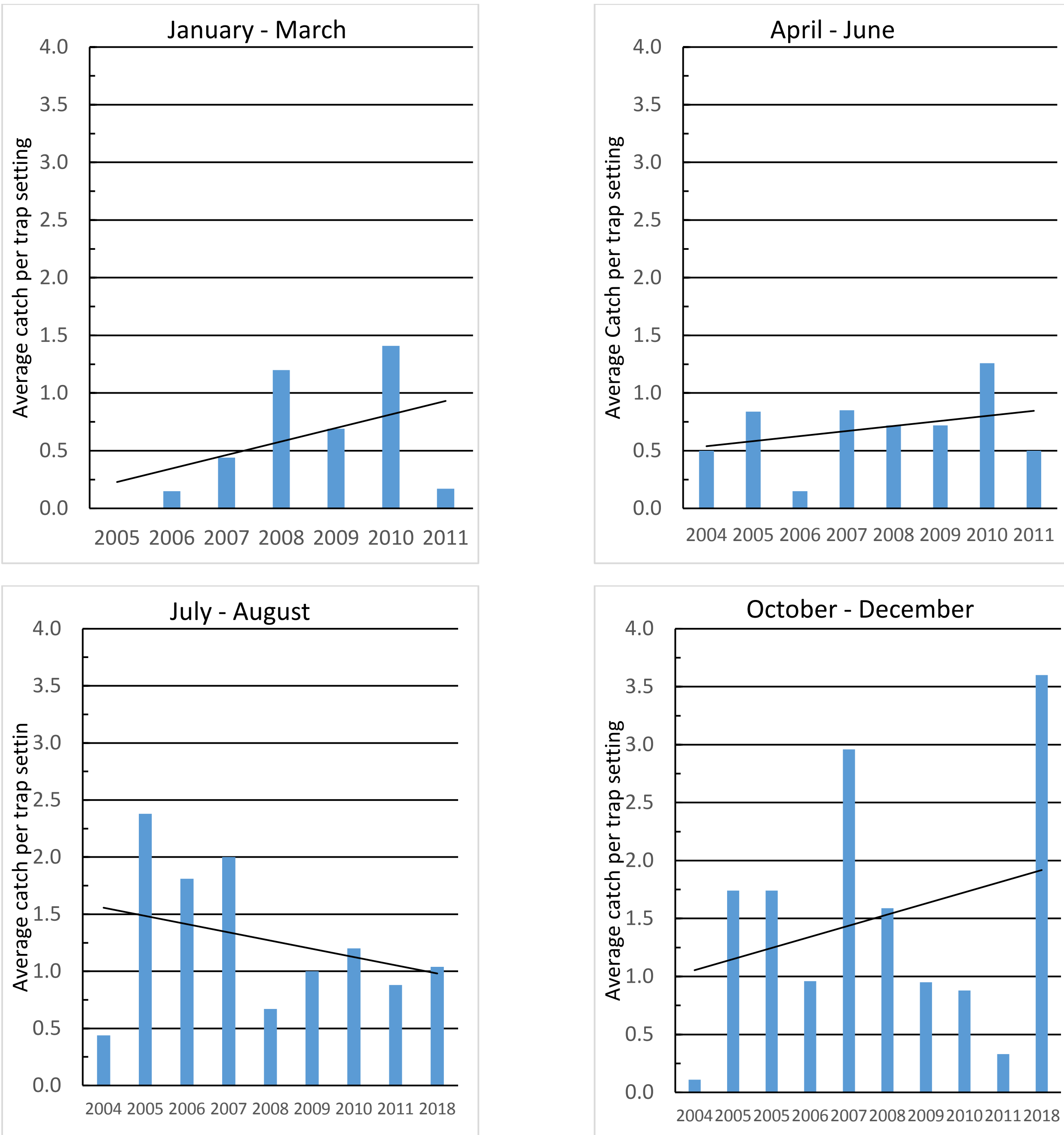


Figure. 46. Average number (with trendline) of juvenile Coho Salmon caught in fish traps in various years in Salmon Creek reach SAL/0.1-0.5. In 2003, Washington Department of Fish and Wildlife completed a major restoration project on this reach. See Restoration Section for project details.

Salmon Creek – Control Reach - SAL/0.5-0.7

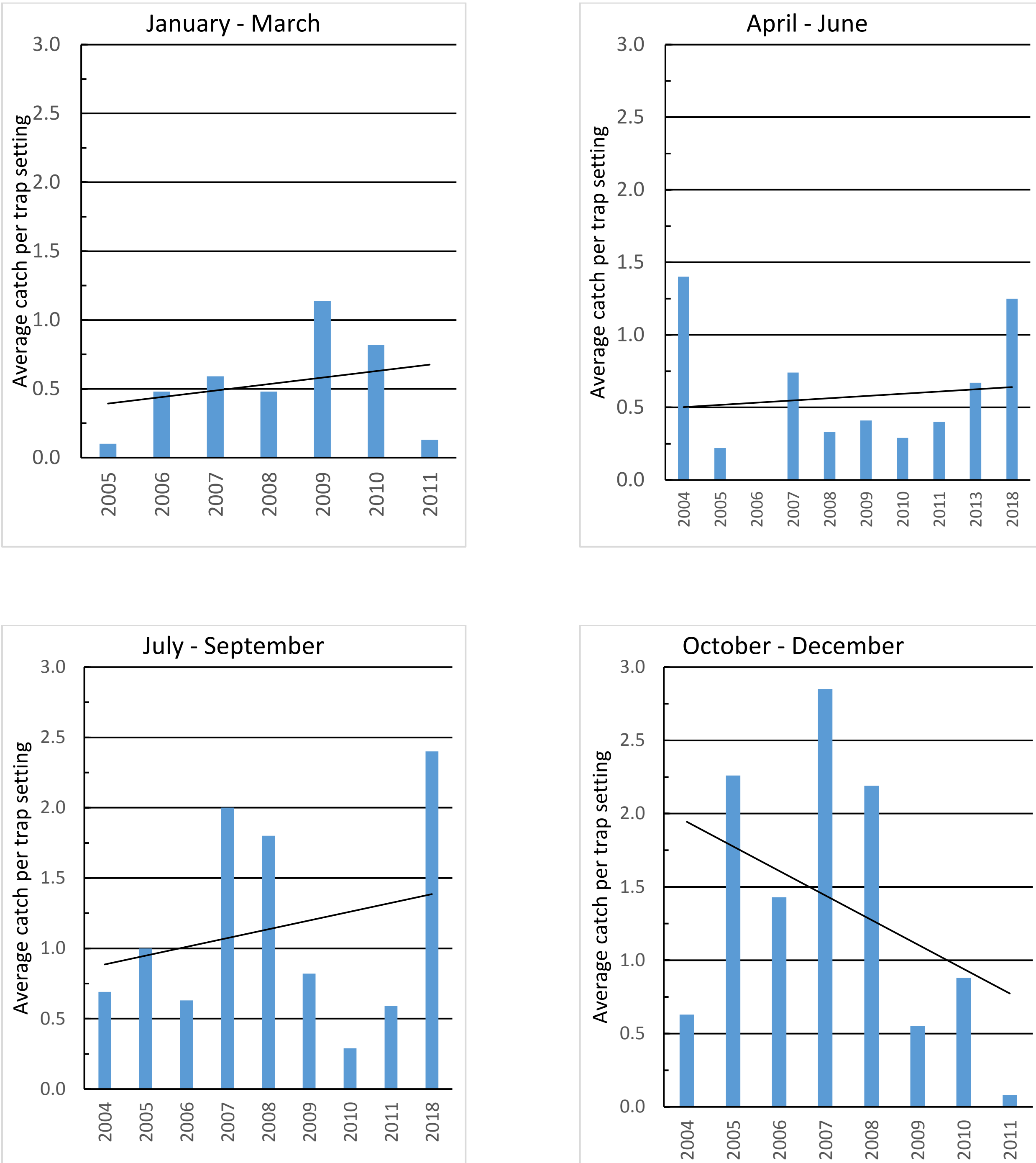


Figure 47. Average number (with trendline) of juvenile Coho Salmon caught in fish traps in various years in Salmon Creek reach SAL/0.5-0.7, upstream from WDFW project.

Andrews Creek - Restoration Project - AND/0.8-1.5

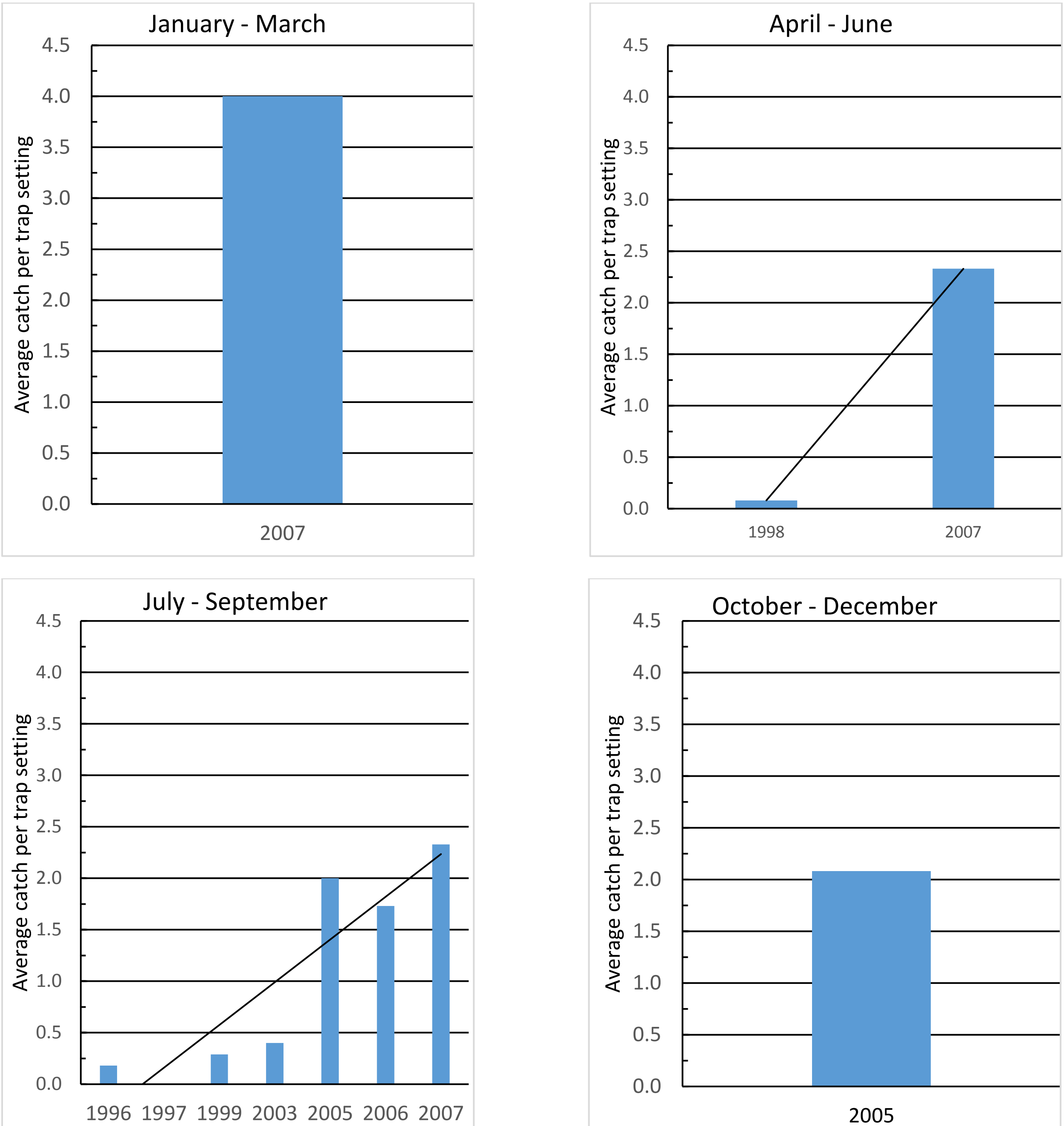
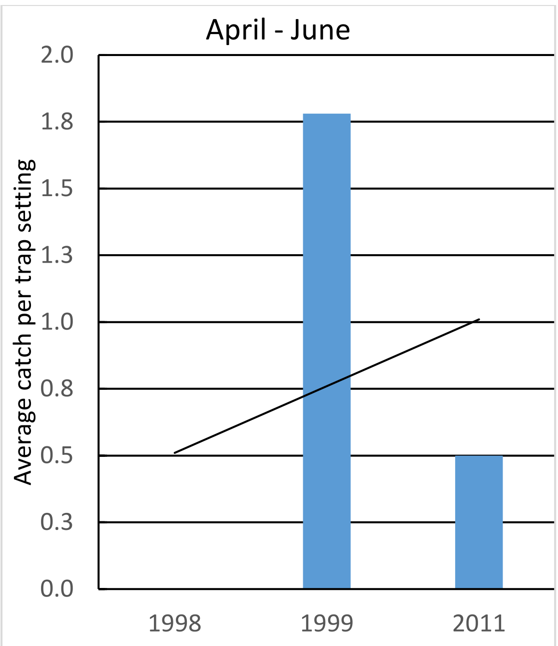


Figure 48. Average number (with trendline) of juvenile Coho Salmon caught in fish traps in various years in Andrews Creek reach AND/ 0.8-1.5, a JCCD buffer project conducted in 1995.

Andrews Creek – DOT Restoration Reach – AND/1.6-2.0



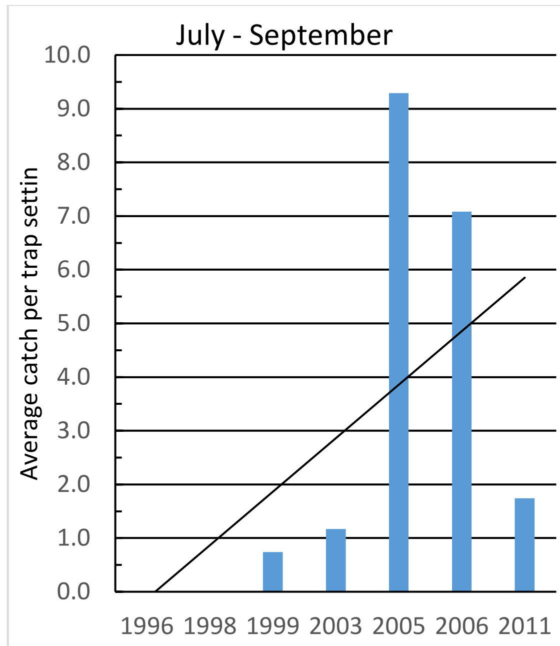


Figure 49. Average number (with trendline) of juvenile Coho Salmon caught in fish traps in various years in Andrews Creek reach AND/1.6-2.0. In 1995, Washington Department of Transportation constructed a new channel and established a riparian buffer for this reach which parallels Highway 101.

Another likely limiting factor to salmon production that is related to fines is Large Woody Debris (LWD). LWD creates stream complexity (alternating pools and riffles). During storm events, high velocity water against wood in the stream channel creates pools, where slower moving water allows suspended solids to settle out. Pools also collect fines moving as bedload. Thus, pools provide temporary storage areas for fines and thereby limit their deposition in the gravel. Also, LWD reduces the potential for redd scouring by lowering stream velocity.

Fox and Bolton (2007) reviewed the many benefits that LWD provides for salmonids:

> The role of LWD in Pacific Northwest streams is linked to channel processes that benefit salmonids. Woody debris plays an important role in controlling channel morphology, the storage and routing of sediment and organic matter, and the creation of fish habitat (Bisson et al. 1987; Bjornn and Reiser 1991). Large wood creates habitat heterogeneity by forming pools, back eddies, and side channels, and by increasing channel sinuosity and hydraulic complexity (Spence et al. 1996). Pools are, perhaps, one of the most important habitat features for salmon *Oncorhynchus* spp. formed by LWD (Keller and Swanson 1979). In high-energy channels, LWD functions to retain spawning gravel and can also provide thermal and physical cover for salmonids (Schuett-Hames et al.1994). Wood indirectly serves as an important food source for salmonids by providing nutrients and insects to the stream (Naiman and Sedell 1979; Spence et al.1996) or by retaining salmon carcasses (Cederholm et al. 1989; Bilby et al. 1996). Wood serves as cover for juvenile salmonids, which are particularly vulnerable to predators when migrating (Larsson 1985). The geo-morphic potential of the channel to process wood into features that benefit salmonids is often limited by the quantity and size of wood (Abbe and Montgomery1996).

The addition of LWD has been shown to restore spawning habitat. MacInnis et al. (2008) installed digger logs and deflector logs in an Atlantic Salmon stream in Nova Scotia, Canada. Digger logs (6-8 in. diameter) were placed across the entire channel and pointed upstream at a 30 degree angle. Deflector logs were placed so as to protrude partway into the channel and angled downstream at a 30 degree angle. In 4 years, the number of redds increased from 43 to 592. In 12 years, reaches with artificial structures had significantly more redds (336) than reaches without the structures (280).

Numerous studies have shown that the addition of LWD increases stream complexity resulting in increased salmonid abundance (House and Boehne 1986; Cederholm et al. 1997; Roni and Quinn 2001; Rosenfield and Huato 2003; Johnson et al. 2005;

Whiteway et al. 2010; Jones et al. 2014; Gonzalez et al. 2017). Beaver dams also provide stream complexity (Pollock et al. 2004).

In reaches lacking riparian buffers, planting trees will eventually provide the needed LWD as the trees grow and fall into the stream. Installing LWD, as was done on lower Salmon Creek (see Figures 21 and 22), speeds up the process.

Marine Limiting Factors

Not all limiting factors occur in the freshwater environment. Ocean conditions can also limit the number of returning salmon. Predation, disease, food quantity and quality, and water quality can affect the return rate. For example, in 2014-15 a large expanse of warm surface water, nicknamed “the Blob,” occurred off the Pacific Coast from Alaska to Mexico. The Blob was followed by a strong El Niño, which kept the water warm into 2016. Biological disturbances resulting from the warm water continued through 2017 (NOAA 2019; Morgan et al. 2019). The warmer water drastically changed the food web and caused the largest harmful algal bloom ever recorded on the West Coast.

In 20 years of surveys conducted from 1998 to 2017 off the Washington and Oregon coasts, the greatest biological changes occurred within the 2014-17 period, when surface water was exceptionally warm (Morgan et al.). Species normally present in low numbers or not at all increased dramatically. These included the North Pacific krill *Euphausia pacifica furcilia*, larval Pacific sand crabs, water jellyfish, egg-yolk jellyfish, juvenile rockfish, Pacific Pompano, Jack Mackerel, young-of-the-year Pacific Chub Mackerel, young-of-the-year Pacific Hake, and the tunicate *Pyrosoma atlanticum*, which had not appeared in surveys until 2017 and then in extremely high abundance. In contrast, yearling Coho Salmon and yearling Chinook Salmon were at extreme lows in 2017. Both species were also in low abundance in 1998 and 2005, which were also warm water years.

Also low in 2017 was chlorophyll *a*, a measure of phytoplankton density. Morgan and his coauthors theorized that the low abundance of phytoplankton could be due to the extremely high abundance of the pyrosome *Pyrosoma atlanticum*, an extremely effective grazer. Furthermore, they said if the presence of this pyrosome persisted, it could outcompete other filter feeders, which in turn could reduce the food supply to organisms higher in the food web.

The low Coho return rate to Snow Creek in 2019 was apparently due to adverse ocean conditions. The return rate that year was only 1.3% (1.3 adults returned for every 100 smolts that migrated to sea), compared to an average return rate of 8%. For most streams we would not have counts of out-migrating smolts and returning adults, but the weir on Snow Creek makes this possible.

It is noteworthy that in the fall of 2019 an expanse of warm surface water again appeared off the coast in an area similar to that of “the Blob” of 2014 (Figure 50). The effects of this warm water remain to be seen.

Restoration

In the settlement days of the 1800s and early 1900s, when salmon returned in large numbers and trees of respectable diameter covered the landscape, there were no or few restrictions on farming and logging. Diverting and channelizing streams, allowing livestock to drink from them, draining wetlands, clearcutting large tracts of land were standard operating procedures. In those early days, government agencies assisted landowners with some of these practices. In retrospect we have learned that some of these practices had unintended consequences, especially to salmon.

For the past three decades, the Conservation District has been working to restore stream habitat and water quality in Jefferson County’s streams. Much of the stream restoration work was accomplished through the Conservation Reserve Enhancement Program (CREP). CREP is jointly funded by the U. S. Department of Agriculture’s Farm Service Agency and the Washington State Conservation Commission. The Conservation District manages the program. Under CREP, landowners receive rent for establishing vegetated buffers along salmon streams. The program pays for the tree planting, livestock fencing, and watering facilities. Through grants from Conservation Commission, JCCD offers landowners cost-sharing for barn gutters and downspouts.

The Washington State Recreation and Conservation Office administers the Family Forest Fish Passage Program (FFFPP) to pay for culverts and bridges on private land to improve fish passage. JCCD manages the program under contract.

The Conservation District is not alone in restoring water quality and salmon habitat. A number of agencies have been involved with restoration projects in the Discovery Bay Watershed.

Jefferson County Environmental Health corrected 31 septic violations in the past three years and 17 additional violations are in the process of being corrected.

NOSC and the Washington Conservation Corps crew have planted thousands of trees in the Discovery Bay Watershed. NOSC completed a multistage project to improve the Salmon and Snow Creek estuaries. NOSC currently is working on a project to assess salmon habitat in the Snow Creek Drainage.

The Jefferson Land Trust has protected 488 acres of land bordering waterbodies in the Discovery Bay Watershed by establishing preserves and easements, and by facilitating purchases to Washington Department of Fish and Wildlife.

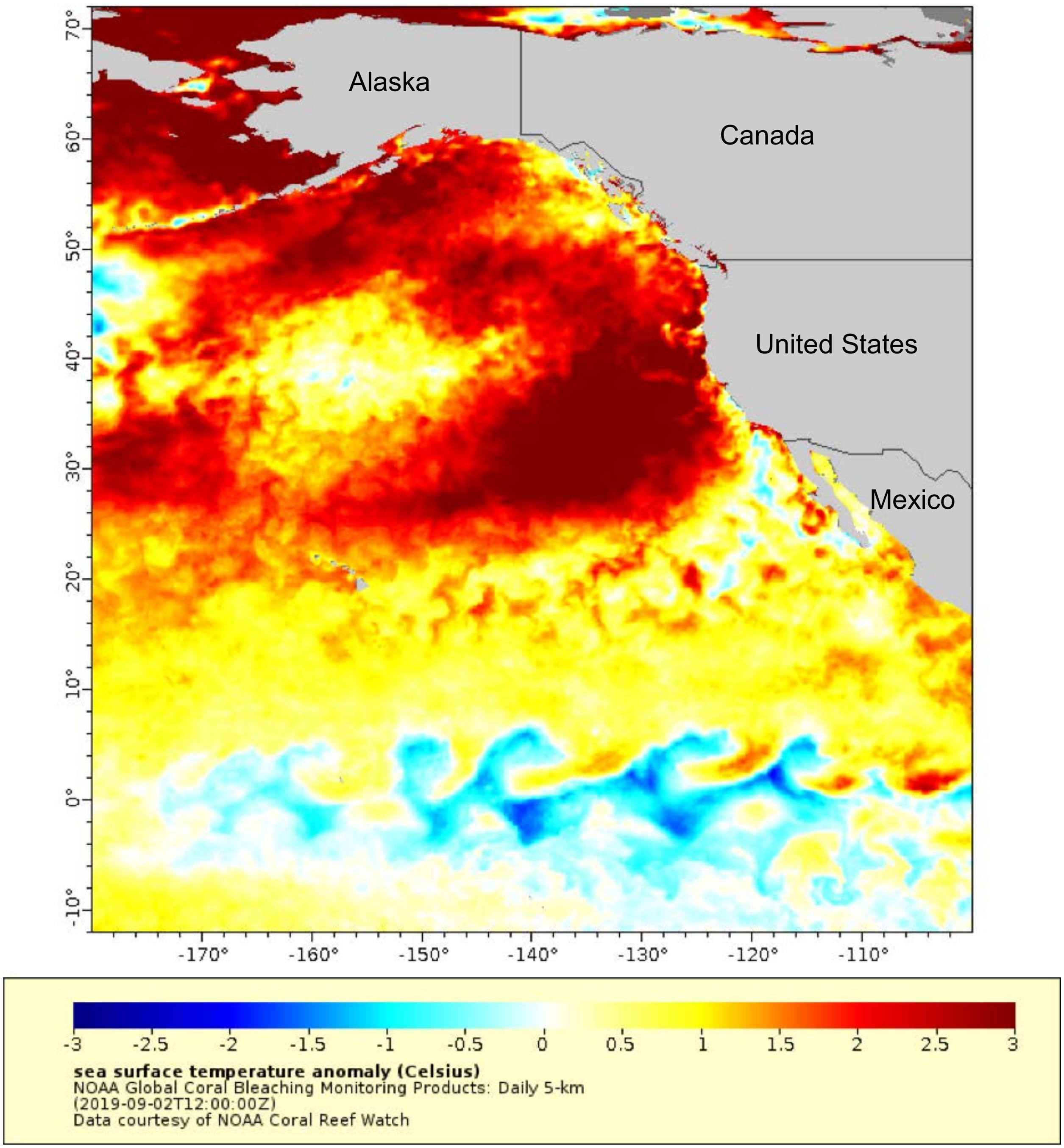


Figure 50. Map of sea surface temperatures off the western coast of North America in September 2019. Colors indicate temperature deviations from normal (average). The darker the red, the greater is the deviation. See above key for a detailed explanation.

Jefferson County Public Works has improved salmon passage on Salmon Creek by replacing a culvert with a bridge on West Uncas Road. This alleviated the need for sand-bagging the downstream end of the culvert every year to make it passable for Summer Chum.

Washington Department of Fish and Wildlife purchased 103 acres of land and restored over half a mile of habitat along lower Salmon Creek, a choice spawning ground of Summer Chum.

Washington Department of Transportation purchased land along Andrews Creek, a Snow Creek tributary, and relocated the creek farther away from Highway 101. The stream was meandered and a riparian buffer was established.

In the last 25 years over 2 miles of riparian buffers have been planted and over 1 mile of fencing has been installed in the Discovery Bay Watershed(Table 7). For more information and pictures of the restoration projects see Appendix D.

Table 7. Restoration projects completed in the Discovery Bay Watershed by the Conservation District, North Olympic Salmon Coalition, Jefferson Land Trust, Jefferson County Public Works, Washington Department of Fish and Wildlife, and Washington Department of Transportation.

Stream	River Mile	Type	Year	Buffer Area	Buffer Length	Stream Length	Buffer Width	Fence
				(Acres)	(Feet)	(Feet)	(Feet)	(Feet)
Andrews Creek	mouth to Crocker Lake	Canary grass removed, planting, and fencing	2019	0.6	2,400	2,400	10	—
Andrews Creek	0.84-1.29	New channel, meanders, planting, and LWD	1995	0.6	2,700	1,350	10	1,350
Andrews Creek	1.6-2.0	New channel, meanders, planting, and LWD	1995	1.7	4,200	2,100	35	
Houck Creek	0.0-0.1	Bank stabilization with rock, half-culvert, grass, and willow stakes	2002	—	—	—	—	—
Salmon Creek	0.0-0.1	Fill Removal, RR Grade Removal, Waterline Relocation, Tidal Channel excavation	2008	11.0				
Salmon Creek	0.1-0.7	New channel, meanders, tree planting, and LWD	2003-06	29.0	7,000	3,500	180	
Salmon Creek	0.65	Livestock Bridge	2008			800		800
Salmon Creek		West Uncas Road Bridge	2019					
Salmon Creek	0.8-0.9	Tree Planting	2009	0.7	300	300	100	
Snow Creek	0.0-0.1	Fill Removal, Tidal Channel excavation	2015	22.0				
Snow Creek	0.0-0.8	Streambed lowered, trees planted, LWD installed	1995-96					
Snow Creek	0.4-0.7	Planting		6.7	1,600	1,600	180	
Snow Creek	0.7-1.0	Fencing & planting	2008-09	4.8	1,600	1,600	160	1,600
Snow Creek	0.7-1.0	Tree planting	2006	7.0	1,690	1,690	180	
Snow Creek	1.0-1.2	Fencing & planting	2008-09	4.1	1,068	1,068	160	1,068
Uncas Valley Ditch	0.1-0.2	Planting	2018	1.2	1,000	500	50	
Uncas Valley Ditch	0.2-0.3	Fencing & planting	2018-19	0.2	1,000	500	7	1,000
Uncas Valley Ditch	0.3-0.6	Fencing & planting	2007-09	1.1	3,000	1,500	15	3,000
Uncas Valley Ditch	0.6-0.9	Fencing & planting	2009	1.0	3,000	1,500	15	3,000
Uncas Valley Ditch Tributary	0.0-0.3	Fencing & planting	2007-09	1.0	2,800	1,400	15	2,800
Zerr Drain	0.0-0.3	House removal, railroad bed removal, planting	2015	2.0				
Totals				**94**	**30,958**	**19,408**		**14,618**

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APPENDIX A

Station Locations

Table A-1. Water quality monitoring station locations.

Station	Stream	Description	Latitude	Longitude
AND/0.0	Andrews Creek	Upstream side of Rt 101; near mouth on Snow Creek.	47.94453	-122.88631
AND/1.71	Andrews Creek	Within DOT stretch at mile marker 287.	47.92570	-122.88640
CON/0.4	Contractors Creek	Downstream side of Highway 101 at edge of woods	48.04112	-122.88038
HOU/0.0	Houck Creek	About 10 ft. u/s from mouth (at confluence with Salmon Creek).	47.97881	-122.90185
SAL/0.15	Salmon Creek	WDFW property in the new channel just u/s of salt water influence.	47.98669	-122.89074
SAL/0.5	Salmon Creek	WDFW property at the u/s end of the new channel.	47.98280	-122.89238
SAL/0.7	Salmon Creek	Downstream side of West Uncas Rd. bridge.	47.98034	-122.89657
SAL/1.0	Salmon Creek	About 10 feet upstream from Houck Creek	47.97911	-122.90197
SNO/0.2	Snow Creek	Downstream side of SR 20 bridge.	47.98790	-122.88566
SNO/0.8	Snow Creek	At WDFW office and weir and gaging station; 5 ft. upstream from staff gage.	47.98134	-122.88637
SNO/1.6	Snow Creek	Upstream side of West Uncas Rd. bridge.	47.96883	-122.88464
SNO/2.3	Snow Creek	B&D Lilies Nursery at 284566 Highway 101; upstream side of bridge, left bank.	47.96012	-122.88335
SNO/3.5	Snow Creek	About 100 ft. upstream of Andrews Creek Highway 101 culvert.	47.94440	-122.88587
SNO/3.9	Snow Creek	At Snow Creek Ranch bridge.	47.94090	-122.88650
TUD/0.0	Tucker Ditch	At confluence of Tucker Ditch and Salmon Creek	47.98669	-122.89074
TUD/0.4	Tucker Ditch	Tucker Ditch at WDFW upstream boundary at wire fence.	47.98439	-122.89465
TUD/0.5	Tucker Ditch	Tucker Ditch at West Uncas Rd. culvert.	47.98504	-122.89597
UVD/0.0	Uncas Valley Ditch	Uncas Valley Ditch about 100 ft. upstream from confluence with Salmon Creek at about SA/0.4 .	47.98316	-122.88993
ZER/0.11	Zerr Drain	Zerr Drain about 0.1 miles upstream from mouth	47.98917	-122.88420

Table A-2. Temperature data logger locations.

Station	Stream	Description	Latitude	Longitude
AND/0.0	Andrews Creek	Near mouth	47.94453	-122.88631
AND/1.0	Andrews Creek	Upstream from Crocker Lake	47.93049	-122.88173
AND/1.6	Andrews Creek	Upstream of Highway 101 bridge	47.92763	-122.88595
AND/2.0	Andrews Creek	Highway 101	47.92046	-122.88739
AND/2.2	Andrews Creek	Boulton Road	47.91869	-122.89125
HOU/0.0	Houck Creek	Top of bank	47.97824	-122.90184
SAL/0.15	Salmon Creek	WDFW property	47.98669	-122.89074
SAL/0.5	Salmon Creek	WDFW property	47.98280	-122.89238
SAL/0.7	Salmon Creek	West Uncas Road	47.98039	-122.89672
SNO/0.2	Snow Creek	State Route 20	47.98757	-122.88565
SNO/0.8	Snow Creek	WDFW weir	47.98134	-122.88637
SNO/1.6	Snow Creek	West Uncas Road	47.96881	-122.88466
SNO/3.5	Snow Creek	Snow Creek Ranch	47.94440	-122.88587
SNO/4.1	Snow Creek	Snow Creek Ranch	47.94020	-122.88780
UVD/0.0	Uncas Valley Ditch	Near mouth (missing in 2019)	47.98316	-122.88993

APPENDIX B

Quality Control

Appendix B -- QUALITY CONTROL

Field replicates of those parameters measured with YSI models 556 and Pro Dss meters (temperature, conductivity, pH, and dissolved oxygen) were taken at the sampling sites. Two sets of measurements were taken within a few minutes of one another. Replicate water samples, collected in separate bottles within a few minutes of one another, were taken for fecal coliform and turbidity. Replicates are shown in Table B-1.

Replicate measurements provide an estimate of the random variability (precision) in the results due to the instrument and its operator. The analysis of replicate samples provides an estimate of the variability due to sampling and analysis. The results for different parameters will exhibit different levels of variability due to the nature of the measurement, sampling and/or analytical process. The variability in the fecal coliform counts exhibits a log normal distribution.

The standard deviation is an estimate of the absolute variability of the results and usually increases with the magnitude of the results. Precision is reported as the *relative standard deviation* (RSD). The RSD is usually inversely proportional to the magnitude of the results. Because the RSD is often small, it is multiplied by 100 to express it as a percent.

The **RSD** (in percent) is given by:

$$\textbf{RSD (\%)} = \mathbf{(s / x) \times 100}$$

where **s** is the estimate of the standard deviation of the individual results; and **x** is the mean of the replicate results (Zar 1984[1]).

Replicate measurements generally showed acceptable precision, especially concerning absolute differences between the two replicates (Table B-1). As is usual, RSDs were highest when values were lowest and near detectable limits.

As is typical, fecal coliform replicates showed the greatest variation. Although much of this variation could simply be due to the uneven distribution of the bacteria in the stream channel, some is probably due to the method because of an uneven distribution in the sample bottle.

[1] Zar, J. H 1984. Biostatistical Analysis. 2nd ed. Prentice-Hall, Englewood Cliffs, New Jersey. 718 pp.

Table B-1. Quality control results of stations monitored in the Chimacum watershed watershed showing the absolute difference (AD) and relative standard deviation (RSD) for field replicates (R1 and R2) sampled for fecal coliform, temperature, dissolved oxygen, pH, conductivity, and turbidity. Minimum, maximum, and mean ADs and RSDs are also shown. Tinted fecal coliform cells were lab replicates.

Station	Date	Fecal Coliform				Temperature				Dissolved Oxygen				pH				Conductivity				Turbidity			
		R1	R2	AD	RSD	R1	R2	AD	RSD	R1	R2	AD	RSD	R1	R2	AD	RSD	R1	R2	AD	RSD	R1	R2	AD	RSD
		FC/100 mL			%	°C	°C	°C	%	mg/L	mg/L	mg/L	%	units	units	units	%	umho	umho	umho	%	NTU	NTU	NTU	%
SAL/0.15	11/7/17	18	14	4	17.7	3.06	3.06	0.00	0.0	13.62	13.81	0.19	1.0									3.7	4.5	0.8	13.8
AND/1.71	11/7/17	8	6	2	20.2	2.99	2.99	0.00	0.0	10.79	10.79	0.00	0.0					149	153	4	1.9	2.5	1.7	0.8	26.9
SNO/3.9	12/5/17	88	66	22	20.2	4.49	4.49	0.00	0.0									67	69	2	2.1	7.7	3.4	4.3	54.8
TUD/0.4	12/5/17	1	1	0	0.0	5.79	5.79	0.00	0.0	6.62	6.84	0.22	2.3	6.46	6.59	0.13	1.4	161	157	4	1.8	4.0	2.8	1.2	25.0
TUD/0.0	1/2/18	2	4	2	47.1	2.23	2.22	0.01	0.3	11.55	11.84	0.29	1.8	6.95	7.01	0.06	0.6	157	157	0	0.0	2.9	2.7	0.2	5.1
AND/0.0	1/2/18	1	1	0	0.0	2.60	2.73	0.13	3.4	9.81	10.10	0.29	2.1					79	75	4	3.7	5.2	5.4	0.2	2.7
SNO/3.5	2/6/18	2	1	1	47.1	6.86	6.88	0.02	0.2	11.32	11.36	0.04	0.2					63	63	0	0.0	4.4	4.7	0.3	4.7
SAL/0.5	2/6/18	162	198	36	14.1	6.94	6.94	0.00	0.0	12.43	12.45	0.02	0.1					106	108	2	1.3	5.0	4.3	0.7	10.6
SNO/2.3	3/6/18	4	2	2	47.1	4.80	4.76	0.04	0.6	13.52	13.64	0.12	0.6					82	80	2	1.7	4.0	4.0	0.0	0.0
UVD/0.0	3/6/18	26	22	4	11.8	4.60	4.54	0.06	0.9	11.01	10.94	0.07	0.5	6.86	6.98	0.12	1.2	135	136	1	0.5	8.2	8.2	0.0	0.0
SNO/0.8	3/28/18	22	28	6	17.0																				
TUD/0.5	4/3/18	68	42	26	33.4	6.70	6.68	0.02	0.2	10.83	10.95	0.12	0.8	7.31	7.28	0.03	0.3	164	168	4	1.7	2.0	2.1	0.1	3.4
CON/0.4	4/3/18	1	1	0	0.0	6.84	6.84	0.00	0.0	11.67	11.80	0.13	0.8					168	165	3	1.3	2.4	2.8	0.4	10.9
SNO/0.2	4/16/18																					33.0	30.0	3.0	6.7
SAL/0.15	4/16/18																					20.0	22.0	2.0	6.7
SNO/0.8	5/8/18																					2.2	2.1	0.1	3.3
SAL/0.7	5/8/18																					1.8	2.1	0.3	10.9
SNO/1.6	6/5/18	44	64	20	26.2	10.40	10.40	0.00	0.0	11.00	11.00	0.00	0.0					104	103	1	0.7	2.6	2.3	0.3	8.7
SAL/1.0	6/5/18	22	20	2	6.7																	2.7	2.7	0.0	0.0
SNO/3.5	7/17/18	46	122	76	64.0																				
HOU/0.0	7/17/18	8	22	14	66.0	14.48	14.46	0.02	0.1	9.62	9.75	0.13	0.9	7.53	7.57	0.04	0.4	157	158	1	0.4	6.3	5.6	0.7	8.3
SAL/0.15	8/14/18	550	222	328	60.1	13.90	13.89	0.01	0.1	10.20	10.18	0.02	0.1	7.29	7.30	0.01	0.1	275	275	0	0.0	2.2	2.4	0.2	6.1
SNO/3.9	8/14/18	550	510	40	5.3	14.80	14.80	0.00	0.0	10.20	10.20	0.00	0.0	7.97	7.97	0.00	0.0	134	134	0	0.0	1.0	1.3	0.3	18.4
SAL/0.5	9/26/18	248	390	142	31.5	10.17	10.16	0.01	0.1	10.69	10.76	0.07	0.5	7.74	7.69	0.05	0.5	292	295	3	0.7	3.7	4.1	0.4	7.3
SNO/0.2	9/26/18	22	18	4	14.1	10.90	10.80	0.10	0.7	10.31	10.26	0.05	0.3	7.73	7.71	0.02	0.2	152	149	3	1.4	3.1	2.6	0.5	12.4
ZER/0.11	10/16/18	88	60	28	26.8	7.00	7.00	0.00	0.0	9.65	9.65	0.00	0.0	7.40	7.34	0.06	0.6	1368	1360	8	0.4	4.8	4.6	0.2	3.0
SAL/1.0	10/16/18	2	2	0	0.0	7.50	7.49	0.01	0.1	11.60	11.48	0.12	0.7	7.71	7.67	0.04	0.4	295	293	2	0.5	1.3	1.3	0.0	0.0

Station	Date	Fecal Coliform				Temperature				Dissolved Oxygen				pH				Conductivity				Turbidity			
		R1	R2	AD	RSD	R1	R2	AD	RSD	R1	R2	AD	RSD	R1	R2	AD	RSD	R1	R2	AD	RSD	R1	R2	AD	RSD
		FC/100 mL			%	°C	°C	°C	%	mg/L	mg/L	mg/L	%	units	units	units	%	umho	umho	umho	%	NTU	NTU	NTU	%
SAL/0.15	11/6/18	4	20	16	94.3	8.53	8.53	0.00	0.0	11.23	11.24	0.01	0.1	7.43	7.45	0.02	0.2	258	260	2	0.5	2.0	2.0	0.0	0.0
AND/1.71	11/6/18	12	28	16	56.6																	2.7	3.3	0.6	14.1
SNO/0.2	12/6/18	6	6	0	0.0																	1.8	1.7	0.1	4.0
SAL/0.7	12/6/18	1	1	0	0.0	1.53	1.52	0.01	0.5	13.75	13.67	0.08	0.4					263	260	3	0.8	1.1	1.5	0.4	21.8
SNO/0.8	12/16/18																					42.4	33.7	8.7	16.2
UVD/0.0	2/5/19																					7.9	10.3	2.4	18.6
SNO/2.3	2/5/19	14	10	4	23.6	0.80	0.80	0.00	0.0	13.90	13.90	0.00	0.0	7.59	7.60	0.01	0.1	95	95	0	0.3	3.8	3.6	0.2	3.8
TUD/0.0	3/12/19	10	6	4	35.4	3.57	3.57	0.00	0.0					7.09	7.11	0.02	0.2	173	173	0	0.0	2.0	2.1	0.1	3.4
SNO/1.6	3/12/19	2	14	12	106.1																	2.7	2.5	0.2	5.4
TUD/0.4	4/2/19	2	1	1	47.1	5.76	5.81	0.05	0.6	6.64	6.74	0.10	1.1	6.98	7.03	0.05	0.5	178	179	1	0.4	22.0	16.0	6.0	22.3
AND/0.0	4/2/19	1	1	0	0.0																	3.5	3.9	0.4	7.6
Minimum				0	0.0			0.00	0.0			0.00	0.0			0.00	0.0			0	0.0			0.0	0.0
Maximum				328	106.1			0.13	3.4			0.29	2.3			0.13	1.4			8	3.7			8.7	54.8
Mean				25	29.4			0.02	0.3			0.09	0.6			0.04	0.4			2	0.9			1.0	10.2

APPENDIX C

Temperature Profiles

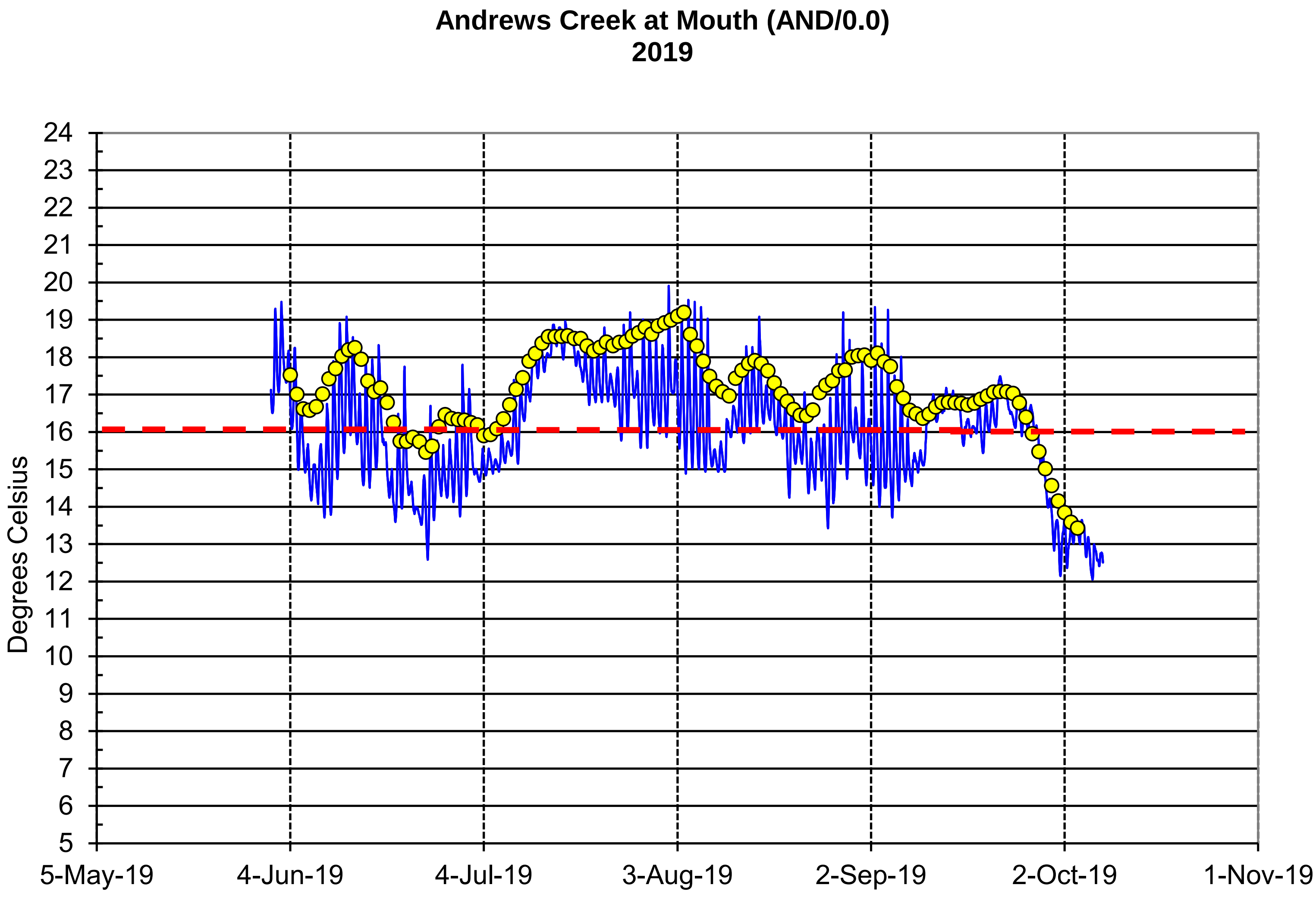


Figure C-1. Hourly temperature profile (blue line) with 7-day average daily maximum temperatures (7-DADMax) shown as yellow circles. Red dashed line represents the 7-DADMax criteria for salmonid spawning and rearing.

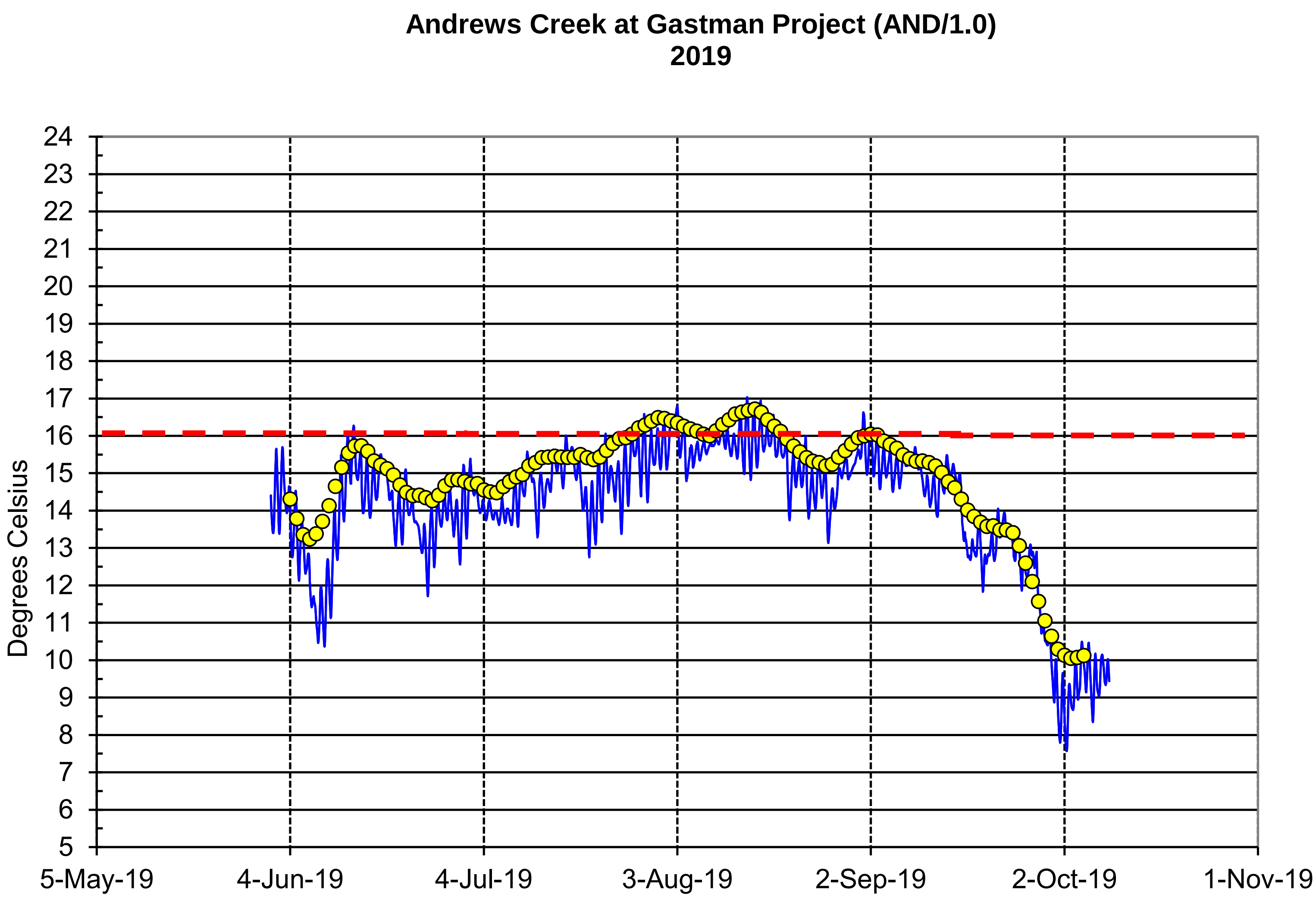


Figure C-2. Hourly temperature profile (blue line) with 7-day average daily maximum temperatures (7-DADMax) shown as yellow circles. Red dashed line represents the 7-DADMax criteria for salmonid spawning and rearing.

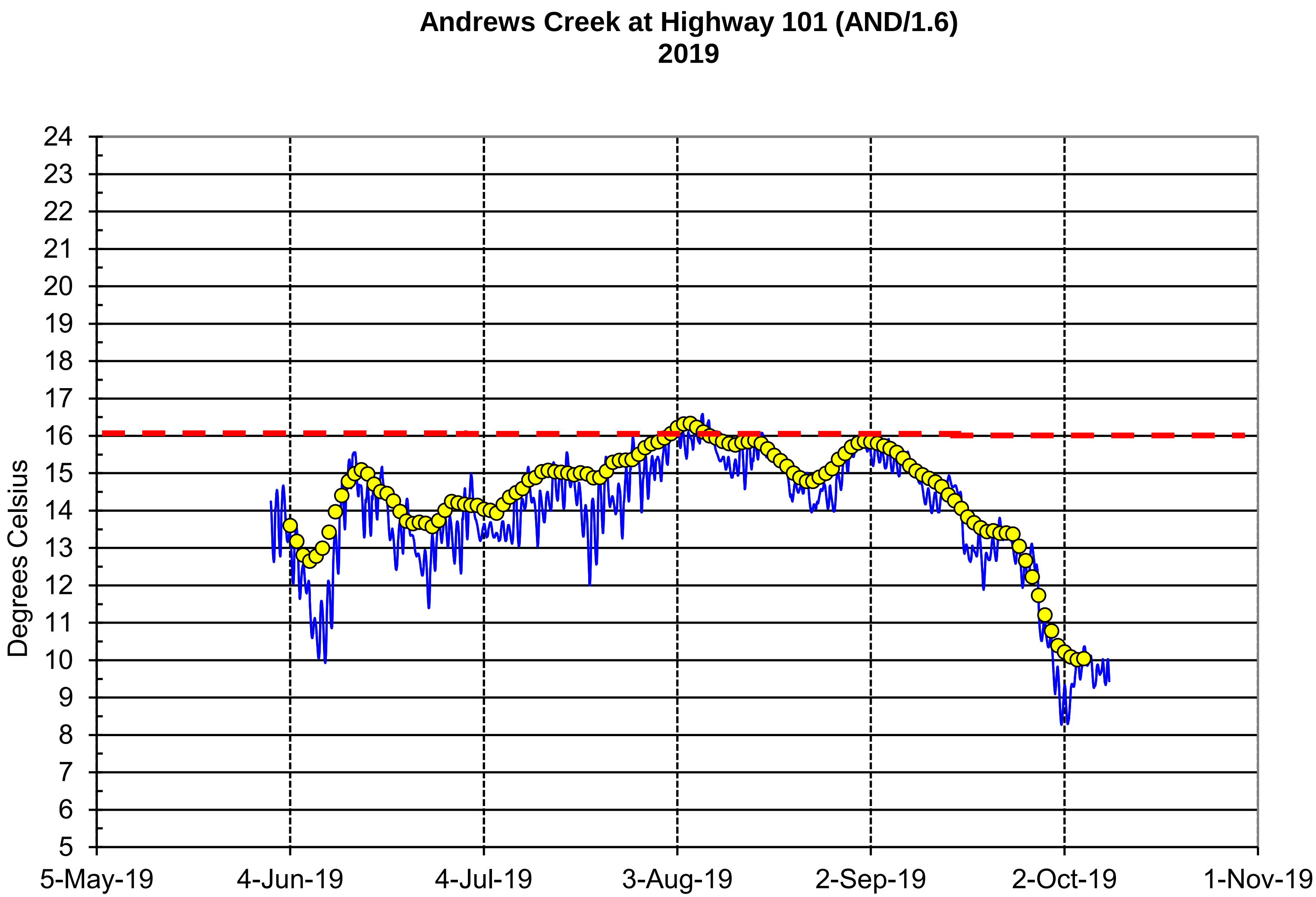


Figure C-3. Hourly temperature profile (blue line) with 7-day average daily maximum temperatures (7-DADMax) shown as yellow circles. Red dashed line represents the 7-DADMax criteria for salmonid spawning and rearing.

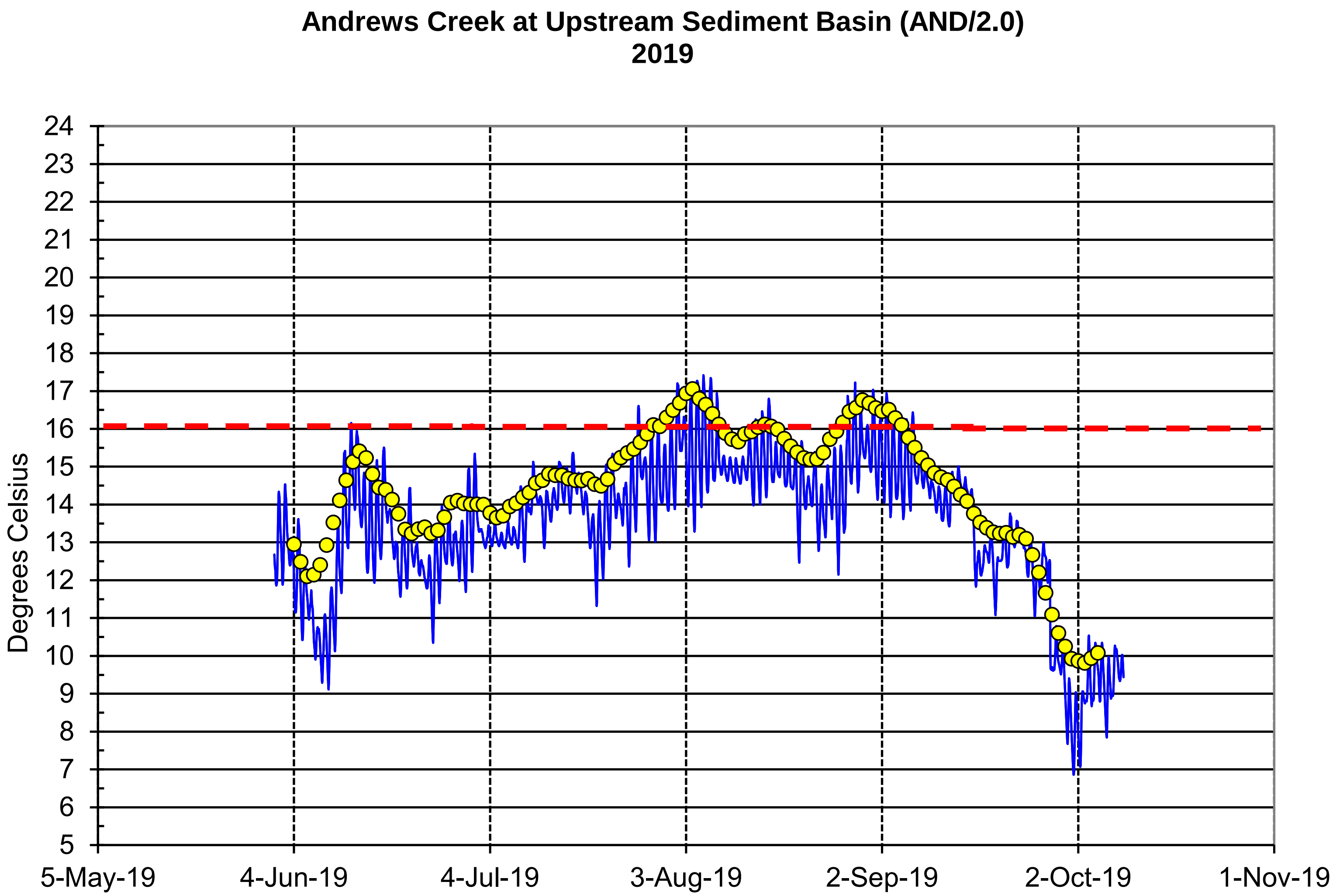


Figure C-4. Hourly temperature profile (blue line) with 7-day average daily maximum temperatures (7-DADMax) shown as yellow circles. Red dashed line represents the 7-DADMax criteria for salmonid spawning and rearing.

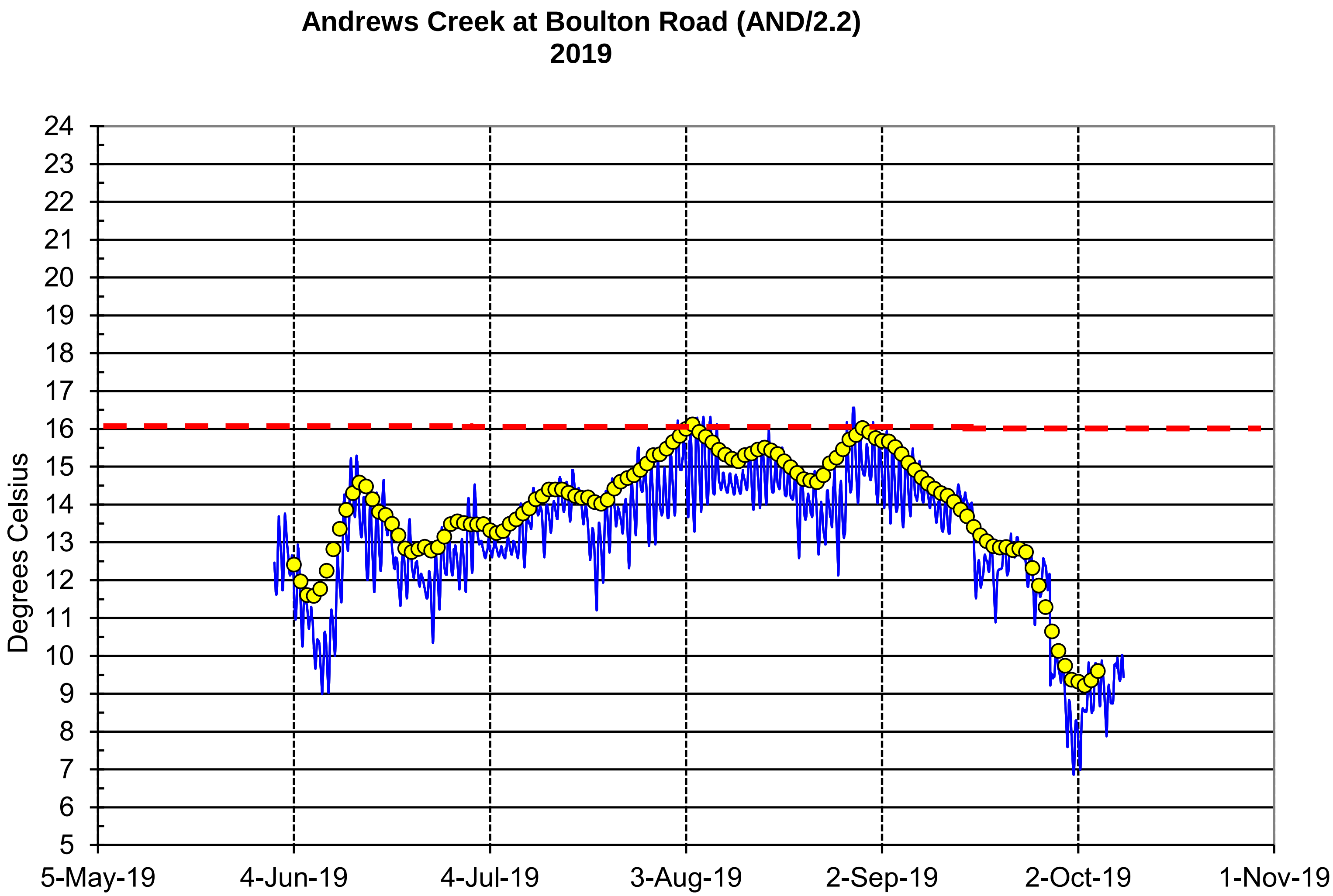


Figure C-5. Hourly temperature profile (blue line) with 7-day average daily maximum temperatures (7-DADMax) shown as yellow circles. Red dashed line represents the 7-DADMax criteria for salmonid spawning and rearing.

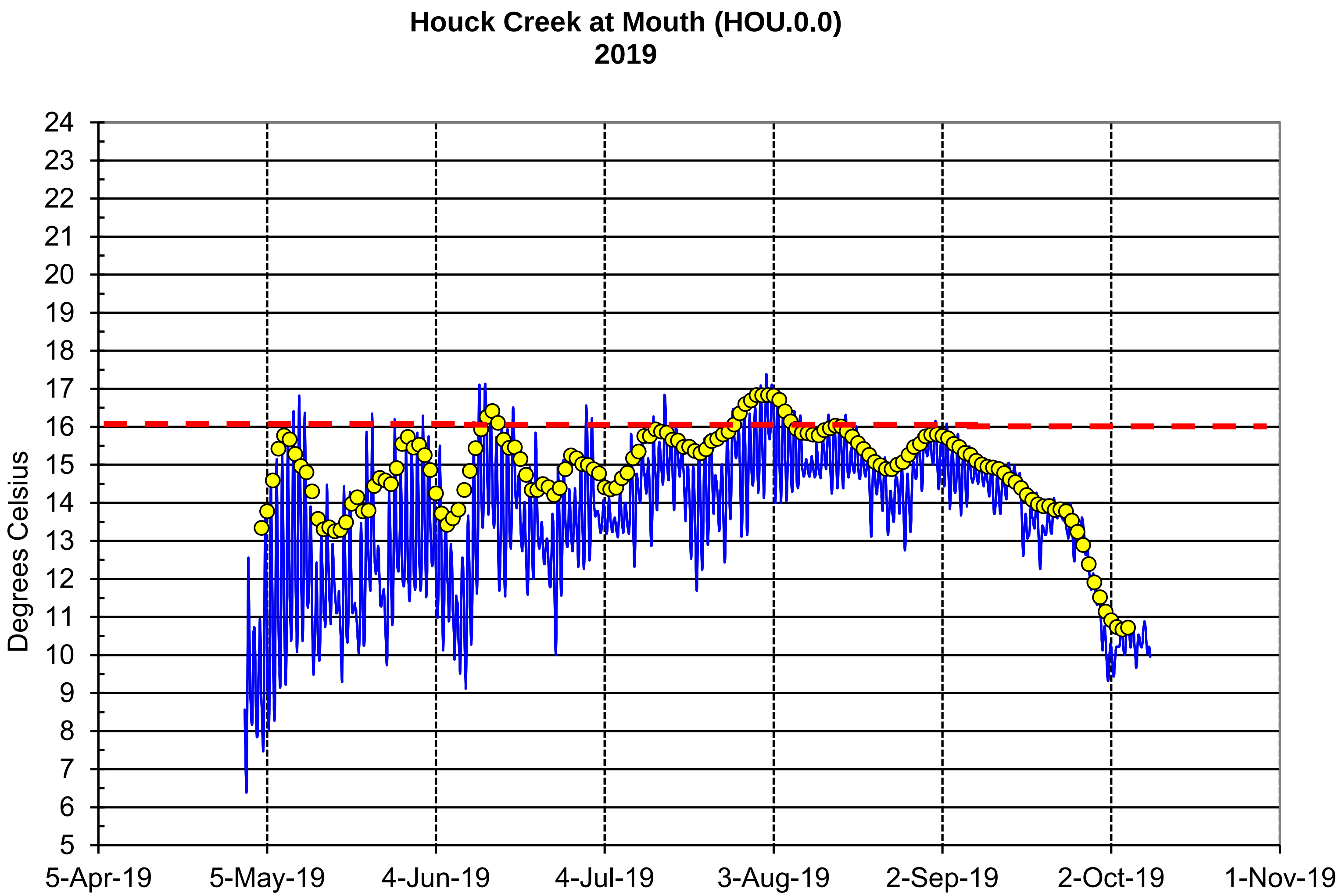


Figure C-6. Hourly temperature profile (blue line) with 7-day average daily maximum temperatures (7-DADMax) shown as yellow circles. Red dashed line represents the 7-DADMax criteria for salmonid spawning and rearing.

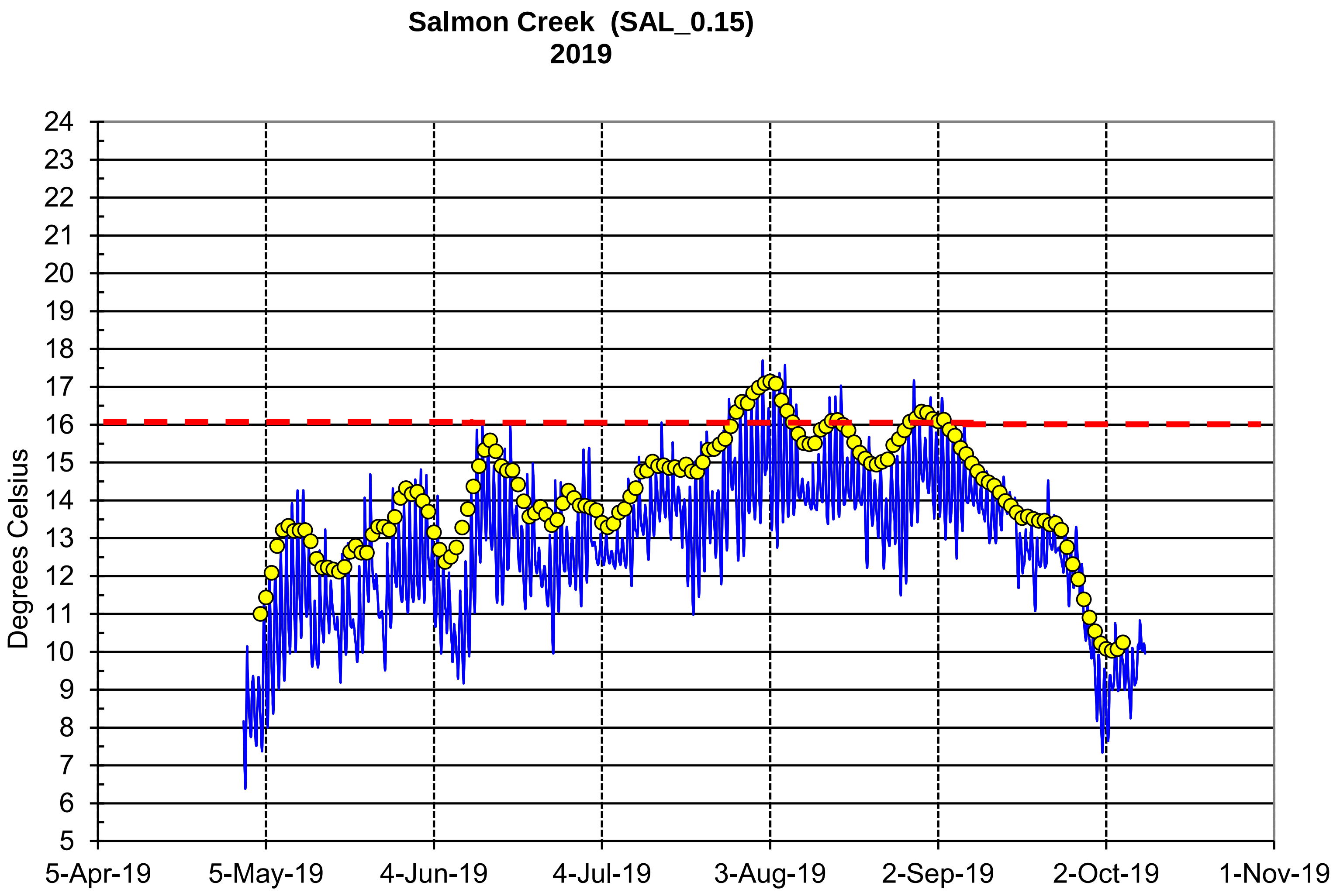


Figure C-7. Hourly temperature profile (blue line) with 7-day average daily maximum temperatures (7-DADMax) shown as yellow circles. Red dashed line represents the 7-DADMax criteria for salmonid spawning and rearing.

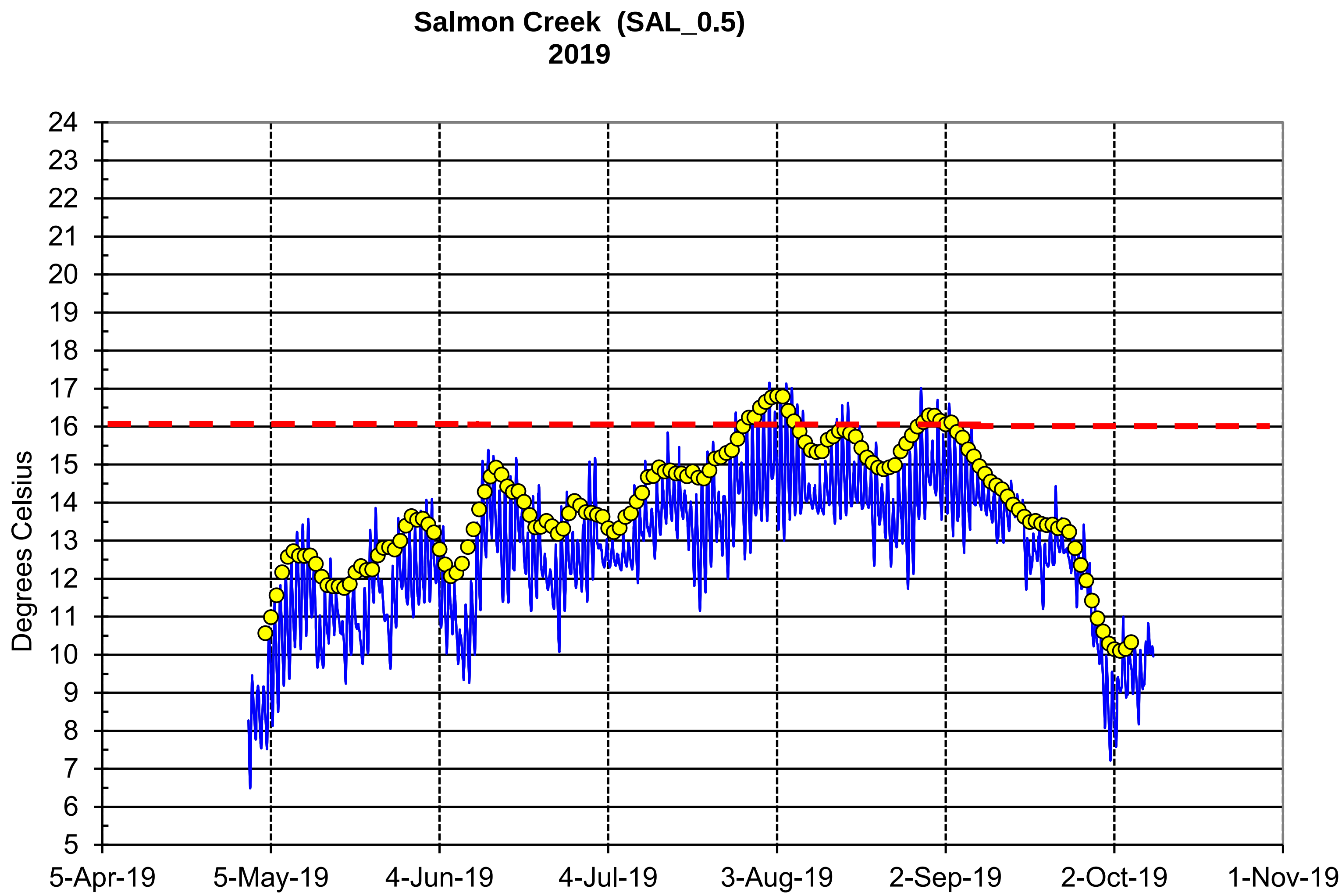


Figure C-8. Hourly temperature profile (blue line) with 7-day average daily maximum temperatures (7-DADMax) shown as yellow circles. Red dashed line represents the 7-DADMax criteria for salmonid spawning and rearing.

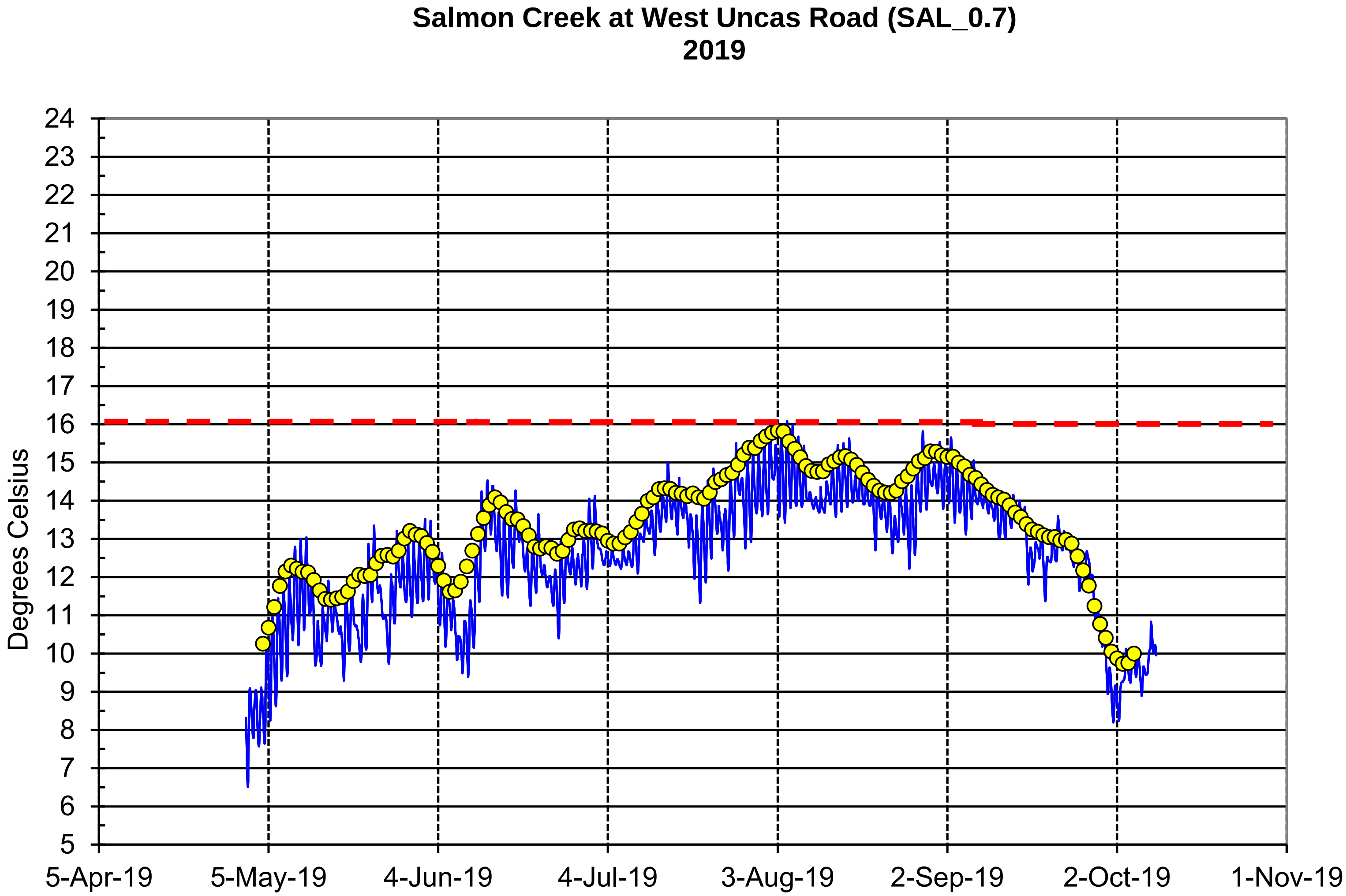


Figure C-9. Hourly temperature profile (blue line) with 7-day average daily maximum temperatures (7-DADMax) shown as yellow circles. Red dashed line represents the 7-DADMax criteria for salmonid spawning and rearing.

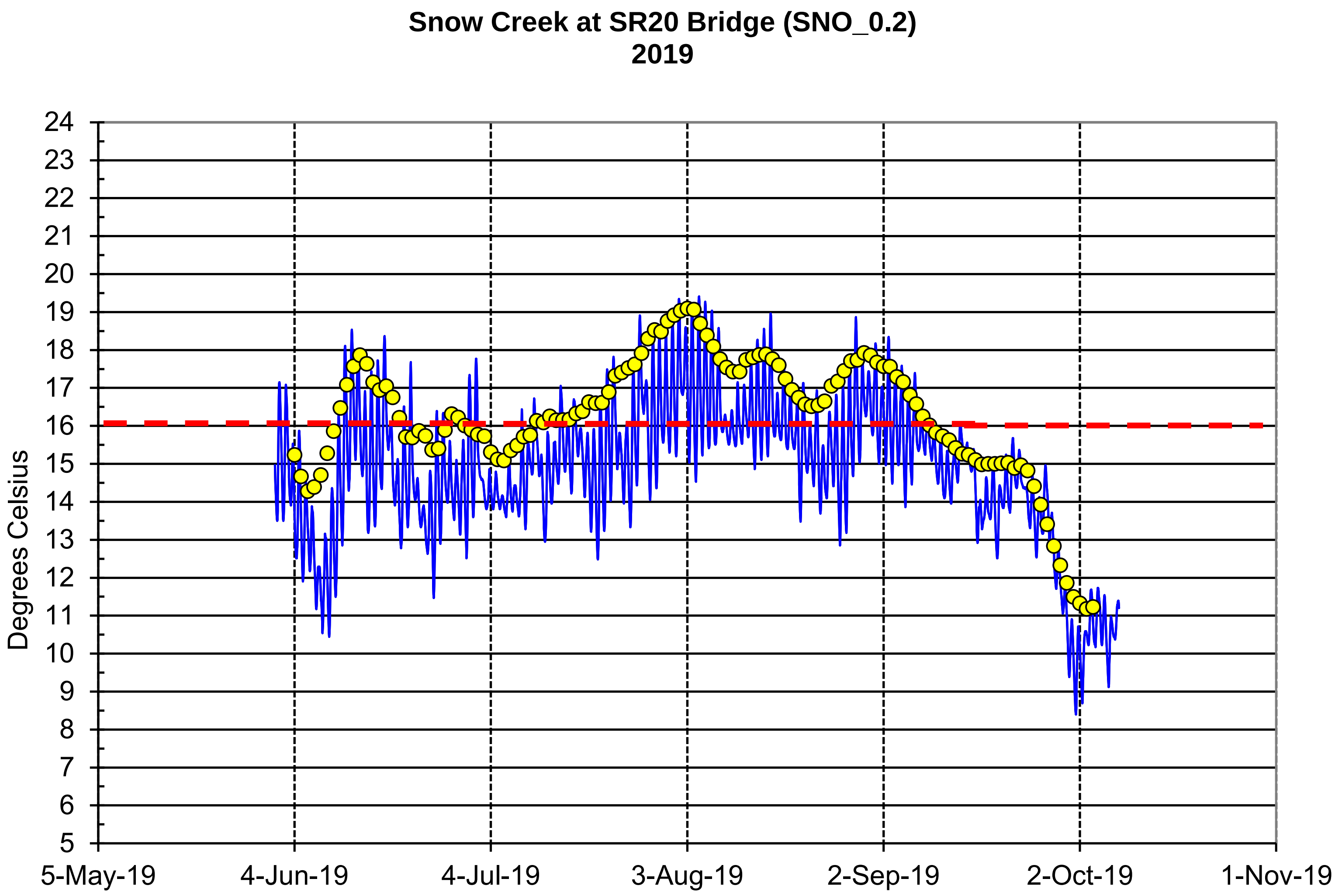


Figure C-10. Hourly temperature profile (blue line) with 7-day average daily maximum temperatures (7-DADMax) shown as yellow circles. Red dashed line represents the 7-DADMax criteria for salmonid spawning and rearing.

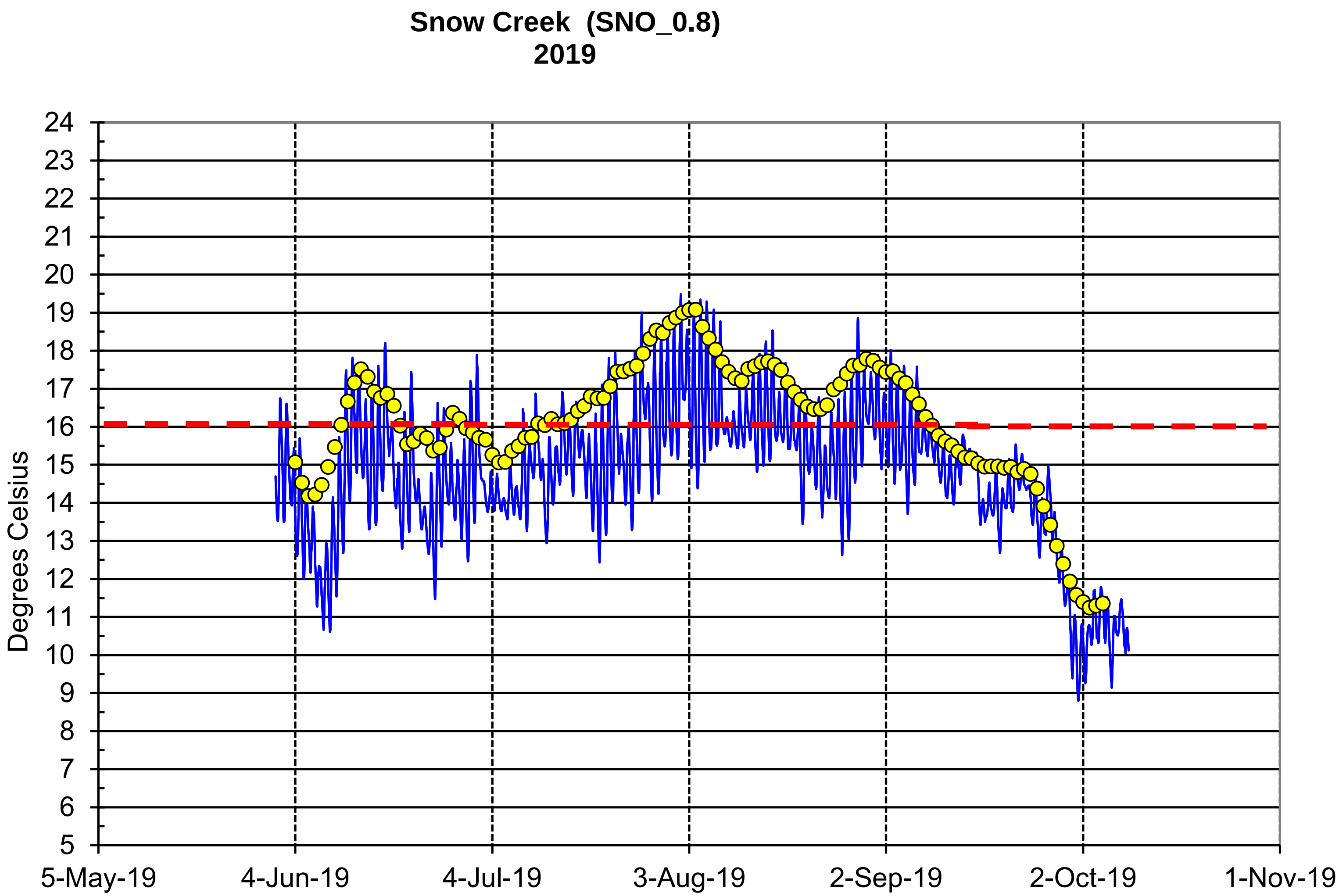


Figure C-11. Hourly temperature profile (blue line) with 7-day average daily maximum temperatures (7-DADMax) shown as yellow circles. Red dashed line represents the 7-DADMax criteria for salmonid spawning and rearing.

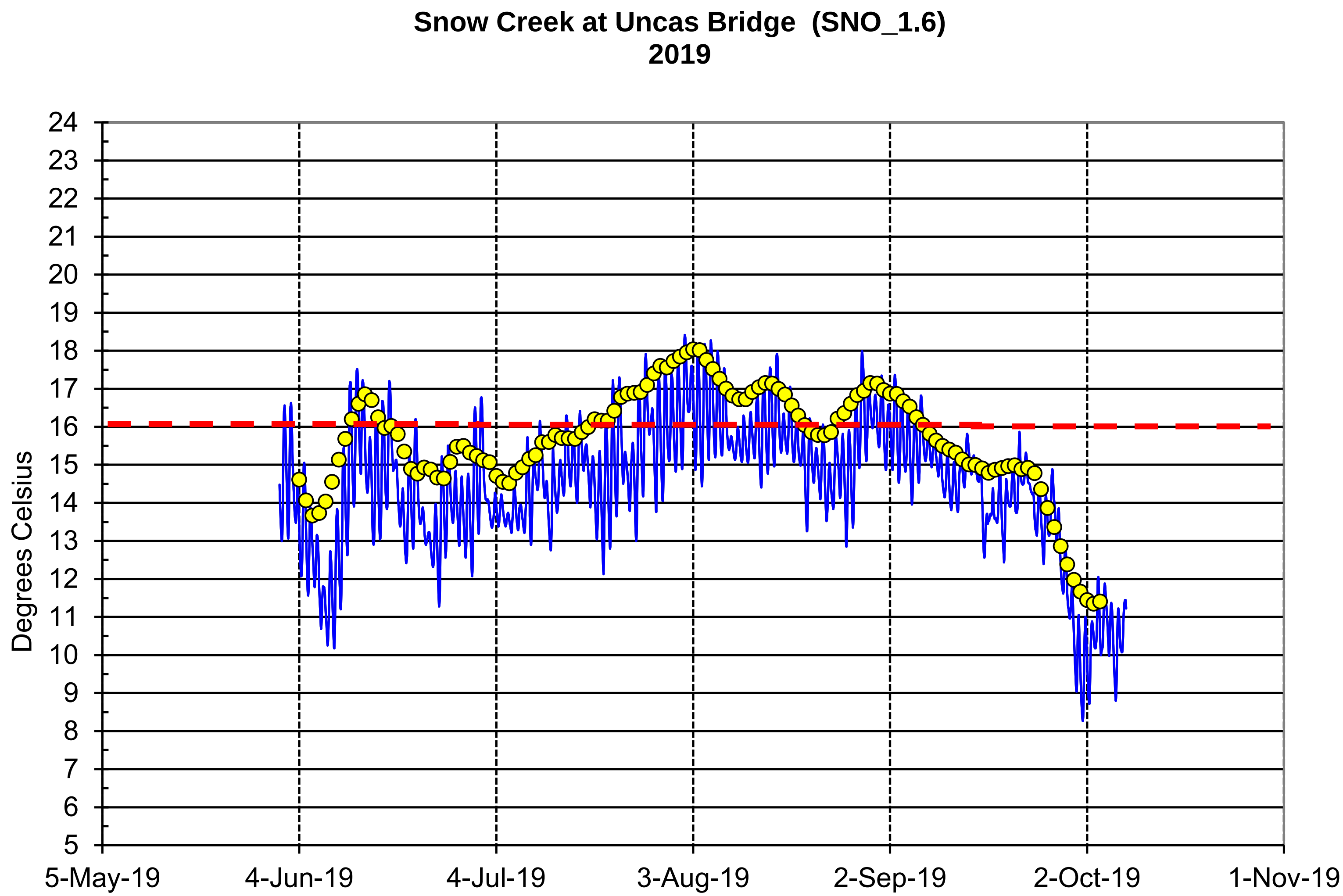


Figure C-12. Hourly temperature profile (blue line) with 7-day average daily maximum temperatures (7-DADMax) shown as yellow circles. Red dashed line represents the 7-DADMax criteria for salmonid spawning and rearing.

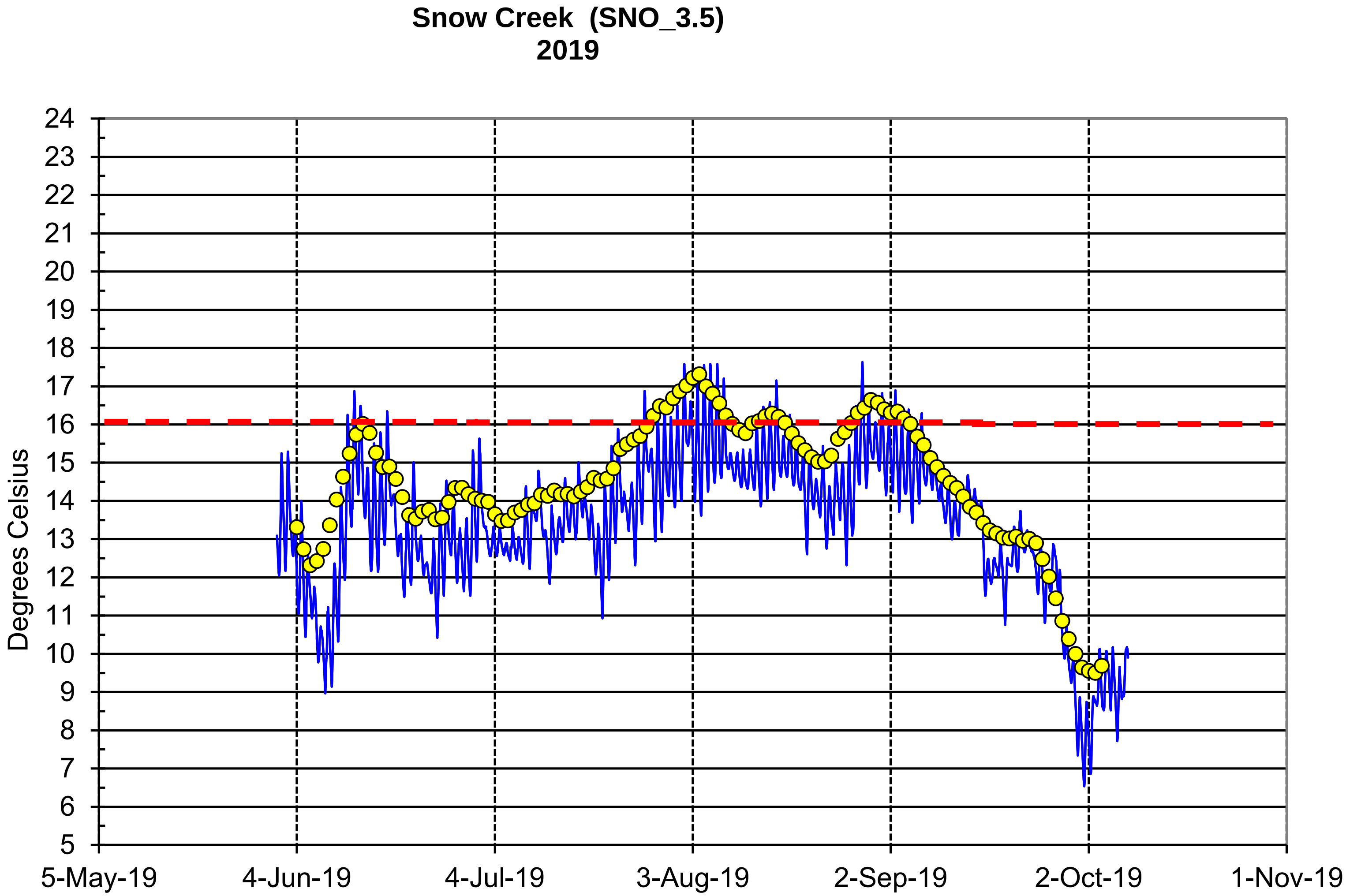


Figure C-13. Hourly temperature profile (blue line) with 7-day average daily maximum temperatures (7-DADMax) shown as yellow circles. Red dashed line represents the 7-DADMax criteria for salmonid spawning and rearing.

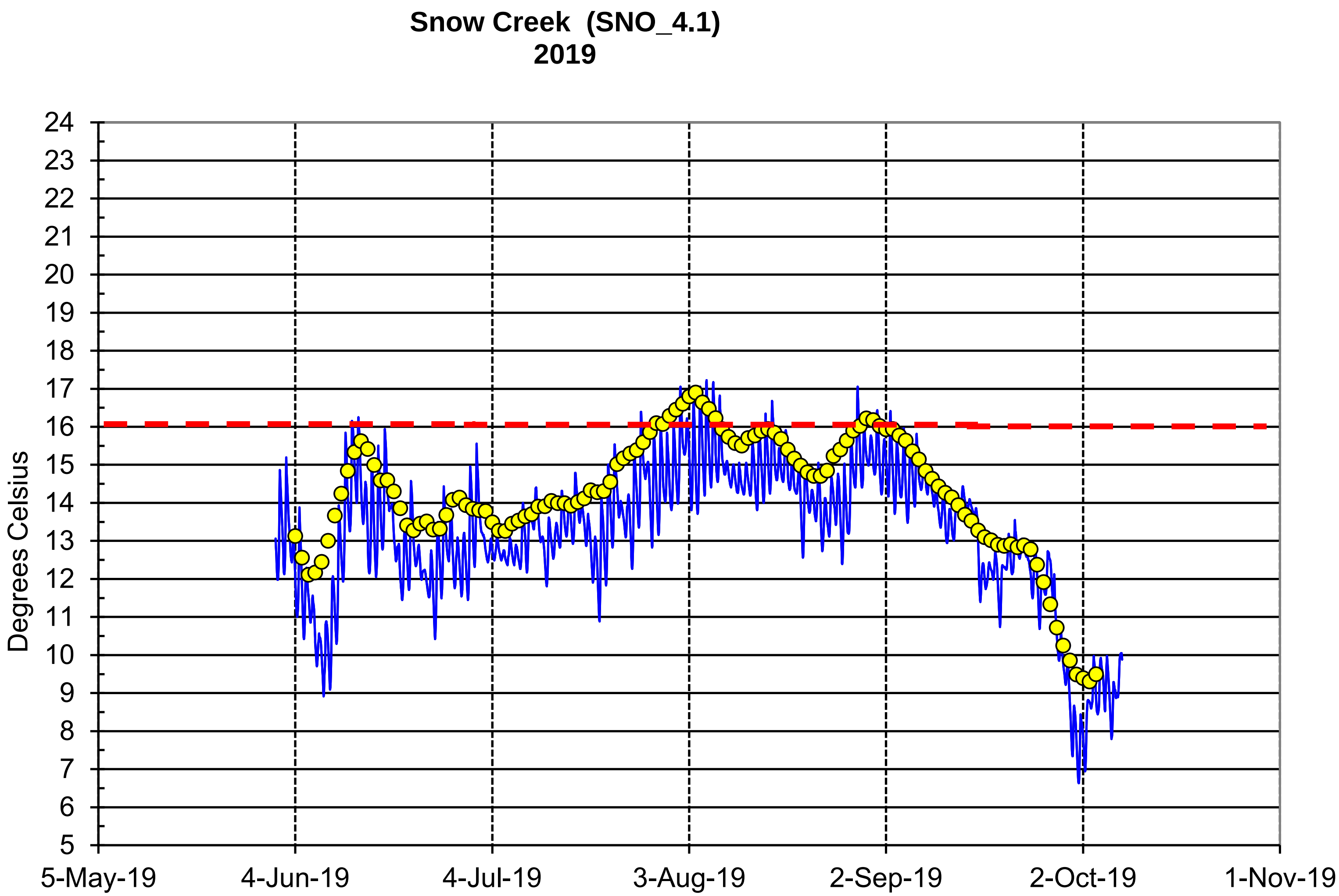


Figure C-14. Hourly temperature profile (blue line) with 7-day average daily maximum temperatures (7-DADMax) shown as yellow circles. Red dashed line represents the 7-DADMax criteria for salmonid spawning and rearing.

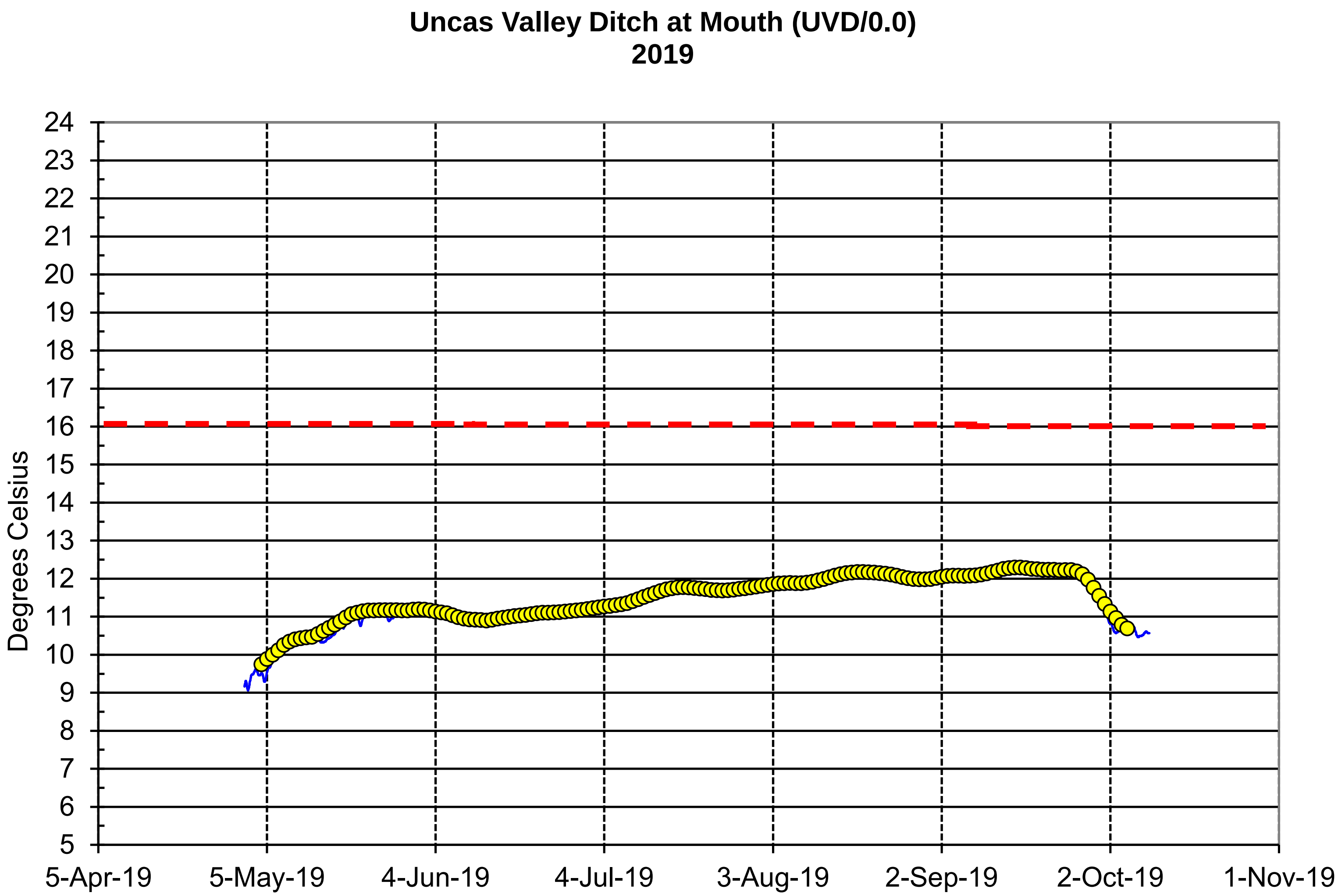
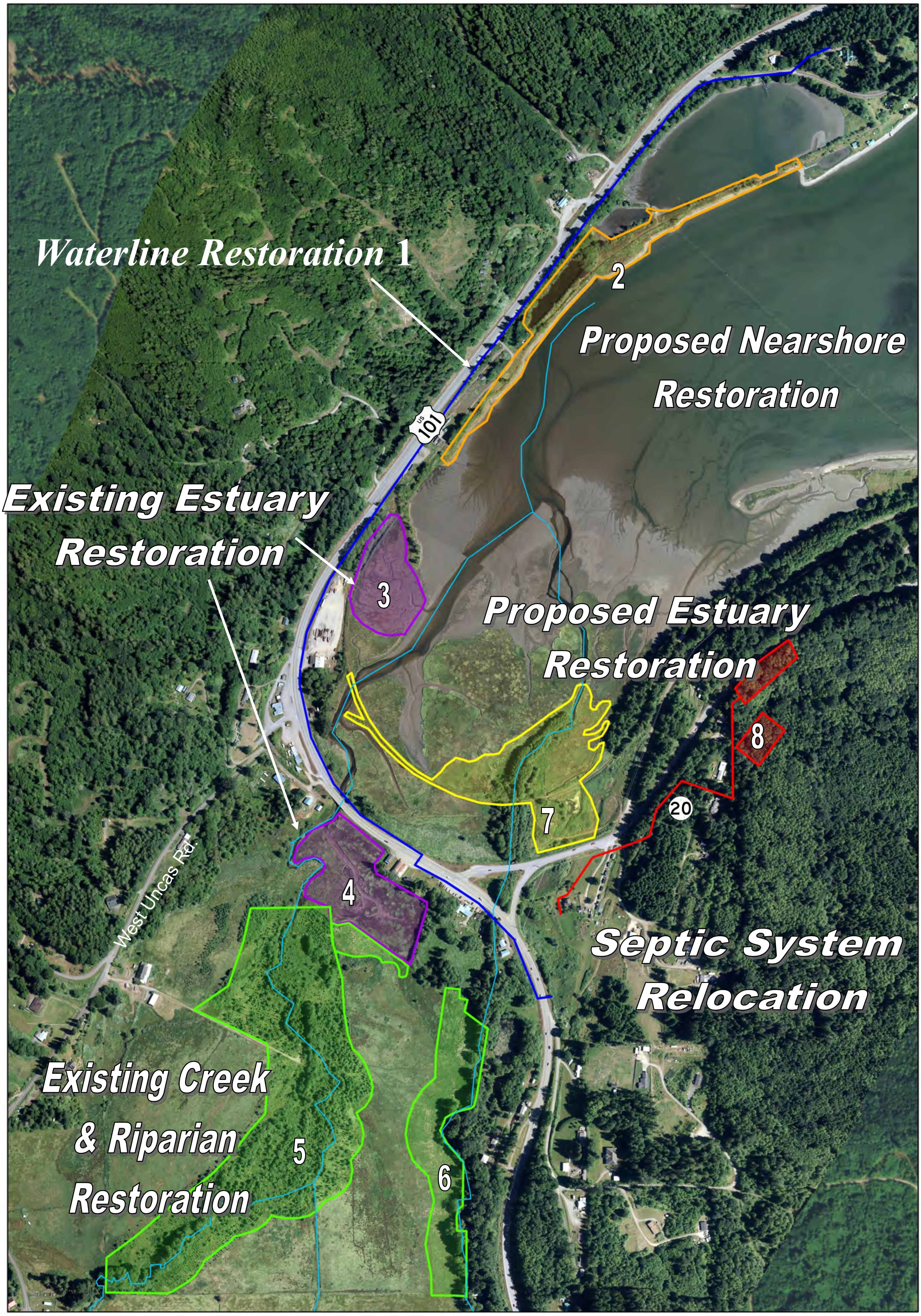


Figure C-15. Hourly temperature profile (blue line) with 7-day average daily maximum temperatures (7-DADMax) shown as yellow circles. Red dashed line represents the 7-DADMax criteria for salmonid spawning and rearing.

APPENDIX D

Restoration Projects



North Olympic Salmon Coalition multi-stage restoration project. See following pages for descriptions of individual projects corresponding to the numbers and colors above.

1. **Waterline Relocation**
   GOAL: Relocate private waterline from RR grade and trestles to clear the way for the habitat restoration project.
   ACTIONS: Relocate and upgrade the waterline. The new waterline will travel from the source, along the Highway 101, Gardiner Road and Cemetery Road right of ways before hooking back into the existing system.

2. **Maynard Nearshore Restoration**
   GOAL: Restore 1,800 feet of marine shoreline impacted by an abandoned RR grade to improve habitat conditions for salmon.
   ACTIONS: Removed portions of the RR grade, all shoreline armoring, a creosote railway trestle and a defunct tide gate. Three small creek mouths in the area were restored and reconnected to the bay. Old concrete bulkheads and cobbles that "paved" the beaches were removed and replaced with sands and gravels suitable for forage fish spawning and shellfish recruitment.

3. **North Site Estuary Restoration**
   GOAL: Return a former salt marsh that was filled with wood waste and industrial fill back to salt marsh to benefit juvenile salmon and birds. ACTIONS: In 2008 25,000 cubic yards (2,000 dump trucks!) of fill and wood waste were removed from the historic saltmarsh. Sawdust and veneer chips were disposed of in the marsh in the mid-1900s. Ground water seeping through the wood waste 'leached' compounds like sulfur and ammonia which created toxic conditions for aquatic life in an existing tidal channel adjacent to the wood waste pile.

4. **South Site Estuary Restoration**
   GOAL: Create healthy salt marsh habitat to replace the habitat lost by the construction of Highway 101 in order to increase juvenile salmon and waterfowl habitat.
   ACTIONS: In 2008, machines excavated soils down to saltmarsh elevations to connect the new marsh to Salmon Creek and Discovery Bay. Some of the excavated material was moved to an upland disposal site on the same property, and some was hauled off site.

5. **Salmon Creek Channel Restoration**
   GOAL: Repair a straightened channelized section of Salmon Creek important for Summer Chum spawning.
   ACTIONS: In 2003 and 2004, a new, re-meandered channel 2,500 feet long was constructed by the Jefferson County Conservation District. Logjams were installed and native trees and shrubs were planted along the bank by NOSC. The site was currently enrolled in the Conservation District's CREP program planting a 180 foot riparian buffer along a 3,500 foot length of stream. This 29 acre buffer is now home to over 18,000 trees.

6. **Snow Creek Riparian Restoration**
   GOAL: Increase stream health and riparian health in the lower reaches of Snow Creek.
   ACTIONS: Remove invasive species. Plant native species and maintain the planting. NOSC's WCC crew prepped the site by removing a 15' wall of blackberry and scalping reed canary grass. School groups and community volunteers helped plant over 5,500 native trees and shrubs at the site which are maintained by the WCC crew.

7. **Snow Creek Estuary Restoration**
   GOAL: Improve function of the Snow Creek estuary and salt marsh and their connection to Snow Creek. ACTIONS: Remove RR grade fill and 3 RR trestles. Remove berms, fill and septic field along the banks of Snow Creek. These fills have changed the hydrology of the area so that Snow Creek has no connection to adjacent salt marsh and have disrupted important tidal processes that compromise the marsh.

8. **Septic System Relocation**
   GOAL: Relocate the drainfield near Snow Creek and wetlands. ACTION: The septic drainfield for the Valley View Motel is located on land along Snow Creek and Discovery Bay that is slated for habitat restoration. The landowner is Jefferson Land Trust and the septic field sits in an easement on the property. Significant effort and cooperation from the Motel owner have resulted in NOSC being able to build a new septic system with the drainfield located at an upland site for the Motel.

9. **Proposed Olympic Discovery Trail Route (not shown on map)**
   GOAL: Install an important link in the Olympic Discovery Trail which will increase recreational and public access opportunities around Discovery Bay.
   ACTIONS: Construct a multi-use trail in the Department of Transportation right-of-way and on Washington Department of Fish and Wildlife property. This project is led by Jefferson County Public Works and Peninsula Trails Coalition.

Update July 18, 2007
May 5, 2005

Salmon Creek
WDFW Project
SA/0.0-0.67

Watershed: Discovery Bay

Waterbody: Salmon Creek

Station: SA/0.0-0.67

BMP's: Channel restoration, remeandering, tree planting, and LWD placement.

Date installed: 2003/2004/2006

Landowner: WDFW

Installed by: WDFW

Assisted by: Jefferson County Conservation District, North Olympic Salmon Coalition, Washington Conservation Corps (tree planting), Farm Service Agency

Problem(s): This channelized stream reach lacked fish habitat including channel diversity/structure and LWD. Additionally, due to a deficiency of riparian cover, water temperatures exceeded state standards at times.

Solutions: A new, remeandered channel of 2,500 feet was constructed in 2003 and 2004. LWD was installed at that time and a variety of trees and shrubs were planted along both banks by the North Olympic Salmon Coalition.

In the spring of 2006, a 180-foot buffer was installed through the Conservation Reserve Enhanced Program and18,000 trees and shrubs where planted along 3,500 feet of stream.

In 2006, a 180-ft. wide riparian buffer was planted with 18,000 trees and shrubs using a special Hygro-tiller.

Salmon Creek— WDFW **SA/0.0-0.67** **Spring 2006**

June 2009

Salmon Creek
Livestock Bridge
SA/0.7

Watershed: Salmon Creek

Waterbody: Discovery Bay

Station: SA/0.7

BMP's: Livestock bridge, fencing, livestock water system

Date installed: August 2008

Installed by: Jefferson Co. Conservation District

Problem(s): .Livestock had access to 800 feet of salmon spawning/rearing habitat, thereby impacting water quality.

Solutions: Constructed a bridge for livestock to cross instead of walking across the creek. Constructed a livestock drinking water facility. Installed 614 feet of fence to fence off stream crossing and replace failing fence. Planning, design, and construction funding came from SRFB; technical assistance funding came from the Washington Conservation Commission.

Salmon Cr. Livestock Bridge

Livestock had access to 800 feet of Salmon Creek for crossing. Jefferson Co. Conservation District worked ith the landowner to obtain funding for a flatcar bridge crossing, fencing and water system. Funding from Salmon Recovery Funding Board, Conservation Commission and Dept. of Ecology.
Project Management: Jefferson Co. Conservation District

Wally Bowman Bridge on West Uncas Road was completed just in time for the 2019 Summer Chum run on Salmon Creek . Prior to this, it was necessary to place sand bags at the drop below the culvert to allow the Chum to pass upstream.

April 29, 2009

Salmon Creek
SRFB Riparian Restoration
SA/0.8-0.9

Watershed: Discovery Bay

Waterbody: Salmon Creek

Station: SA/0.8-0.9

BMP's: Black berry removal and tree planting to restore and enhance stream buffer.

Date installed: Spring 2009

Installed by: Jefferson County Conservation District

Assisted by: SRFB funding.

Problem(s): This portion of stream reach had dense black berry brush along the bank and very few trees on one side of the stream.

Solutions: Establish a new riparian buffer by removing the black berry brush and planting the site with conifers, hardwoods, and native brush species. 350 trees and shrubs were planted on 0.7 acres along one side of Salmon Creek.

SRFB funded restoration project. This project consisted of planting 0.7 acres with 350 native trees and shrubs. The buffer is 300 feet long on the inside bend of Salmon Creek. and averages 100 feet wide.

<u>Upper Right</u>: Planted seedlings along Salmon Creek. Prior to planting, this area was dense blackberry brush, which was mulched before planting. <u>Upper Left</u>: site prep sprayed planting spots prior to planting. <u>Lower Left</u>: Pasture prior to planting. <u>Inset</u>: overview map.

Salmon Creek -Private property **SA/0.8-0.9** **Spring 2009**

June 18, 2003

Houck Creek Project

Watershed: Discovery Bay / Salmon Creek

Waterbody: Houck Creek

Station: HO/0.0-0.02

BMP's: Bank stabilization and erosion control plantings

Date installed: August 2002

Managed by: Jefferson County Conservation District

Funded by: North Olympic Salmon Coalition (NOSC)

Engineered by: 4 Seasons Engineering

Installed by: Rock and culvert by Seton Construction Inc.; willow and grass planting by NOSC volunteers

Problem(s): Prior to 1960 Houck Creek and East Houck Creek entered Salmon Creek separately. In the 1960's these two tributaries were joined together and routed down a steep slope before joining Salmon Creek. Over the years erosion carved a deep gully as tens of thousands of cubic yards of soil washed into Salmon Creek. This erosion has resulted in the sedimentation of the historic spawning grounds of Salmon Creek's summer chum salmon and has probably contributed to its population decrease.

Solution(s): One thousand cubic yards of rock were placed in the eroded gully and a half-round culvert was placed at the top of the bank to prevent further head-cutting by Houck Creek. Check dams were constructed between the toe of the rock fill and Salmon Creek and willow stakes and grass were planted on exposed slopes.

Results: Prior to the project, turbidity often increased 100 to 200 percent as Houck Creek flowed down the eroding bank. After completion of the project, the first measurements taken on Jan. 2, 2003 showed an increase of only about 40 percent from top to bottom. And on the following three monitoring dates (January 8 and 17, and March 14, 2003), turbidity actually decreased slightly (Figure). For more information about this project and turbidity in Houck Creek see page .

Houck Creek Stabilization Project

Back in the 1960's, two small drainages were re-routed down a steep slope. At that point, winter flows of 9.3 cfs were later recorded. Over the years a deep gully eroded, sending large amounts of sediment into Salmon Creek. In an effort to stabilize the gully and reduce sediment input to Salmon Creek summer chum spawning grounds, 1,000 cubic yards of rock were placed in the gully. A half-round culvert section was also placed at the top of the fill to move the stream flow away from the head-cut.

Project Management: Jefferson Co. Conservation Dist.
Funding: North Olympic Salmon Coalition
Engineering: 4 Seasons Engineering
Construction: Seton Construction Inc.

Houck Creek site prior to reconstruction.

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High flows - view of Houck culvert.

Houck Creek Stabilization Project

After the rock was placed in the gully, North Olympic Salmon Coalition (NOSC) volunteers constructed several rock check dams between the toe of the fill and Salmon Creek. Willow stakes and grass seed were planted on exposed slopes not covered by rock.

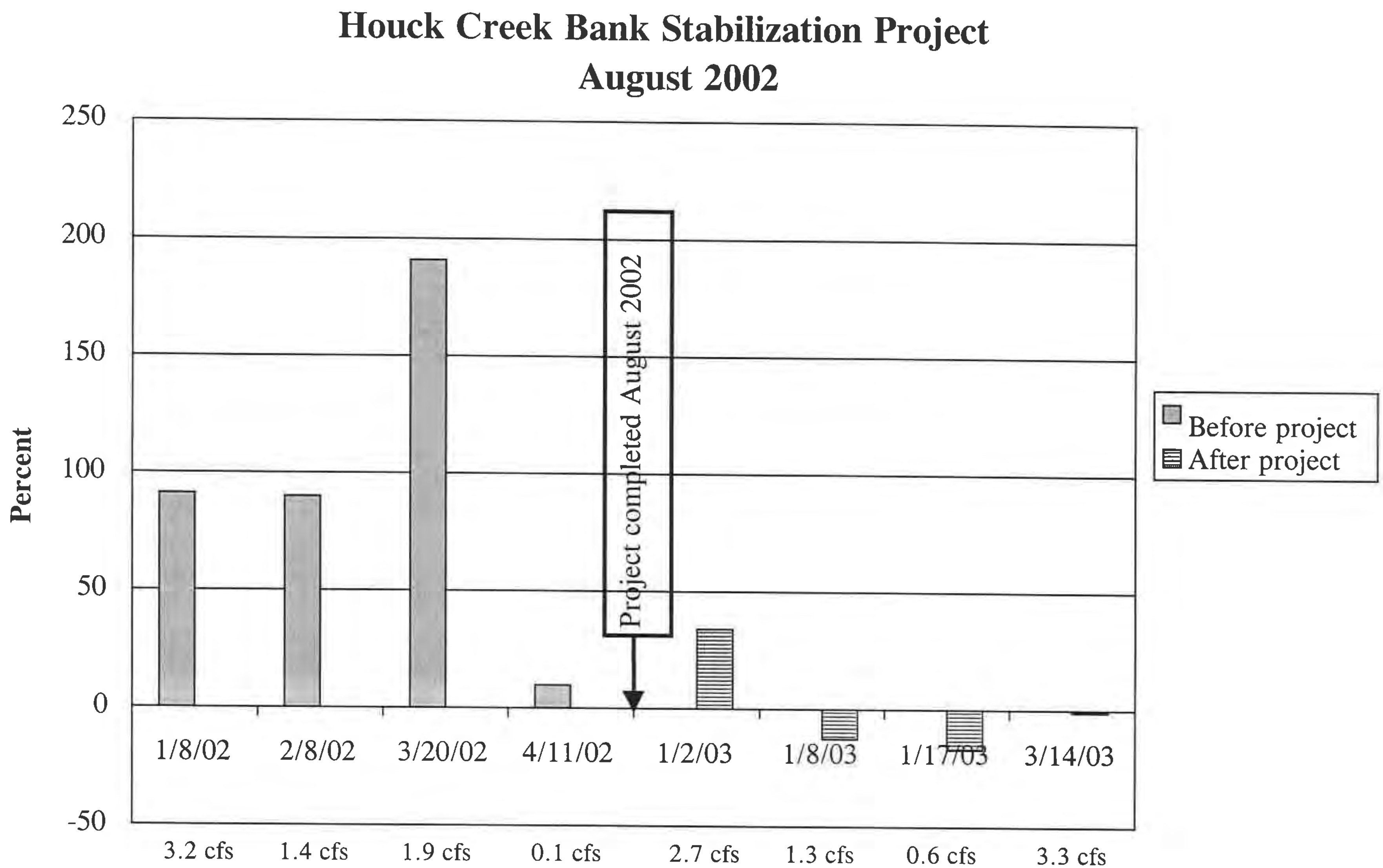

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Figure . Percent increase or decrease in turbidity from upstream of the project to downstream of project. Stream flow (cfs) at time of sampling is shown at bottom. Tss Turb % inc. cht 6/16/03

Uncas Valley Ditch’s 500 ft.-reach UVD/0.1-0.2 on Washington Fish and Wildlife property was planted with a variety of trees and shrubs in 2018 by North Olympic Salmon Coalition’s Washington Conservation Corps Crew.

Uncas Valley Ditch 500 ft. reach UVD/0.2-0.3 was fenced and planted with the shrub Spirea in 2018.

November 4, 2011

Uncas Valley Ditch
UVD/0.3-0.6

Watershed: Discovery Bay

Waterbody: Uncas Valley Ditch (tributary to Salmon Creek at RM 0.4)

Station: UVD/0.3-0.6

BMP's: Fencing and planting.

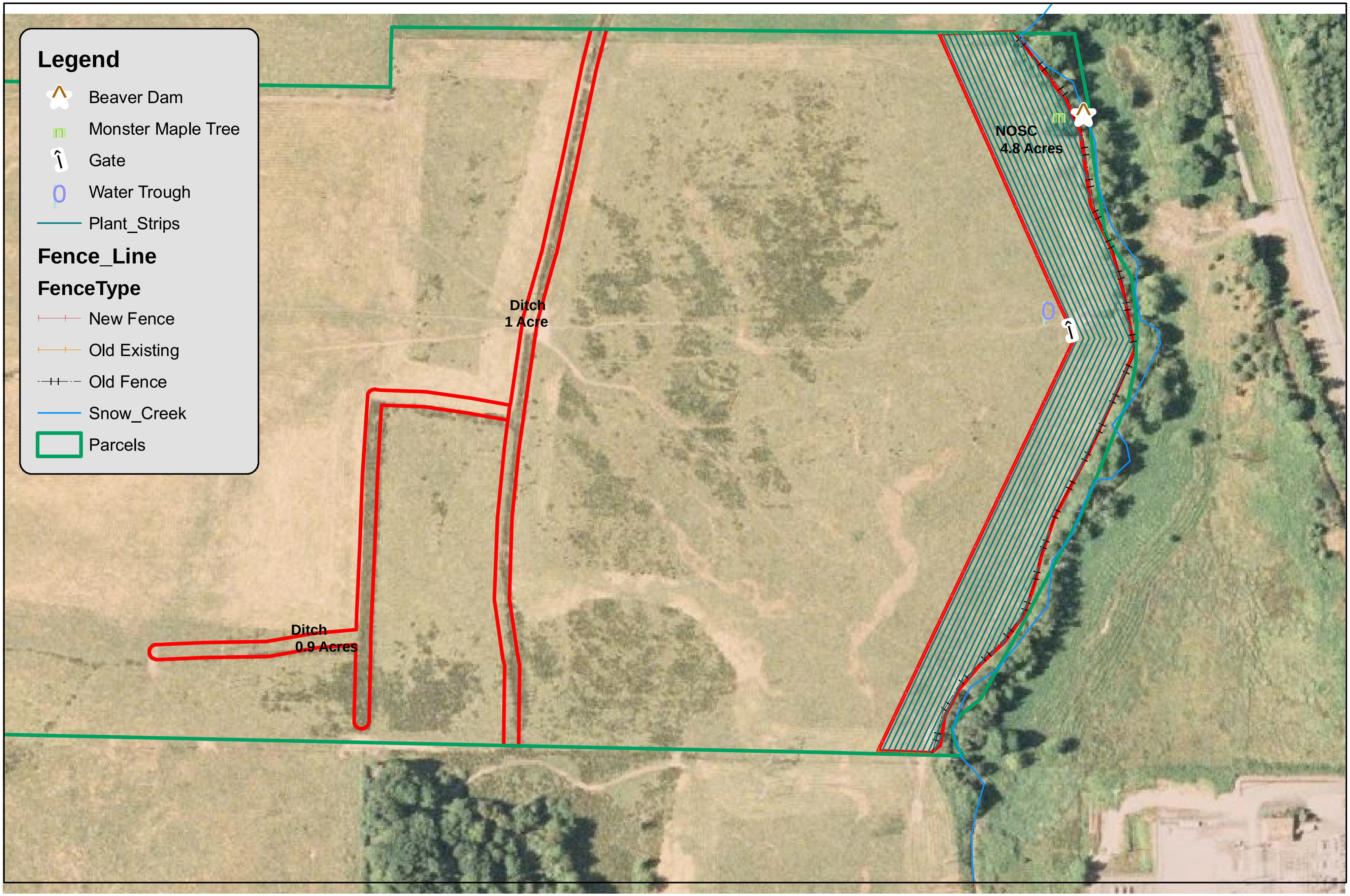
Date installed: Fencing – Fall 2007; planting March 2009.

Installed by: Jefferson County Conservation District

Assisted by: SRFB funding.

Problem(s): Cattle had access to Uncas Valley Ditch thereby causing erosion and manure pollution.

Solutions: Fencing was installed on both sides of 1500 ft. of Uncas Valley Ditch and on both sides of 600 ft. long ditch entering Uncas Valley Ditch. Riparian buffers were planted with red osher dogwood, vine maple, and ninebark.



3

Jefferson County Conservation District
PORT HADLOCK, WASHINGTON, U.S.A.

Ditch Buffer

D-18

350 175 0 350 Feet

November 4, 2011

Uncas Valley Ditch
UVD/0.6-0.9

Watershed: Discovery Bay

Waterbody: Uncas Valley Ditch (tributary to Salmon Creek at RM 0.4)

Station: UVD/0.6-0.9

BMP's: Ditch relocation, fencing, tree planting, wetland protection, culvert installation.

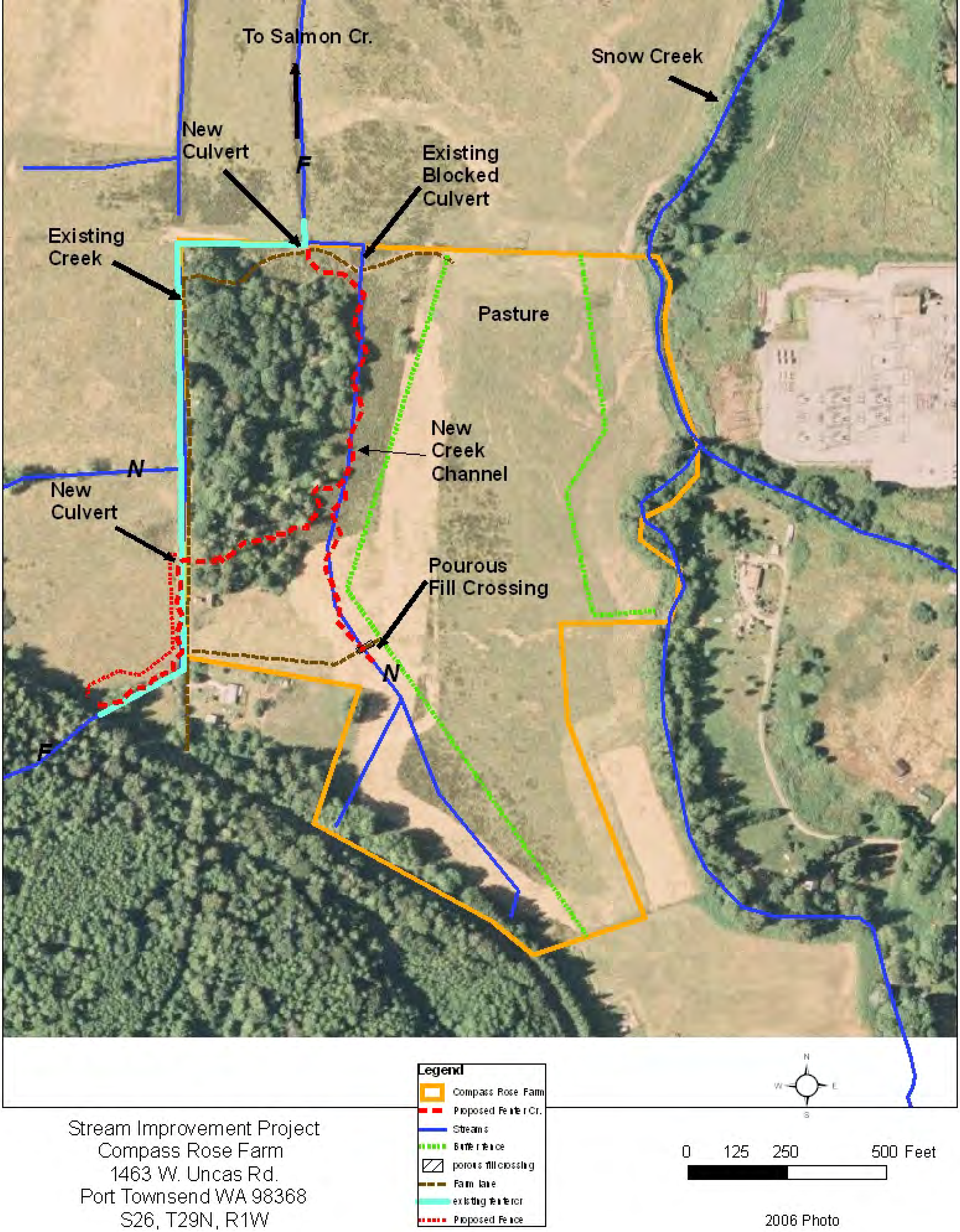
Date installed: 2009

Installed by: Jefferson County Conservation District

Assisted by: SRFB funding.

Problem(s): Cattle had access to Uncas Valley Ditch thereby causing erosion and manure pollution. Cattle also had access to a wetland.

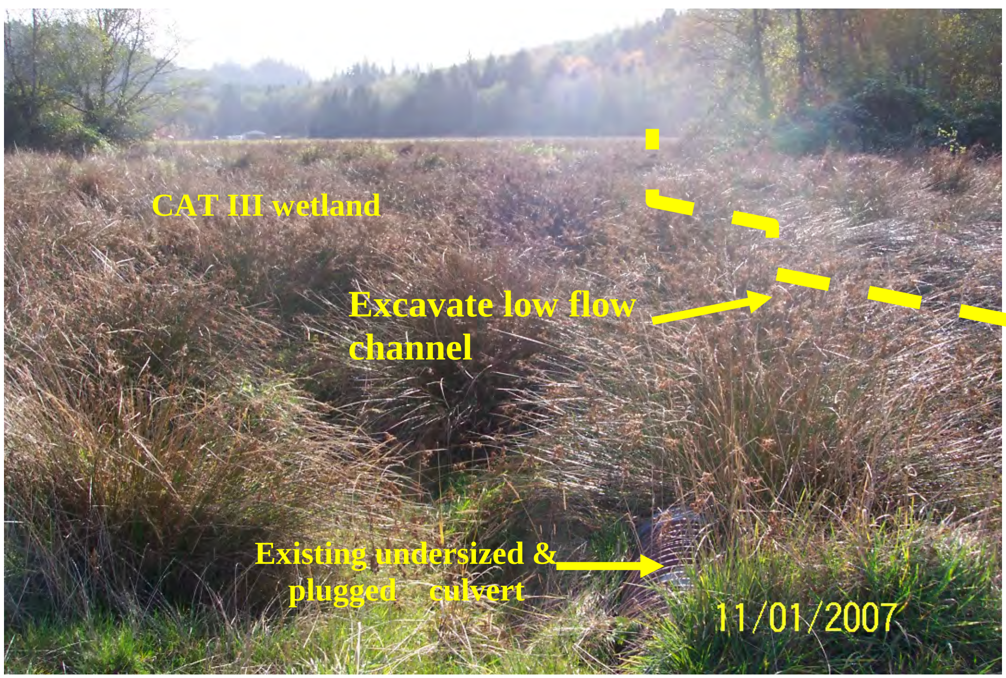
Solutions: The ditch was relocated; some of it was put back into its original, forested stream bed. Fencing along 3100 ft. of ditch and wetland was installed. Trees and shrubs were planted in the riparian buffer. Two culverts were installed. A porous wetland crossing was installed for farm equipment to cross the wetland.


To Salmon Cr.
Snow Creek
New Culvert
F
Existing Blocked Culvert
Existing Creek
Pasture
New Creek Channel
N
New Culvert
Pourous Fill Crossing
N
F
Legend
Compass Rose Farm
Proposed Fence Cr.
Streams
Buffer fence
porous fill crossing
Farm lane
existing fence
Proposed Fence
N
W
E
S
0 125 250 500 Feet
2006 Photo
Stream Improvement Project
Compass Rose Farm
1463 W. Uncas Rd.
Port Townsend WA 98368
S26, T29N, R1W

Existing stream/ditch (fenced 2008) to be improved w/LWD through pasture—riparian plantings done 2009

Existing stream/ditch—view upstream from new culvert site where stream flows into new channel (red). This reach also will be improved.

Fence and improve existing channel

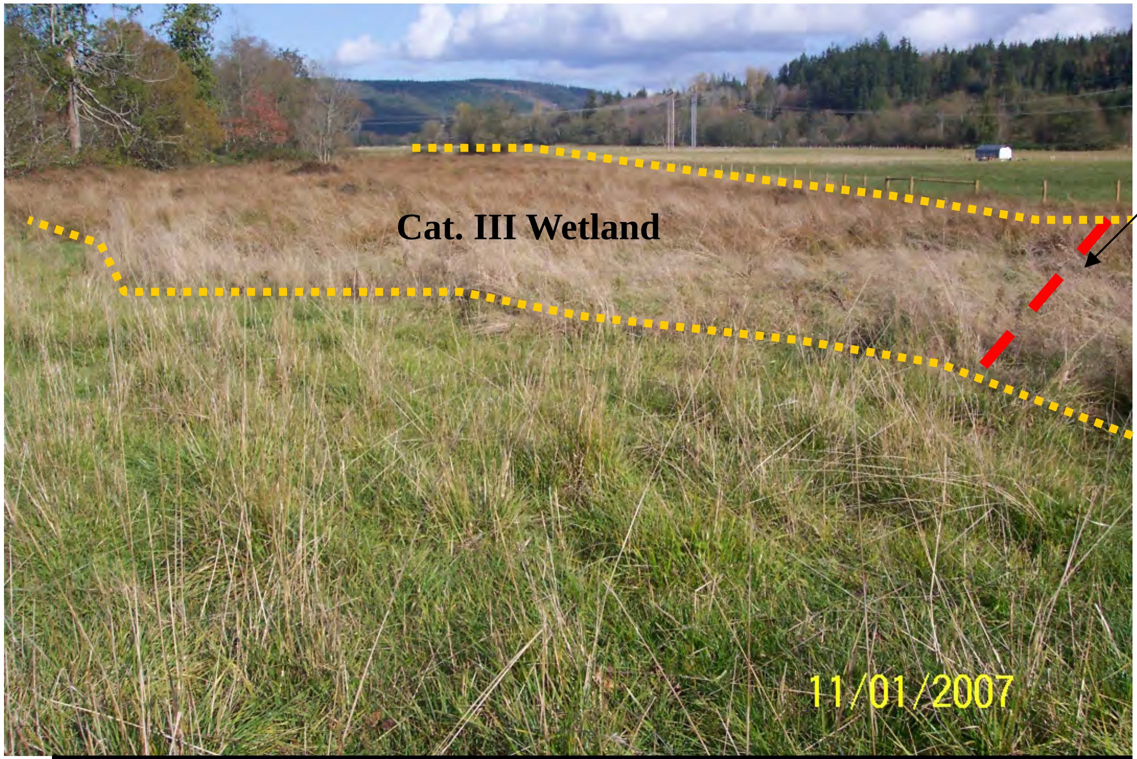


Compass Rose Farm
Pioneers in Conservation 2009 Project

- **Improve ditched stream reach**
- **Re-locate ditched stream to improved old channel location through forest.**
- **Install 2 culverts in existing farm lane.**
- **Fill in abandoned ditch**
- **Excavate low flow channel through wetland**
- **Construct porous fill wetland crossing**
-

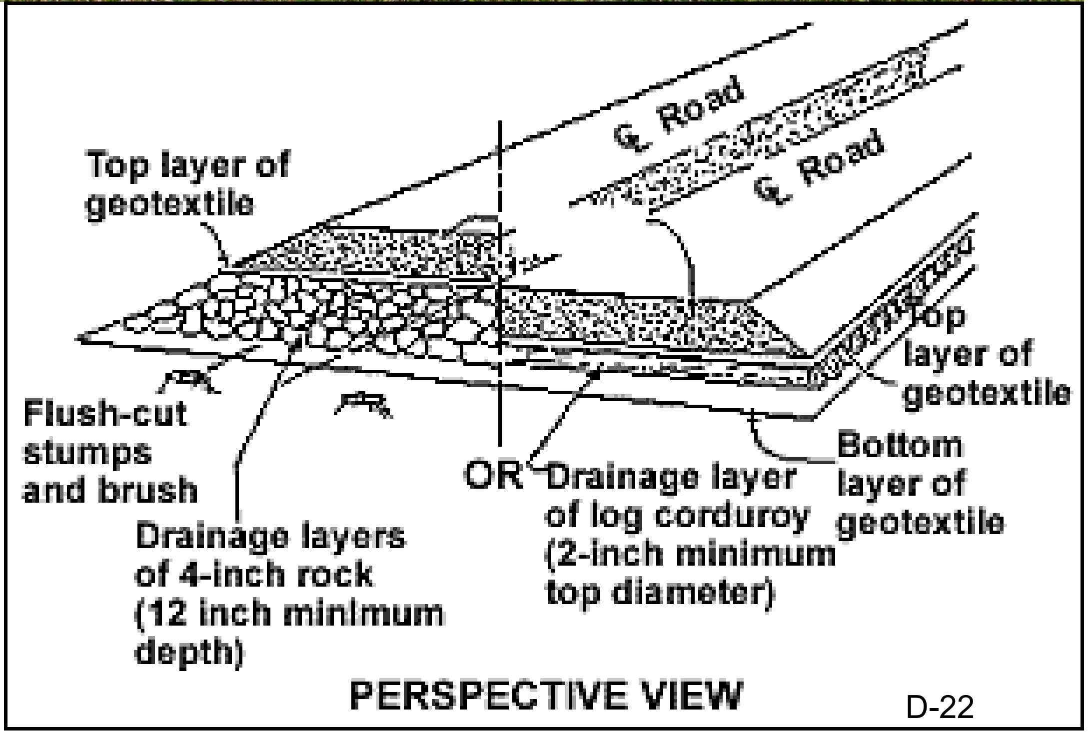
Project components completed to date -

- **Plant riparian vegetation in newly fenced reach (done 2009).**
- **Plant Snow Cr. 150’ buffer 4 ac (SRFB funds) (done 2009)**
-



"Porous Fill" livestock and farm equipment crossing.

Previous landowner grazed and mowed the Cat. III wetland. New landowners have fenced wetland and restricted wetland crossing for farm equipment to one location (red dash). To reduce impact on wetland crossing area a porous fill (see conceptual diagram below and engineered plans) has been designed for a lane across wetland. This lane will allow movement of water through the fill and livestock/farm equipment to cross with minimal impact.



June 16, 1997

LOWER SNOW CREEK

Watershed: Discovery Bay

Waterbody: Snow Creek

Station: SN/0.0-0.8

BMPs: Channel restoration, tree planting, large woody debris (LWD) placement

Date installed: 1995, 1996

Landowner: Phil Zerr, Carl Schmidt, Elsie Andrews, Hargrave Garrison, Wally Bowman, Cliff Larrance

Installed by: Zerr Logging, Jobs for the Environment

Assisted by: Washington Dept. of Fish and Wildlife (WDFW)

Problem(s): Channel aggradation and encroachment by willows has caused flooding to occur every year for the past several years. Pools had filled in and LWD was lacking. An old beaver dam downstream of the trestle (RM 0.1) apparently blocked summer chum from coming upstream.

Solution(s): About 2850 ft. of the stream bed was lowered 2-3 ft. from the WDFW weir (RM 0.8) to a point 1220 ft. downstream of the Rt. 101 bridge. The channel was widened in the lower 1600 ft. of the stream section. Pools were dug and the streambanks were planted with trees and shrubs.

Result(s): No flooding has occurred in the project area since the channel restoration was completed, even during the major storm event of January 1, 1997 (>430 cfs). In 1996 Snow Creek had one of the largest chum runs in recent years. Fish made it up to the WDFW weir (RM 0.8) where they were caught and transported farther upstream.


Downstream view from SR 20 bridge of widened stream channel


Downstream view from SR 20 bridge showing planted trees


Downstream view from above SR 20 bridge


Large woody debris provides cover for fish

Snow Creek SN/0.0-0.8 June 1997

May 8, 2009

Snow Creek
SN/0.5-1.0

Watershed: Discovery Bay

Waterbody: Snow Creek

Station: SN/0.5-1.0

BMP's: Riparian fencing, solar powered stock watering trough. Establishment of riparian buffer.

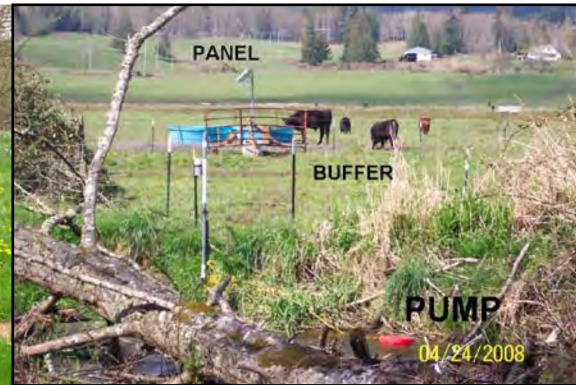
Date installed: 2008, fencing, water trough; 2009, spring site preparation and riparian planting.

Installed by: Jefferson County Conservation District.

Assisted by: Salmon Recovery Funding Board.

Problem(s): The stream channel lacked riparian cover. Live stock had access to stream channel. Water temperatures exceeded the state standard.

Solutions: Riparian fencing and a solar powered water trough were installed. In the spring of 2009 a 4.8 acre riparian buffer, averaging 160 feet wide, was planted with 2125 native trees and shrubs.



SRFB funded restoration project.
This project consisted of installing a Solar powered livestock watering facility, fencing the buffer to exclude livestock from the restoration area, and planting 4.8 acres with 2125 native trees and shrubs. This buffer is 1600 feet long and averages 160 feet wide.

Upper left: Planted seedlings along Snow Creek. Upper Right: Blackberry brush mulched along stream prior to planting. Lower Left: Site prep sprayed planting rows. Upper Inset: Installed livestock watering facility. Lower Inset: overview map.

Snow Creek-Private property **SN/0.5-1.0** **Spring 2009**

July 28,1999

SNOW CREEK
Brown / Andrews

Watershed: Discovery Bay

Waterbody: Snow Creek

Station: SN/1.0-1.4

BMPs: Fencing, livestock watering access

Date installed: Spring 1998

Landowner: George Brown / Elsie Andrews

Installed by: Jobs for the Environment

Assisted by:

Problem(s): Livestock had access to 2000 feet of stream.

Solution(s): Fencing was installed along 2000 feet of one side of the stream and along about 40 feet of the other side of the stream. One livestock drinking access was installed.

Result(s): In 1994, there was a substantial downstream increase in fecal coliform concentration from station SN/1.6 (46 FC/100 mL) to station SN/0.2 (469 FC/100 mL). In 1998, after the fencing of 2000 feet of stream between these stations (RM 1.0-1.4), this increase was considerably less (24 FC/100 mL to 86 FC/100 mL). Average fecal coliform loading from Snow Creek in 1998 was about half what it was in 1994, decreasing from 58 billion/day to 27 billion/day.

July 11, 2007

Snow Creek
WDFW Project
SN/0.9-1.2

Watershed: Discovery Bay

Waterbody: Snow Creek

Station: SN/0.9-1.2

BMPs: Tree Planting.

Date installed: 2006

Landowner: Washington Department of Fish and Wildlife (WDFW)

Installed by: Jefferson County Conservation District, North Olympic Salmon Coalition

Assisted by: Farm Service Agency, WA Conservation Commission, and WDFW

Problem(s): The stream channel lacked riparian cover. Water temperatures exceeded the state standard.

Solutions: Under the Conservation Reserve Enhanced Program, a 180-ft. wide, 1,690-ft. long riparian buffer covering 7.8 acres was planted with 4,300 trees and shrubs in the spring of 2006.

In 2006, a 180-ft. wide riparian buffer was
planted with 4,300 trees and shrubs.

Snow Creek WDFW Property SN/0.9-1.2 Spring 20006

July 27, 2007

Snow Creek and Salmon Creek
BMP Implementation

Watershed: Discovery Bay

Waterbody: Snow Creek and Salmon Creek

Station: Various

BMPs: Fencing and Livestock Water

Date installed: June 2007

Installed by: JCCD & Jefferson Land Trust (JLT)

Problem(s): Livestock had access to streams for drinking and minimal riparian buffers.

Solutions: Jefferson Land Trust worked with landowners to establish conservation easements on 3 properties that protected land for agriculture with provisions for wider riparian buffers along Snow Creek and ditch fencing. Livestock access in this area is one of several sources of bacterial pollution. JCCD, using WS Conservation Commission funding for technical assistance, assisted JLT with planning, and used JLT funding and WRIA 17/Ecology funding to implement water quality best management practices including:

- 10,250 lineal feet of stream, wetland and ditch fencing.
- 2 - livestock crossings (culverts) installed.
- 1- gravity feed livestock watering system installed to replace existing livestock stream access

JCCD also installed a demonstration solar water pump to provide livestock with drinking water. The demonstration was very successful and resulted in the water access point being fenced off. A permanent system will be installed when funding is available.

Snow Creek Riparian Fencing

Uncas Valley ditch fencing and livestock crossing

Gravity water supply

Solar pump water supply system

Jefferson Land Trust worked with landowners to establish conservation easements on 3 properties that protected land for agriculture with provisions for wider riparian buffers along Snow Creek and ditch fencing. Livestock access in this area is one of several sources of bacterial pollution. JCCD, using WS Conservation Commission funding for technical assistance, assisted JLT with planning, and used JLT funding and WRIA 17/Ecology funding to implement water quality best management practices including:

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Snow Creek and Salmon Creek **BMP Implementation** **Summer 2007**

June 2009

Snow Creek
Fencing & Solar Pump System
SN/1.0

Watershed: Snow Cr.

Waterbody: Snow Cr.

Station: SN 1.0

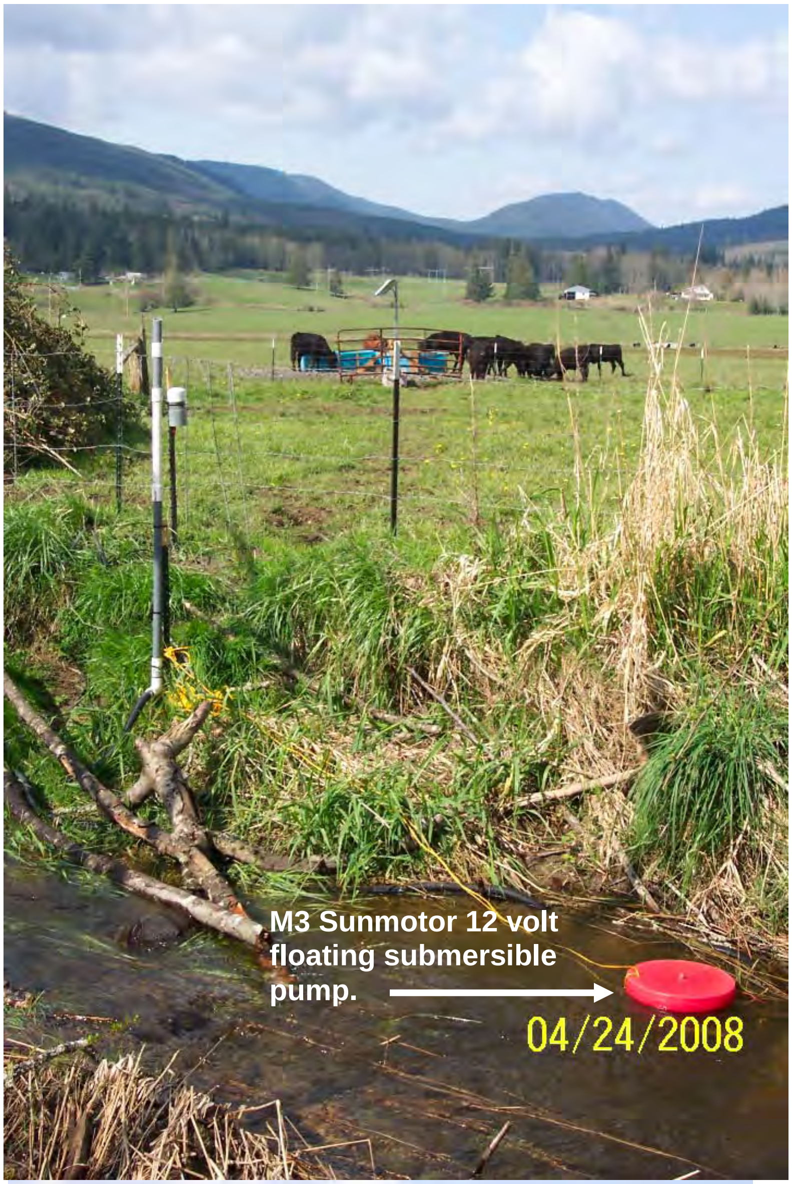
BMP's: Stream fencing and solar water system.

Date installed: Sept. 2007

Installed by: Jefferson Co. Conservation District

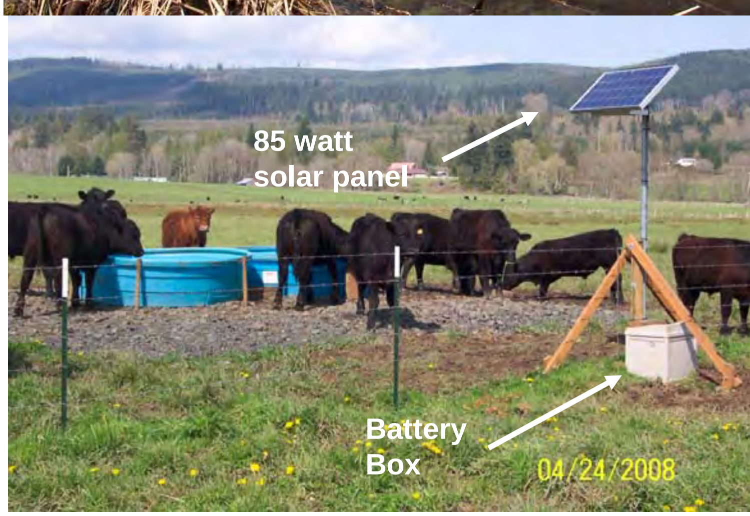
Assisted by: Centennial Clean Water Fund, Jefferson Land Trust grant, Salmon Recovery Funding Board, and Conservation Commission contributed funding.
Problems: Livestock had access to Snow Creek at a drinking place and to unfenced ditches.

Solutions: Fenced a 150' riparian buffer on Snow Creek as well as ditches ditches for a total of 3,048' of fence). Constructed a solar powered livestock drinking water system, and constructed two stream crossings.



SOLAR POWERED PUMP
Snow Cr., Jefferson Co. WA

Livestock were fenced out of Snow Cr. on this farm several years ago. One gap was left in the fence so livestock could access the creek for drinking water—they also drank from unfenced ditches which flowed into another stream. Additional ditch and stream fencing to protect water quality and salmon habitat depended on development of a reliable alternative system to provide drinking water for the livestock. Jefferson Co. Conservation District set up a solar powered pumping demonstration using an M3 floating pump system and it successfully supplied enough water for 150 beef cattle for two summers. In 2007 a conservation easement was purchased for a 100'-150' creek buffer. Ditches were fenced, and a permanent solar powered pump installation was completed. The pump has been operated successfully for 12 years!



Funding for easement, fencing and water system provided by Jefferson Land Trust, WA Salmon Recovery Funding Board, WA Dept. of Ecology through the WRIA 17 Planning Unit. Jefferson Co. Conservation District provided project planning and management using funding from the Washington State Conservation Commission.

April 27, 2009

Snow Creek
SN/1.0-1.2

Watershed: Discovery Bay

Waterbody: Snow Creek

Station: SN/1.0-1.2

BMP's: Aquatic Vegetation removal, riparian fencing, riparian buffer installation.

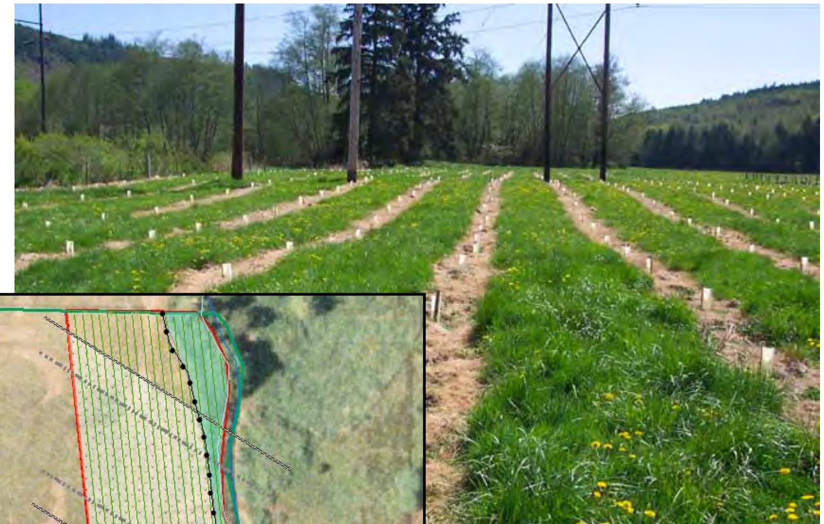
Date installed: Fencing 2008; Site Prep 2009; Planting Spring 2009.

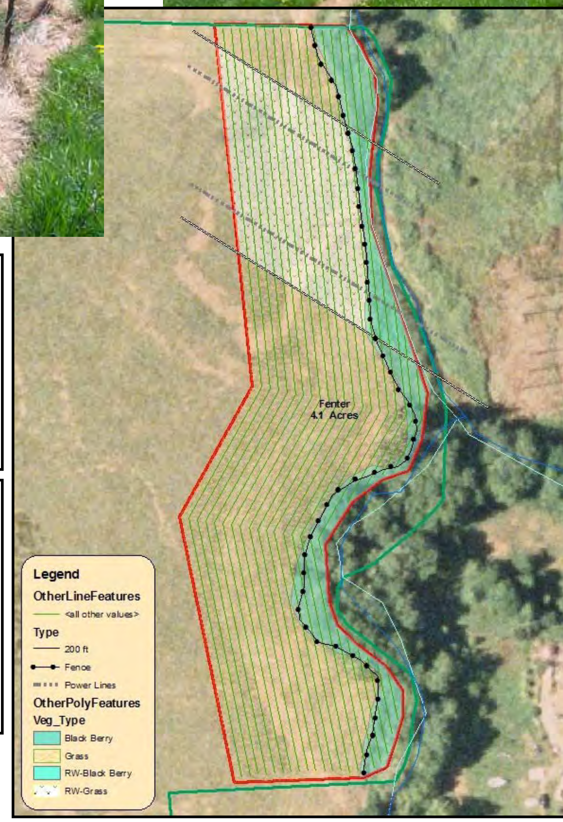
Installed by: Jefferson County Conservation District.

Assisted by: Jefferson Land Trust Funding and Salmon Recovery Funding Board.

Problem(s): The stream channel lacked riparian cover. Live stock had access to stream channel. Water temperatures exceeded the state standard.

Solutions: Riparian fencing was installed. In the spring of 2009 a 4.1 acre riparian buffer, averaging 160 feet wide, was planted with 1950 native trees and shrubs.





SRFB and Jefferson Land Trust funded riparian restoration project completed by JCCD. This project consisted of establishing a 4.1 acre buffer along 1068 feet of one side of Snow Creek with an average width of 160 feet. The site was planted with 1950 native trees and shrubs.

Upper left: Blackberry brush adjacent to channel was removed before planting. Upper Right: Site prep. spraying in rows completed before trees planted. A 200 foot utility right-of-way on the site required planting brush species only in this area. Lower Right: The site was fenced to exclude live stock from the stream. Inset: Site overview.

Snow Creek—Private property **SN/1.0-1.2** **Spring 2009**

May 24, 1997
July 27, 2007 update

Andrews Creek
AND/0.8-1.5

Watershed: Discovery Bay

Waterbody: Andrews Creek

BMPs: a channel restoration, sediment and canary grass removal, fencing, tree planting.

Date installed: September-October 1996

Installed by: Jobs for the Environment

Problems: Just upstream of Crocker Lake, Andrews Creek flowed through an unfenced horse pasture. The upper and lower end of the half-mile section upstream was buffered by willow trees. In between, however, a channelized stream generally lacked tree cover and canary grass clogged the channel. Canary grass grew to a lesser extent beneath the willows at the lower end of the section. The willows also impeded drainage by growing into the creek. The closer to Crocker Lake, the more undefined the channel became and the less was its ability to carry water. Much of the water spread out through the pasture. Summer dissolved oxygen levels are acutely low at the downstream end of the section.

Solution(s): Sediment and canary grass were removed from the channel by an excavator; trees were planted on both sides of the stream; and fencing was installed to keep out the horses.

Result(s): Oxygen levels measured just before the project began showed a decreasing pattern (9.7-2.7 mg/L) from upstream to downstream. Immediately after the project, oxygen levels exceeded 8.0 mg/L throughout the entire stretch.

Relative fish abundance of juvenile coho salmon, measured by the average number of fish caught per trap, increased substantially from 0.2 in 1996, one year after the project, to 2.3 in 2007 (Figure 1).

Sept. 1996--Pink ribbons mark canary grass-clogged channel

Sept. 1996--Channel being cleared by excavator

Sept. 1996--Cleared stream channel

April 1997--Trees planted and fence under construction

Andrews Creek AND/0.84-1.29 1996-1997

Trees growing along left bank of Andrews Creek

Trees at edge of field on left bank of Andrews Creek

Tree canopy limiting growth of canary grass

Beavers do what comes naturally

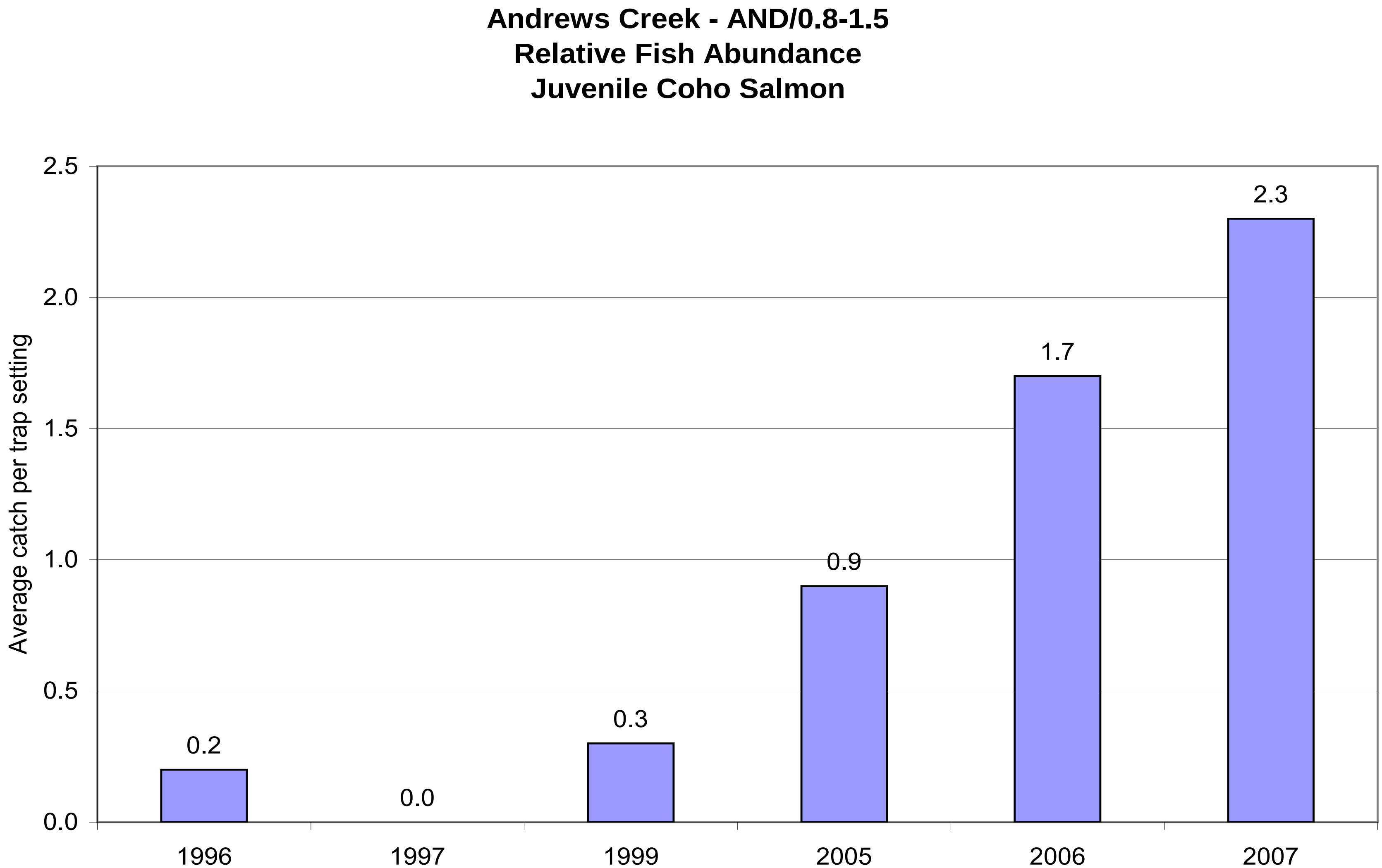


Figure . Relative fish abundance of juvenile coho salmon caught in minnow traps during the summer months from 1996 to 2007 in a reach of Andrews Creek rehabilitated in 1996. Rehabilitation included channel restoration, sediment and canary grass removal, fencing, and tree planting.

July 25, 2007

Andrews Creek
DOT Stretch
AND/1.6-2.0

Watershed: Discovery Bay

Waterbody: Andrews Creek

BMPs: Stream channel lowered; meanders, sediment basins, and large woody debris installed; trees planted.

Date installed: summer 1995

Installed by: WA State Dept. of Transportation (DOT)

Assisted by: Jobs for the Environment

Problems: The 2000-foot stretch of channelized stream paralleling Highway 101 had become full of sediment and canary grass. The combination of sediment and canary grass in the stream channel has resulted in flooding across Highway 101. Decaying vegetation has caused dissolve oxygen (DO) levels to be low in the summer. Due to the close proximity of the stream channel to Highway 101, the riparian cover along both banks was periodically cut by DOT as part of their highway maintenance.

Solution(s): The WA State Dept. of Transportation moved the stream channel farther away from the highway, deepened the channel, put in some meanders, installed two sediment basins, planted a variety of coniferous and deciduous trees and shrubs, and placed large woody debris in the channel. As measured in 2006, the average bankfull width of the improved stream channel was 13.0 ft. and the average buffer width was 19.5 ft.

Result(s): In 2006, an average canopy closure through the project was estimated to be 90 % during the summer months. In 2005, water temperature was the same at the downstream end of the project at station AND/1.6 that it was at the upstream end at station AND/2.0.

Average summer DO level increased from 5.3 mg/L in 1994 prior to the project to 7.8-9.2 mg/L in years following the project (Figure 1).

Relative fish abundance of juvenile coho salmon, measured by the average number of fish caught per trap, increased substantially from 0.0 in 1996, one year after the project, to 7.1 in 2006 (Figure 2).

Upstream view showing fenced pasture

Alder and willow new growth along stream edge

Downstream view from upper sediment basin

Downstream view—willow and blackberry in foreground

Andrews Creek AND/1.6-2.0 June 1997

Trees growing along right bank of Andrews Creek with Highway 101 on the left

Andrews Creek, middle of stream

Tree canopy effectively shading the stream channel

Andrews Creek **AND/1.6-2.0** **May-June 2006**

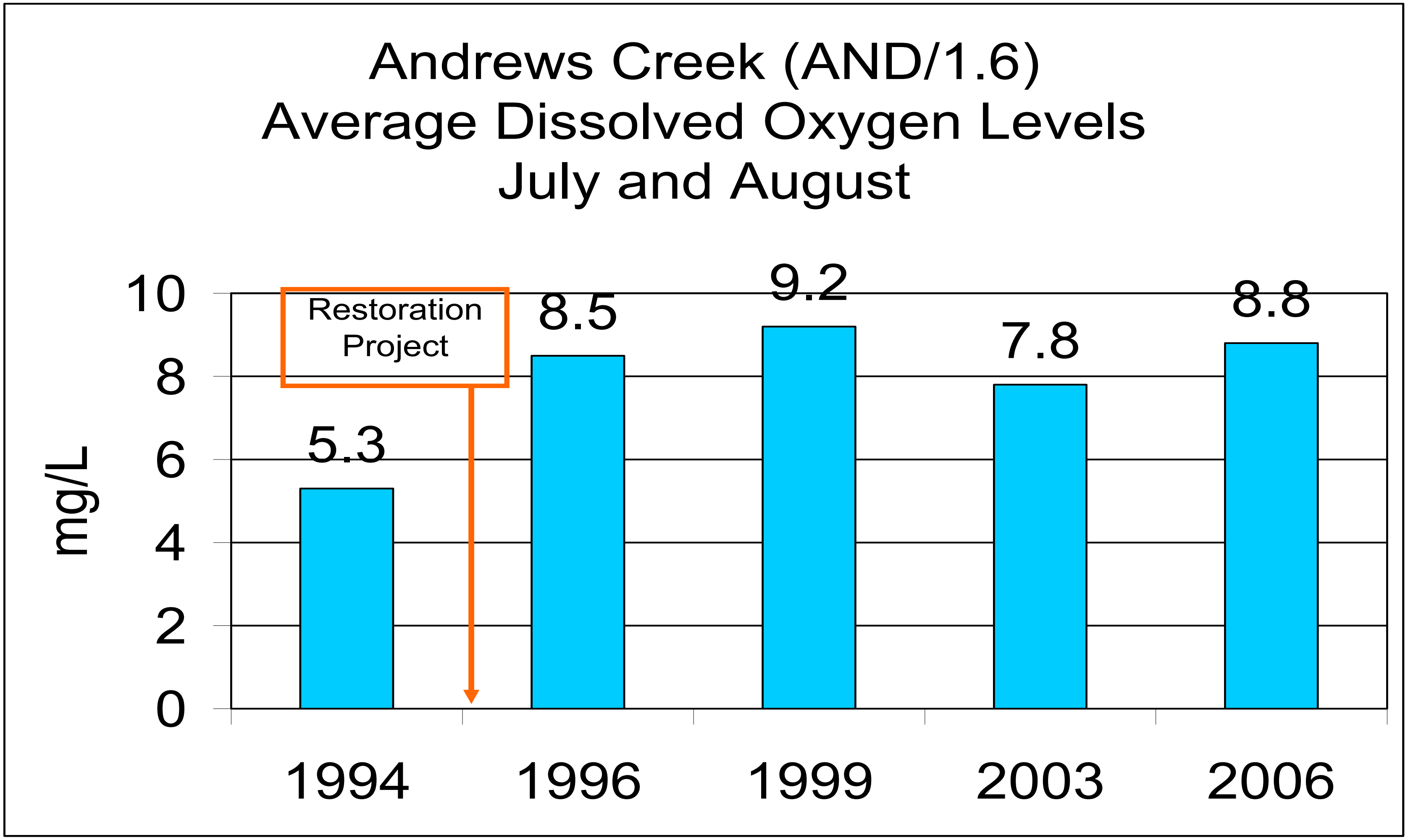


Figure 1. Average dissolved oxygen levels for June and July from 1994 to 2006 at station AND/1.6 at the downstream end of the DOT stretch on Andrews Creek.

Summer Chum Supplementation/Reintroduction Project
Salmon Creek and Chimacum Creek

In the 1980s, summer chum salmon experienced a severe drop in abundance in Hood Canal and Strait of Juan de Fuca streams. This critical situation resulted in the National Marine Fisheries Service listing the summer chum of this Evolutionary Significant Unit as “threatened” under the Endangered Species Act. To counteract the decline of summer chum, the Washington Department of Fish and Wildlife (WDFW) in 2000 developed the Summer Chum Salmon Conservation Initiative. One of the strategies of this initiative was to supplement natural reproduction by releasing fry reared artificially from eggs obtained from the parent stock.

About 10 years prior to the WDFW’s formalizing the Summer Chum Salmon Conservation Initiative, a group of concerned citizens known as Wild Olympic Salmon (WOS) took some initiative of their own. Their concern was focused on the run of summer chum in Chimacum Creek, or more aptly stated, “lack of a run.” By the mid-1980s, after several years of monitoring a weir on Chimacum Creek without observing a single chum salmon, WOS concluded that the Chimacum Creek summer chum was extinct. The only solution appeared to be starting a new run, but where would the fish come from? Because each river system has its own genetically distinct stock of fish, WOS looked for a system that best matched Chimacum Creek. After considering the possibilities, they chose Salmon Creek.

There was one problem, however. Salmon Creek was currently experiencing record low returns of summer chum (Figure SC-1, Table SC-1). Before any eggs could be donated to Chimacum Creek, the run in Salmon Creek would have to be bolstered. WOS and WDFW got together and developed a plan to supplement natural reproduction in Salmon Creek. WOS constructed a hatchery on a Salmon Creek tributary, and in 1992 the first eggs were taken to supplement natural reproduction. The eggs were incubated to eye-up at a WDFW hatchery on the Dungeness River and then transferred to the WOS hatchery. After hatching, the fry were transferred to net-pens in Discovery Bay, grown to a larger size, and released into the bay. By 1996 Salmon Creek returns had increased to 894 fish and the first group of eggs were transferred to a hatchery on Chimacum Creek. Success was first evidenced in 1999 when 38 3-year-old summer chum returned to Chimacum Creek (Figure SC-2). Since then, numbers have increased to 2,026 fish in 2006. The highest return for Salmon Creek occurred in 2005 when 6,152 fish returned.

In the later years of the supplementation program, the newly formed North Olympic Salmon Coalition (NOSC) stepped in to help keep things going. NOSC assisted in the field work with its own personnel as well as coordinated the many volunteers needed for trapping, egg taking, fish rearing, and fish counting. Supplementation was discontinued in both Chimacum Creek and Salmon Creek in 2004. It is expected that the number of summer chum in both creeks will decrease to their natural carrying capacities as time goes on. Preliminary results of otolith marking (which distinguishes fish of natural origin from those of hatchery origin) is showing that a substantial number of returning adults were reproduced naturally. Hopefully, when things stabilize, returns to both Salmon Creek and Chimacum Creek will be higher than when the supplementation program began. For Chimacum Creek any return would be a success.

Summer Chum Supplementation/Reintroduction Project—Salmon and Chimacum Creeks