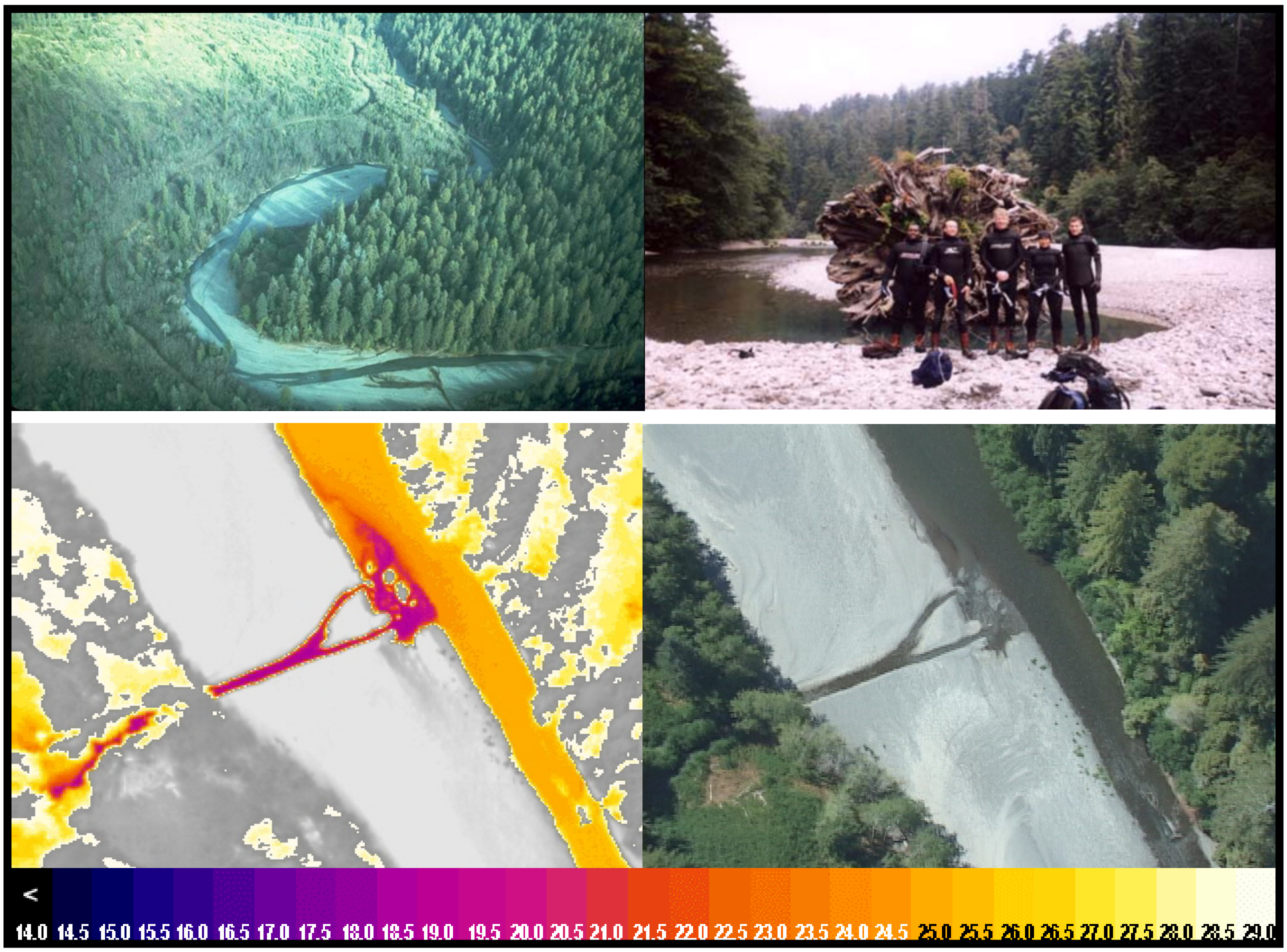
U.S. Department of the Interior
National Park Service

Natural Resource Program Center
Water Resources Division
Fort Collins, Colorado

Evaluation of Stream Temperature Regimes for Juvenile Coho Salmon in Redwood Creek Using Thermal Infrared (California)

Natural Resource Report NPS/NRWRD/NRTR—2005/331



ON THE COVER:

Top Left Photo:	Redwood Creek at the Tall Trees Grove (RNSP)
Top Right Photo:	Summer steelhead survey dive crew (David Anderson)
Bottom Left:	Thermal infrared photo of Tom McDonald Creek flowing into Redwood Creek (Watershed Sciences, Inc)
Bottom Right:	Natural color photo of Tom McDonald Creek flowing into Redwood Creek (Watershed Sciences)

Evaluation of Stream Temperature Regimes for Juvenile Coho Salmon in Redwood Creek Using Thermal Infrared (California)

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The Natural Resource Technical Reports series is used to disseminate the peer-reviewed results of scientific studies in the physical, biological, and social sciences for both the advancement of science and the achievement of the National Park Service's mission. The reports provide contributors with a forum for displaying comprehensive data that are often deleted from journals because of page limitations. Current examples of such reports include the results of research that addresses natural resource management issues; natural resource inventory and monitoring activities; resource assessment reports; scientific literature reviews; and peer reviewed proceedings of technical workshops, conferences, or symposia.

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Errata Sheet

Corrections:

Front and back cover pages changed to new Water Resource Division publication standards

Page 7 - Corrected format of third-level heading for *Data Collection* and *Data Processing*.

Page 8 – Added correct acknowledgment for Figure1. Corrected figure caption text which wrapped to next page.

Page 9 – Added correct acknowledgment for Figure 2.

Page 10 – Added correct acknowledgment and corrected transparency of yellow overlay in Figure 3.

Page 11 - Added correct acknowledgment for Figure 4.

Page 12 - Added correct acknowledgment for Figure 5.

Page 12 - Added correct acknowledgment for Figure 6.

Page 13 - Added correct acknowledgment for Figure 7.

Page 17 - Corrected format of second-level header *Relationship of coho distribution to stream temperature*.

Page 18 - Corrected format of second-level header *Thermal Infrared*

Contents

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Project Summary

In 2003, Redwood National and State Parks contracted for thermal infrared imaging of Redwood Creek, California. On July 29, 2003, about sixty miles (90 % of the stream length) of Redwood Creek was photographed in 1½ hours and 2,653 overlapping thermal images were acquired. The surface water temperature along the main channel of Redwood Creek was measured from thermal images, the spatial distribution of water temperature quantified, and warm versus cool reaches identified. A color digital video of the Redwood Creek channel, acquired in tandem with the thermal images, also provided good coverage of existing channel and riparian conditions. This project supports water quality assessments focused on the recovery of federally listed salmonid species (chinook and coho salmon and steelhead trout) in Redwood Creek and provides baseline data on which to measure future thermal response/recovery.

Introduction

Redwood Creek is located in north coastal California and flows into the Pacific Ocean near the town of Orick, about 35 miles north of Eureka. The watershed is approximately 285 mi^2 and 68 miles in length. The lower 40 percent of the basin is in Redwood National and State Parks and the upper 60 percent is private lands under mixed ownership that is managed primarily for timber production. Redwood Creek is currently listed as impaired for elevated sediment levels and high water temperatures under the Section 303(d) of the Clean Water Act. The watershed supports federally listed as threatened populations of coho salmon (*Onchorhynchus kisutch*), Chinook salmon (*O. tshawytscha*), and steelhead trout (*O. mykiss*), and the non-listed cutthroat trout (*O. clarki*).

Purpose

The purpose of this project was to evaluate if summer stream temperatures are a limiting factor for juvenile coho salmon in Redwood Creek. Remote sensing techniques were needed to acquire data for a large basin with mixed ownership and limited access. Thermal imagery was used to characterize and quantify the spatial distribution of surface water temperature in the river and identify warm versus cool reaches along the mainstem of Redwood Creek. The data and analysis improves our understanding of watershed processes in Redwood Creek, support on-going basin-wide stream temperature monitoring by Redwood National and State Parks (RNSP), and provide support for the current Clean Water Act 303(d) listing of Redwood Creek as temperature impaired. This project is related to the Government Performance and Results Act Ia4 Water Quality Objective.

Juvenile Coho Salmon Temperature Requirements

Juvenile coho salmon, like most salmonids require cool water to survive and grow and are susceptible to increased summer water temperatures because they rear in freshwater for a year. Many factors such as food availability, habitat quality, and competition, in addition to water temperature affect salmonids. Willey (2004) modeled bioenergetics of juvenile coho salmon on northern California streams and based on his study inferred that on streams with limited food resources, juvenile coho growth may decrease as daily average temperatures increase above 15.7°C. Stein *et al.* (1972) reported that juvenile coho growth decreased as temperature increased from 13 to 18°C.

Brett (1952) reported that when five species of Pacific salmon, including coho, were exposed to various temperature gradients all juvenile salmonid species preferred temperatures between 12-14°C and juveniles generally avoided stream temperatures above 15°C.

The estimated upper lethal temperature for juvenile coho varies depending on the techniques used. Brett (1952) reported the upper lethal temperature at 26.0°C based on the incipient lethal temperature. In this test, fish were acclimated at 20°C before being placed into higher temperature water. However, due to an accidental loss of coho during the experiment, he based his findings for coho on the upper thermal limits of spring salmon. Becker and Genoway (1979), as referenced in Bjorn and Reiser 1991) reported 28.8°C as the upper lethal temperature based on the critical thermal maximum technique where the water and fish were slowly heated. Using the same technique, McGeer *et al.* (1991) determined juvenile coho survived at temperatures up to 23°C but none survived at water temperatures higher than 25.5°C.

In the absence of lethal effects, stream temperature can influence the distribution of juvenile salmonids. For a nearby northern California stream, Welsh *et al*. (2001) reported that juvenile coho were not present in tributaries where the seven-day average daily maximum temperature (MWMT) exceeded 18.1°C.

Methods and Results

Thermal Infrared Imagery (TIR)

In 2003, the parks contracted with Watershed Sciences, Corvallis, Oregon for thermal infrared imaging of Redwood Creek. On July 29, 2003, fifty-nine miles (90 % of the stream length) of Redwood Creek was photographed in 1½ hours (Fig. 1). The creek was flown in a downstream direction starting at the confluence with Pardee Creek (river mile (rm) 59). Coastal fog prevented imaging of the lower 1.5 miles of channel and the estuary. Discharge on lower Redwood Creek during the survey was 23.4 cfs on Redwood Creek (above Hayes Creek) and 7.4 cfs at the O'Kane gaging station.

Over 2,650 overlapping thermal images were acquired. Thermal imagery was coupled with color digital videography of the main channel of Redwood Creek and riparian zones.

In-stream temperature monitoring indicate TIR images captured the time period when daily maximum temperatures occurred (between 2:22 to 3:58 pm) and the flight occurred on the hottest day of the summer. The final report (Watershed Sciences 2004), TIR and color images, digital videography, longitudinal profile of stream temperature, basic data, and an ArcView GIS database of TIR image locations were received by the park in March 2004.

Data Collection

Watershed Sciences (2004) describes the data collection as follows: Images were collected with TIR (8-12µm (micrometers)) and visible-band cameras attached to a gyro-stabilized mount on the underside of a helicopter. The two cameras were aligned to present the same ground area, and the helicopter was flown longitudinally along the stream channel with the sensors looking straight down. Thermal infrared images were recorded directly from the sensor to an on-board computer in a format in which each pixel contained a measured radiance value. The recorded images maintained the full 12-bit dynamic range of the sensor. The individual images were referenced with time and position data provided by a global positioning system.

A consistent altitude of 1400 ft above ground level was maintained during the flight in order to preserve the scale of the imagery throughout the survey. The altitude elevation was selected based on the channel width and morphology and Redwood Creek. At this altitude, the images presented a ground width of 494 ft (150 m) and had an image pixel size of 1.54 ft (0.5 m). During the flight, images were collected sequentially with approximately 40% overlap.

Watershed Sciences deployed five in-stream data loggers prior to the TIR survey to verify the accuracy of the TIR data (Fig. 1). The in-stream data loggers were distributed throughout the survey extent as access permitted. These points were supplemented with additional in-stream monitoring data from six sites provided by Redwood National and State Parks. Meteorological data including air temperature and relative humidity were recorded using two portable weather stations. One station was located at the Highway 299 Bridge and the other at the Redwood National Park Information Center near the Pacific Ocean.

Data Processing

Processing of TIR images was described by Watershed Sciences (2004) as follows: Measured radiance values contained in the raw TIR images were converted to temperatures based on the emissivity of water, atmospheric transmission effects, ambient background reflections, and the calibration characteristics of the sensor. The radiant temperatures were then compared to the temperatures measured by the in-stream data loggers. Calibration parameters were fine-tuned to provide the most accurate fit between the radiant and kinetic (in-stream) temperatures. The average absolute differences between the temperatures recorded by the in-stream data loggers and the radiant temperature derived from the TIR images were within the desired accuracy of 0.5°C.

Once the TIR images were calibrated, stream temperatures were interpreted and sampled. For each photo, the radiant temperature (pixel values) of 10 points along the center of the stream channel was determined. The temperature value for each thermal image was estimated by using the median value of the ten-point sample (Fig. 2). The temperatures of detectable surface inflows (i.e. surface springs, tributaries) were also sampled at their mouth. In some cases, tributaries or other features detected in the imagery were not sampled due to their small size. In addition, data processing focused on interpreting spatial variations in surface temperatures observed in the images. The images were assigned a river mile based on a 1:24,000 routed GIS stream coverage (measures assigned from this coverage may not match stream measures derived from other map sources).

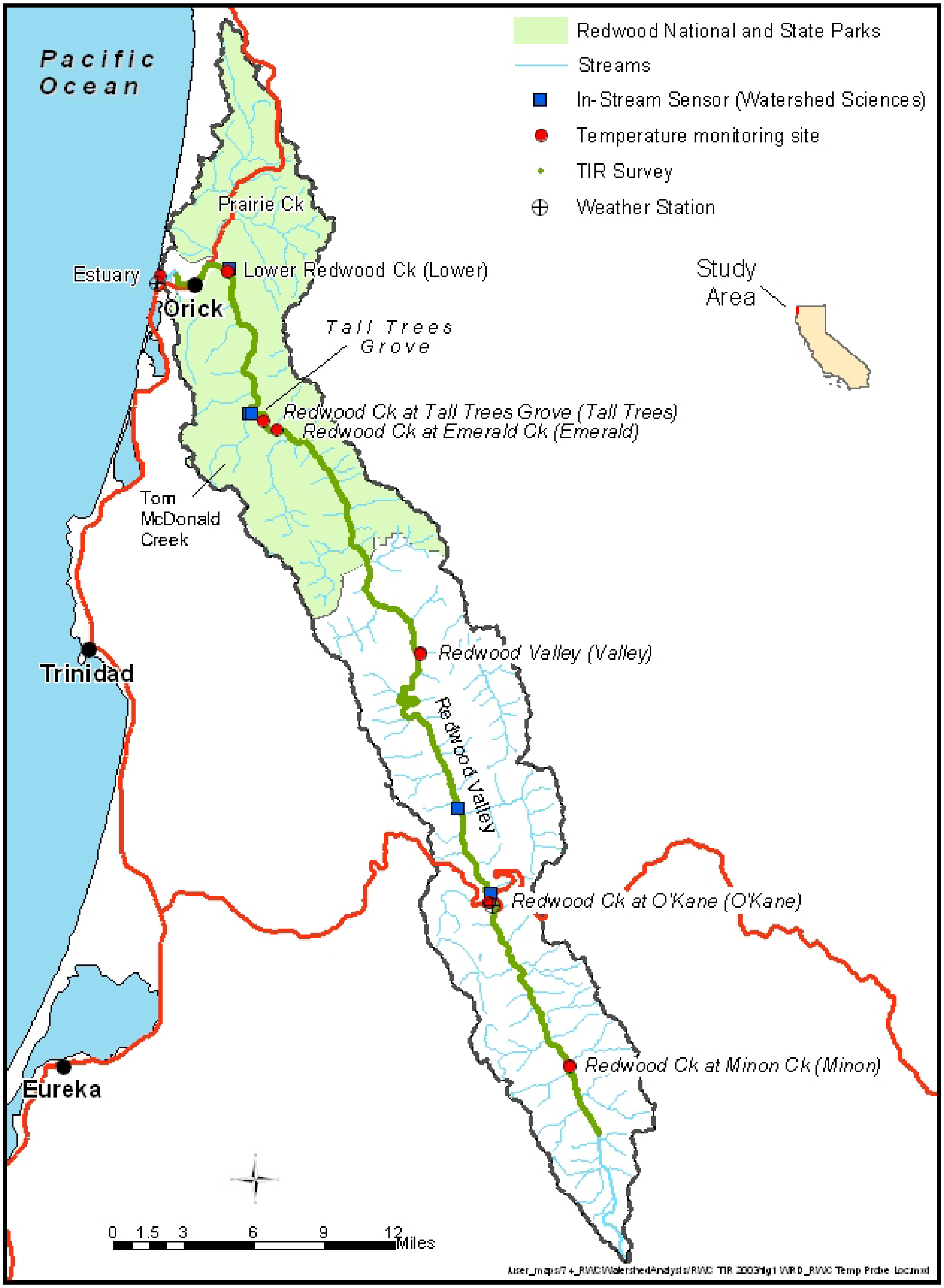

Figure 1. Length of channel surveyed with TIR on Redwood Creek, California on July 29, 2003. The map also shows the location of in-stream temperature sensors used to ground truth radiant temperatures derived from TIR images and RNSP stream temperature monitoring sites on Redwood Creek (after Watershed Sciences 2004).

Variable water surface conditions (i.e. riffle versus pool), slight changes in viewing aspect, and variable background temperatures (i.e. sky versus trees) can result in differences in the calculated radiant temperatures within the same image or between consecutive images. The apparent temperature variability is generally less than 0.6°C (Torgersen *et al*. 2001). In general, apparent stream temperature changes of < 0.6°C are not considered significant unless associated with a tributary or other source.

The median temperatures for each sampled image were plotted versus the corresponding river mile to develop a longitudinal temperature profile. The profile illustrates how stream temperatures vary spatially along the stream gradient (Fig. 3). The location and median temperature of all sampled surface water inflows (e.g. tributaries, surface springs, etc.) are included on the plot to illustrate how these inflows influence the main stem temperature patterns. Where applicable, tributaries or other features that were detected in the imagery, but were not sampled, due to their small size (*relative to pixel size*) or the inability to see the stream through riparian vegetation, are included on the profile to facilitate the interpretation of the spatial patterns.

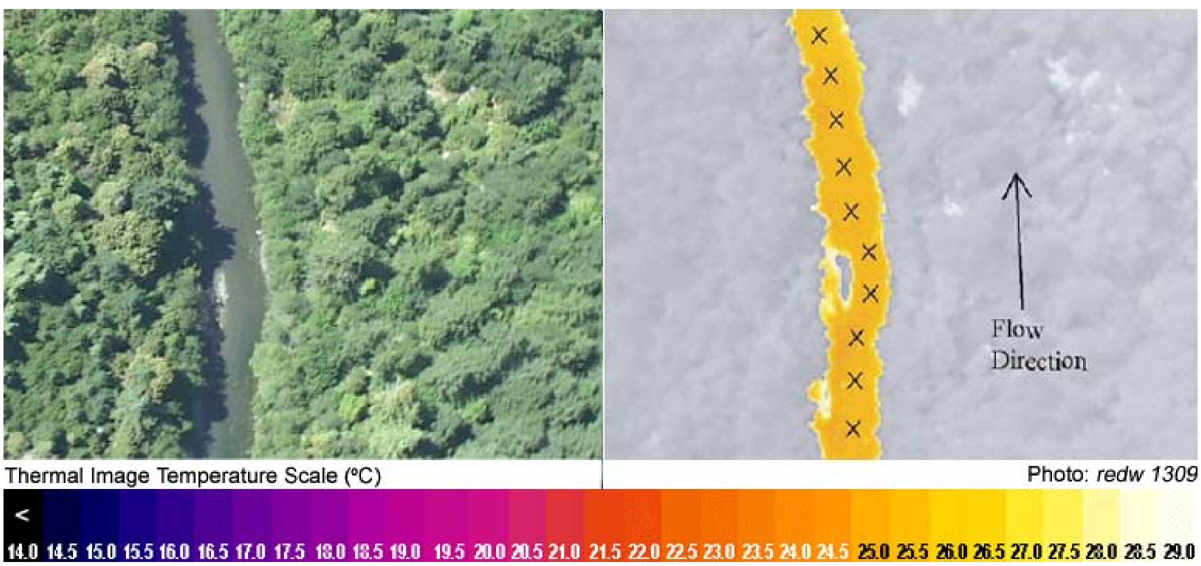

Figure 2. Natural color and TIR image pair showing how temperatures were sampled from the TIR images. Black X's on the TIR image show typical sampling locations near the center of the stream channel. The recorded temperature for this image is the median of the sample points (from Watershed Sciences 2004).

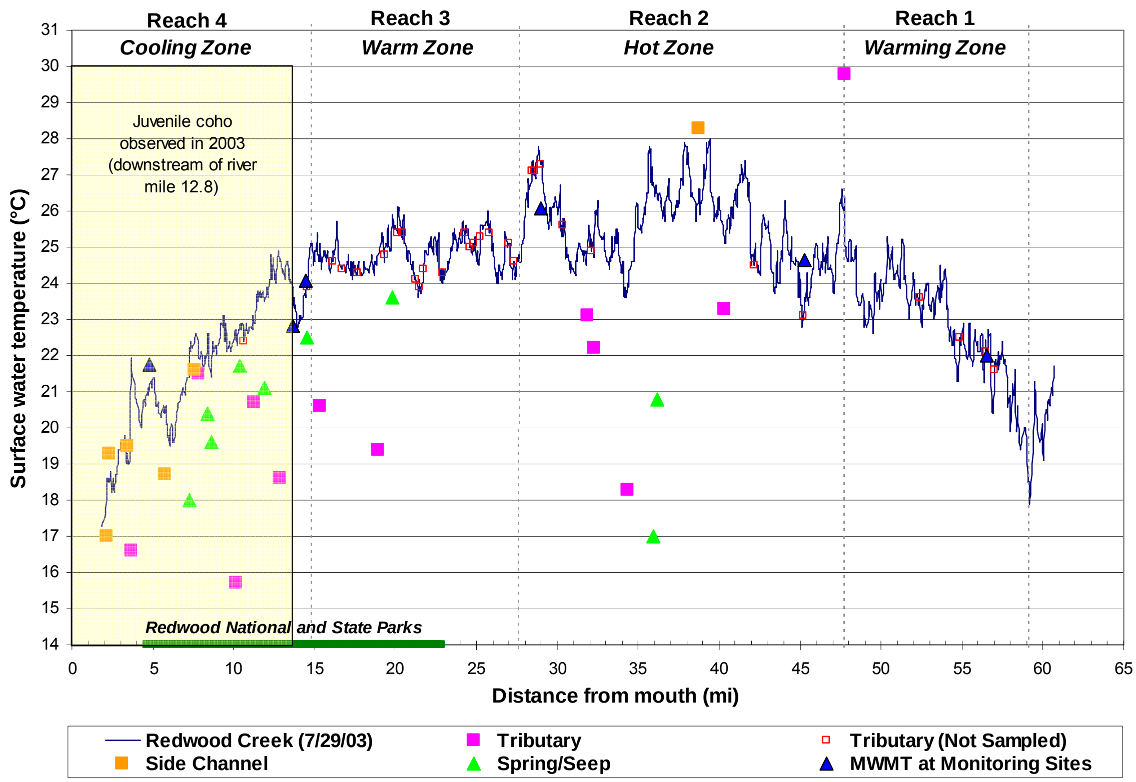

Figure 3. Plot of the median water temperature versus river mile for Redwood Creek, July 29, 2003. The plot shows the location of surface inflows detected during the TIR survey including tributaries that were detected but not sampled for temperatures. The yellow shaded area shows where juvenile coho were observed in the summer of 2003 (after Watershed Sciences 2004).

TIR Results

The thermal profile of Redwood Creek generally increases in temperature from the headwaters to the middle part of the basin and then cools as it approaches the coast (Fig. 3). This thermal signature has been observed on other nearby north coastal streams (Russ Faux, Watershed Sciences, personal communication). TIR longitudinal profile data acquired in 2001 for the Mattole River, a nearby coastal stream, shows a remarkably similar distribution of temperature to Redwood Creek (Fig. 4). However, Redwood Creek had the highest stream temperatures and more dramatic fluctuations in temperature over short distances.

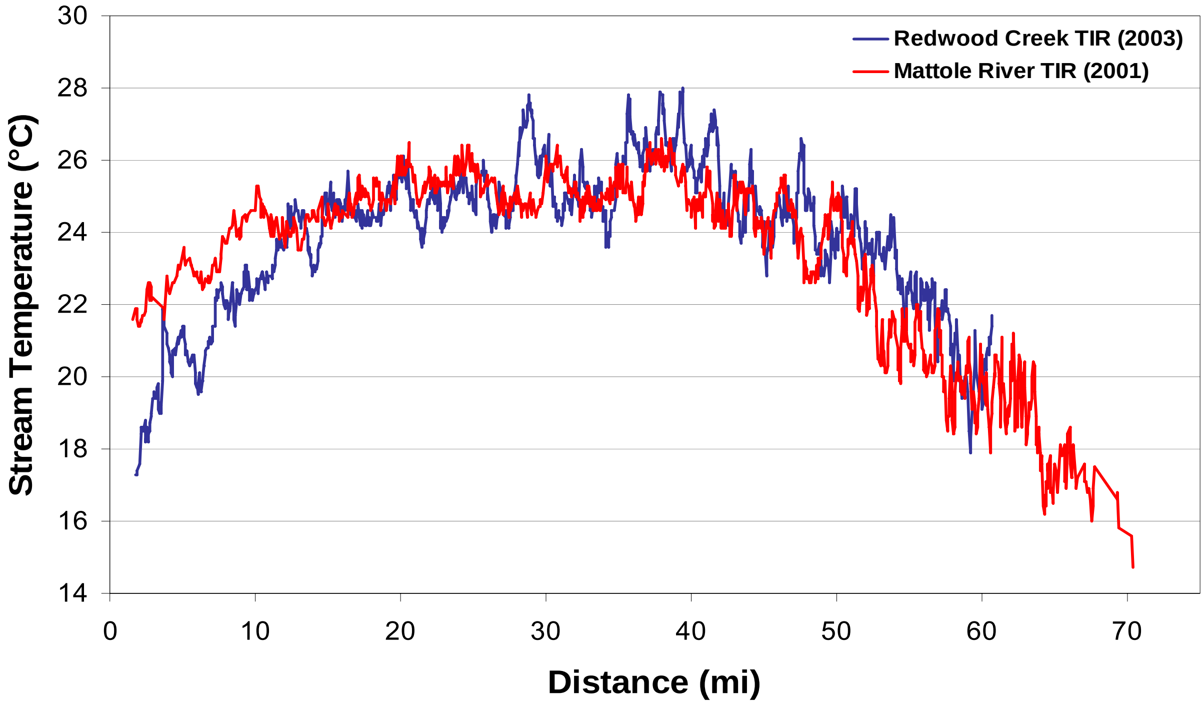

Figure 4. Comparison of stream temperature distribution on Redwood Creek and Mattole River from thermal infrared (after Watershed Sciences, 2002 and 2004).

The water temperature profile of Redwood Creek showed quite a bit of variability with large changes of stream temperature over relatively short distances (Watershed Sciences 2004). For example, changes in water temperature greater than 1°C occurred in less than a half-mile and many were associated with the inflow of tributaries (Fig. 5) or springs (Fig. 6).

Watershed Sciences (2004) found that based on TIR data Redwood Creek can generally be divided into four main reaches that showed similar temperature characteristics (Fig. 7).

Reach 1: *Warming Zone* - Near the headwaters of Redwood Creek, water temperature generally increased from 17.9°C to about 25°C as it traveled downstream.

Reach 2: *Hot Zone* – In the middle basin, stream temperatures were relatively warm but had a high degree of variability. Surface water temperatures ranged from 23°C to 28°C. For comparison, a community pool is kept at a comfortable temperature of about 28°C. Highest water temperatures were observed in this reach. Temperatures above 25°C have been reported to be the upper lethal stream temperature for coho salmon (Brett 1952; Becker and Genoway 1979; and McGeer 1991).

Reach 3: *Warm Zone* – In the middle to lower basin, stream temperatures remained warm. The average surface water temperature was 24.8°C.

Reach 4: *Cooling Zone* - In the most downstream section of Redwood Creek, stream temperatures generally cooled as it approached the ocean. The highest number of cool springs, seeps and side channels were measured in this reach.

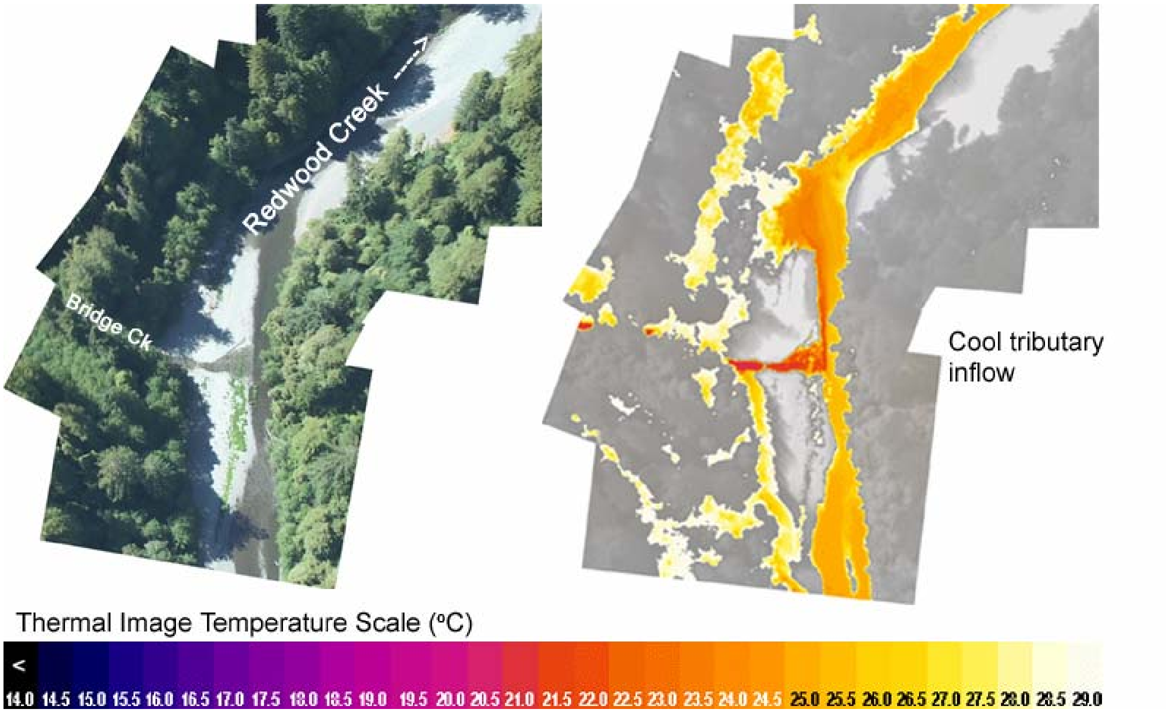

Figure 5. Cooler water from Bridge Creek (dark orange color) flows into Redwood Creek on the left side of the channel. Bridge Creek is more than 4.5°C (10.8°F) cooler than the mainstem and the colder water mixes with Redwood Creek as it flows downstream (from Watershed Sciences 2004).

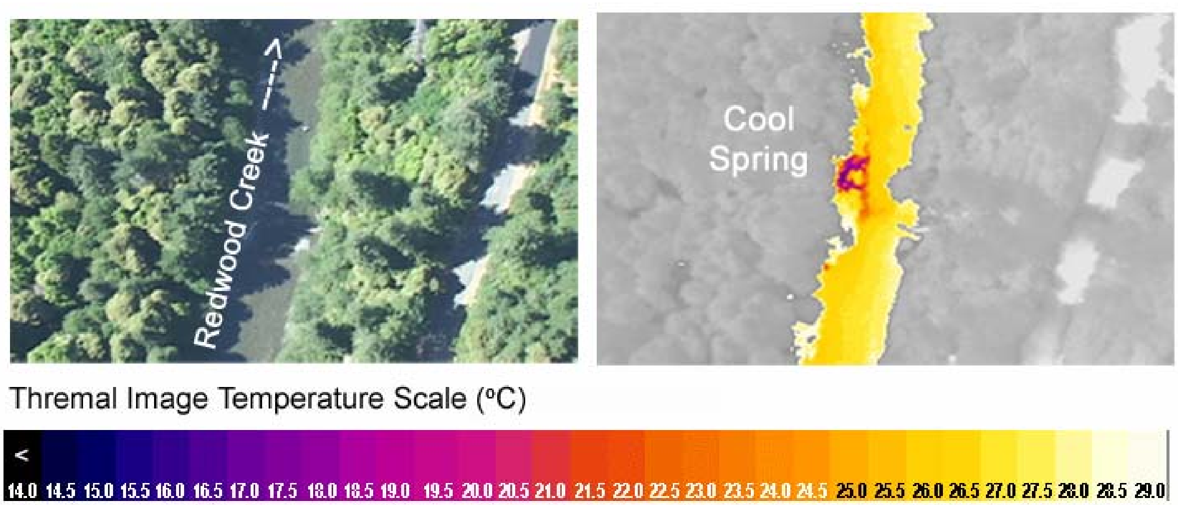

Figure 6. A cold spring emerges from the streambank of Redwood Creek creating a cooler pocket of water in the main channel (from Watershed Sciences 2004).

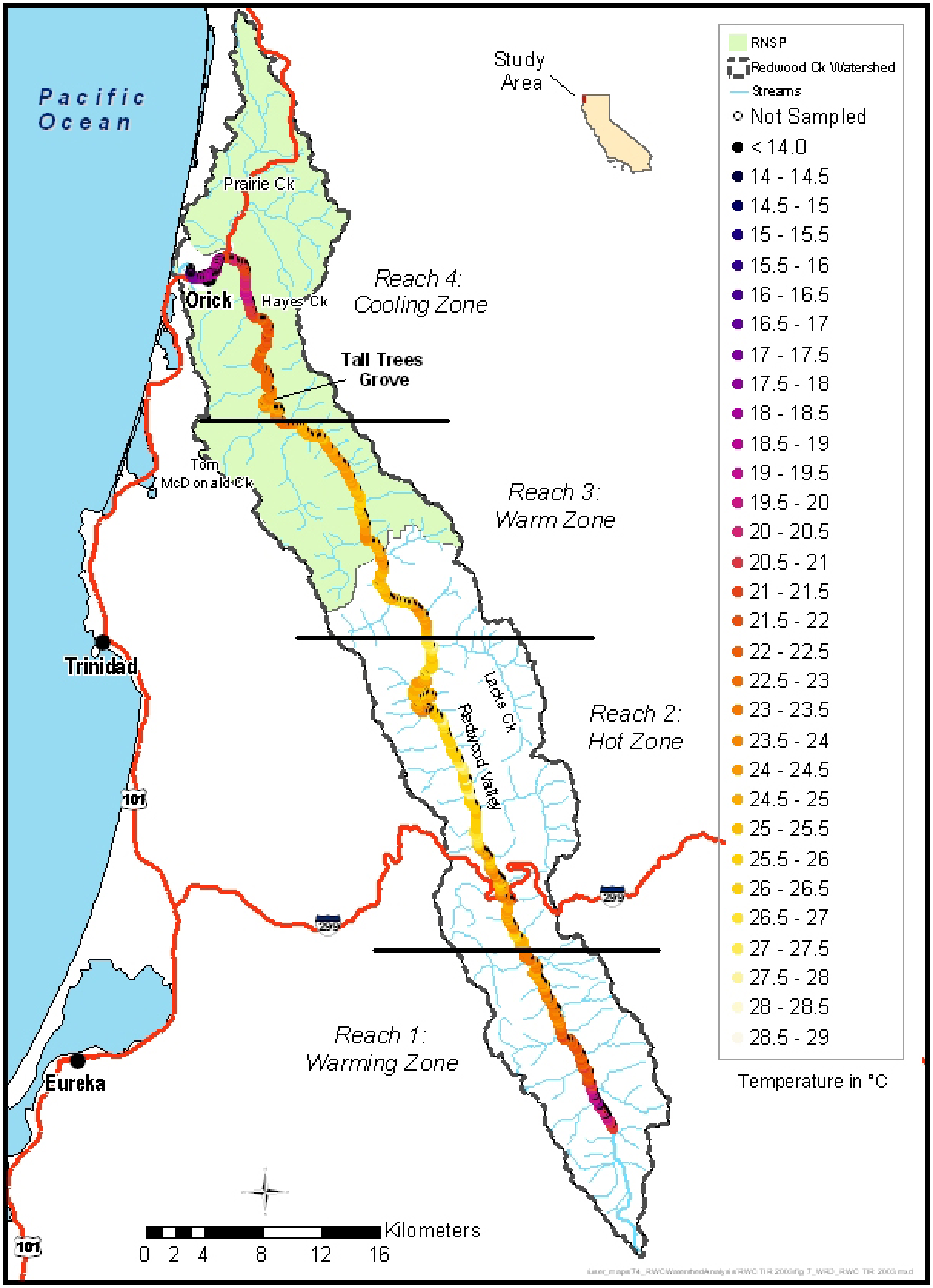

Figure 7. Distribution of water temperature along the main channel of Redwood Creek from TIR data. Reaches 1 - 4 display different thermal characteristics (after Watershed Sciences 2004).

Water Temperature Monitoring

RNSP has monitored summer water and air temperatures on Redwood Creek and several tributaries since 1997. Seven mainstem monitoring sites are distributed from the headwaters downstream to the estuary (Fig. 1). Water temperature monitoring is a cooperative effort with private landowners and the U.S. Geological Survey. Three monitoring sites, located in the upper and middle basin, are on private land. Four monitoring sites in the lower basin and the estuary are on parklands. In 2003 and 2004, the park monitored summer water temperature at seven monitoring sites using calibrated data loggers (Onset Tidbits). The accuracy of the probes was ±0.2°C. Data loggers were deployed from June through September and provided a continuous record of water temperature at one-hour intervals. Temperature probes were positioned at mid-water depth in well-mixed water (runs) and not exposed to direct sunlight.

In-stream temperature monitoring provided daily and seasonal maxima and minima, diurnal ranges, Maximum Weekly Average Temperature (MWAT) and Maximum Weekly Maximum Temperature (MWMT) at specific sites within the river. The MWAT and MWMT are the highest seven-day moving average of the daily mean or maximum temperature, respectively. Stream temperature statistics for 2003 are in Table 1. Data from 2004 are currently being analyzed.

Table 1: 2003 Summer Water Temperature Statistics (°C)

Location on Redwood Creek	**Miles from mouth***	**MWAT****	**MWMT****	**Max. Daily Range****	**Max. Daily****
Estuary	0.2	20.2	21.1	5.7	22.1
Lower	4.8	18.7	21.8	5.7	22.0
Tall Trees	13.7	21.2	22.8	4.7	23.5
Emerald	14.5	21.3	24.1	5.3	24.8
Valley	29.0	22.5	26.1	6.8	27.0
O'Kane	45.3	22.2	24.6	6.2	24.4
Minon	56.6	19.0	22.0	6.4	22.8

* Miles from the mouth of Redwood Creek are based on RNSP GIS tributary distance data derived by D. Hines.

**Temperature Calculations/Definitions:

MWAT (maximum weekly average temperature) is the highest seven-day moving average of the daily mean temperatures. The date of the seven-day moving averages are attributed to the mid-point of the 7-day period (for example, for Week 1 (Day 1 - Day 7) the mid-point of the period is Day 4).

MWMT (maximum weekly maximum temperature) is the highest seven-day moving average of the daily maximum temperature. The date of the seven-day moving averages are attributed to the mid-point of the 7-day period (for example, for Week 1 (Day 1 - Day 7) the mid-point of the period is Day 4).

Maximum Daily Range is calculated by computing the difference between the maximum and minimum temperatures for each day and selecting the highest one-day range for the time period. This gives an idea of thermal variability the fish experience during the season.

Maximum Daily - Maximum one-hour temperature during the summer.

The Valley monitoring site (river mile (rm) 29.0), located in the middle basin of Redwood Creek, had the highest values for daily maximum temperature, MWAT, MWMT, and maximum daily range. Interestingly, there appears to be a significant increase for MWMT above Tall Trees monitoring site (rm 13.7; Fig. 8), which coincides with the upstream extent of where juvenile coho were observed during a 2003 presence-absence survey (David Anderson, RNSP, personal communication).

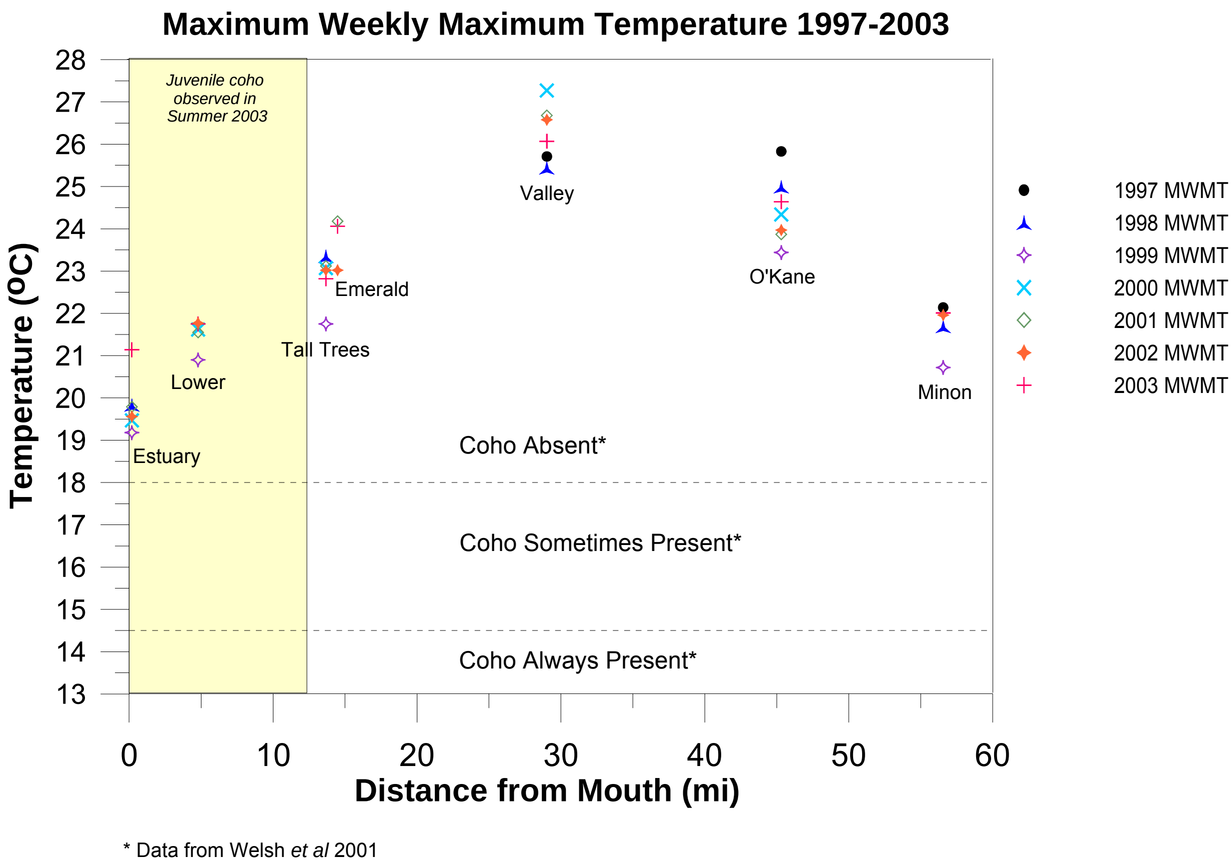

Figure 8. Redwood Creek Maximum Weekly Maximum Temperatures (MWMT) from 1997-2003. MWMT temperature thresholds for presence or absence of coho is from Welsh et al. 2001.

In 2003, water temperature recorded by in-stream data loggers helped validate stream temperatures derived from TIR images. TIR temperature data corresponded to within ±0.5°C of the water temperature recorded at points along Redwood Creek.

Fish Observations

Current distributions of coho salmon can be generally determined from recent fish work in Redwood Creek. Adult coho salmon spawners were observed in Redwood Valley during the winter 2000-01 spawning season (PCFWWRA 2002). Spawning surveys conducted in 1989 and 1990 on this same section of creek also documented several coho salmon in the middle basin of Redwood Creek (RNSP, in house data). These spawning surveys, although infrequent, indicate mainstem use by adult coho extends up to Redwood Valley. In contrast, a downstream migrant trap located in the middle basin of Redwood Creek in Redwood Valley (rm 33), has never captured a juvenile coho in the past five consecutive years of trapping (Sparkman 2004). The California Department of Fish and Game typically runs the trap from March until mid-late July when juvenile Chinook out-migration slows significantly. Although few in number, juvenile coho were captured at a downstream migrant trap on lower Redwood Creek (rm 4) in 2003 and 2004. In 2003, unusually high flow conditions early in the season made the lower trap inoperable for several weeks and low juvenile coho numbers precluded determining population estimates (Bill Pinnix, USFWS, personal communication). Only 110 young-of-the-year (yoy) and 12 1+ coho were trapped in 2003. In 2004, 202 yoy juvenile coho and 69 1+ coho salmon were caught at the lower trap (Sparkman 2004).

During the summer of 2003, RNSP conducted annual summer steelhead surveys during the last week of July and first week of August to determine the number and location of adult summer steelhead and cutthroat trout. As part of this project, park biologists conducted a juvenile coho "presence-absence" snorkel survey of the lower half of Redwood Creek (Lacks Creek downstream to Hayes Creek). In 2003, no coho were observed in the main channel above rm 12.8 (Tom McDonald Creek). Juvenile coho were only observed in nine locations in the lower 13 miles of channel, downstream of the Tall Trees Grove. Of the few juvenile coho sighted in Redwood Creek, seven of the nine locations were side pools (Fig. 9). Side pools were separated from the main channel by a gravel bar but open to Redwood Creek on the downstream end. Many of the pools were influenced by cool seeps and springs, intragravel flow, groundwater or small tributaries and had similar characteristics to cold pools described by Ozaki (1988). These pool features were generally the same temperature or cooler than the mainstem. The two other locations used by juvenile coho were mainstem habitat located in the lowermost stream section closest to the coast.

Concurrent with this project, the California Department of Fish and Game has completed a coho status report to support a state listing of the species. The database and digital copies of bibliographic references to all observations in Redwood Creek will be provided to the park when the legal review is complete.

Figure 9. Park biologists search for juvenile coho in a side pool along Redwood Creek.

Discussion

Relationship of coho distribution to stream temperature

Although the main channel of Redwood Creek is accessible to salmon and steelhead for most of its length, there is a noticeable lack of juvenile coho salmon upstream of the park. TIR data, in-stream water temperature monitoring, and coho presence-absence surveys indicate that high stream temperatures may limit juvenile coho rearing to the lower most section of Redwood Creek and less than 20 percent of the main channel currently supports young coho during the summer. In 2003, juvenile coho selected side pools where the water temperature was the same or cooler than the main channel. Stream temperature monitoring indicates that there is a decrease in the MWAT, MWMT, and maximum daily water temperature on the lower river between rm 13.7 (Tall Trees) and 4.8 (Lower). Above the Tall Trees Grove, no juvenile coho were observed in the mainstem of Redwood Creek. Stream temperature monitoring by the park since 1997 indicates that this temperature pattern occurs every year.

Studies by Welsh *et al.* (2001) on tributaries of the Mattole River, California suggest that streams with MWMT greater than 18.1^{o}C or MWAT greater than 16.8^{o}C may restrict the presence of juvenile coho salmon. Coho salmon in Redwood Creek and the Mattole River are grouped within the same Evolutionary Significant Unit. In 2003, all MWMT values for Redwood Creek exceeded 18.1^{o}C and ranged from 21.1 to 26.1°C (Fig. 8). However, this study suggests that the presence of colder thermal refugia in the lower river helped support juvenile coho use. The TIR profile showed the greatest thermal complexity in the downstream most reach of Redwood Creek and where many cools springs, seeps, side channels, and tributaries were measured.

In the last five years, no juvenile coho have been caught at the downstream migrant trap in Redwood Valley (rm 33.0) indicating no use by juvenile coho upstream of the trap site (Sparkman 2004). TIR data indicate that Redwood Valley is the hottest reach in Redwood Creek. In-stream temperature monitoring supports this conclusion and since RNSP monitoring began in 1997, Redwood Valley has the highest maximum daily water temperatures, MWAT and MWMT along the entire length of the creek. Stream temperature monitoring also shows highest stream temperatures occur in this section of the channel and that peak water temperature equals or exceeds 26^{o}C every year.

During 2004, Sparkman (2004) caught young-of-the-year coho salmon at the lower downstream migrant trap (rm 4) on Redwood Creek every month from April to July. This indicates that lower Redwood Creek and the estuary may provide important rearing habitat for juvenile coho salmon.

Thermal Infrared

Thermal infrared remote sensing technology successfully provided spatially continuous stream temperature data for a large basin. This technology enabled stream temperature assessment across mixed ownership and inaccessible areas of the basin.

Faux *et al.* (2001) compared TIR stream temperature data on several Oregon rivers collected for different years on the same stream reach. They found that while the absolute temperature of the stream reaches changed from year to year, the longitudinal stream temperature patterns observed were consistent over time. Although TIR data for Redwood Creek provides a thermal profile for only one day during the summer, it provides an overall assessment of the general thermal characteristics and spatial distribution of temperature on Redwood Creek.

The longitudinal temperature profile from TIR imagery provides a clear snapshot of the current thermal regime in Redwood Creek and a baseline for monitoring future changes in stream temperature. The TIR data also identified four general stream reaches with differing thermal characteristics. Small cool water seeps, springs and side channels within the warmer river channel were also identified using TIR. The smallest cool water area that TIR could measure stream temperature was about 215 ft^2 (20 m^2).

TIR longitudinal profile data were also used to evaluate locations of long-term temperature monitoring sites. In-stream data loggers provide point data along the length of Redwood Creek, but TIR data integrates the spatial distribution and general thermal characteristics of the creek. We compared the location of stream temperature monitoring sites with the spatial distribution of water temperature throughout the basin from the TIR survey. The parks' stream temperature monitoring locations complemented the TIR data and indicates the current monitoring locations provide a good representation of temperature distribution in Redwood Creek. Based on TIR data, the park discontinued one monitoring site and established a new site farther downstream.

While TIR remote sensing can map surface water temperature, it cannot be used as a tool to identify thermally stratified pools which may be several degrees cooler at depth. Past studies have shown that although few in number, cold pools exist in lower Redwood Creek (Keller *et al.* 1995; Ozaki 1988; Moses 1984) and provide important cold water refugia for salmonids during periods of thermal stress (Nielsen *et al.* 1994). For the past couple years, juvenile steelhead have been observed using cooler thermal areas in Redwood Valley during periods of high water temperature (Michael Sparkman, CDFG, personal communication). Similarly, in 2003 juvenile coho were found using colder water refugia in the lower river. Some of the most interesting cool water interactions occur along the channel banks. Unfortunately with TIR data riparian vegetation commonly obscures channel edges, where cool groundwater seeps may emerge. Small areas (< 32 ft^2 or < $3m^2$) of groundwater seeps or cool upwelling are non-detectable at the scale of the TIR flight used in this study. As a result, small cool water refugia may exist in warm reaches of Redwood Creek, but must be quantified by a different method.

The TIR report from Watershed Sciences has been provided to the California State Water Quality Control Board, California Department of Fish and Game, NOAA Fisheries, and large private landowners in the Redwood Creek basin. TIR data are available for the agencies and landowners to use. This project also provides current data to support the continued listing of Redwood Creek as temperature impaired. Projects to increase future riparian trees and vegetation, and using of best watershed management practices to protect riparian corridors would help correct stream temperature issues in the long-term.

Park staff is working with the U.S. Geological Survey to synthesize all the in-stream water temperature monitoring and TIR data and is submitting a paper for publication that evaluates stream temperature influences on the distribution of coho salmon in Redwood Creek.

Future Work

Future studies should focus on:

- Evaluating juvenile coho use of side pools and determining the thermal and habitat characteristics of side pools.
- Determining coho use and thermal characteristics of tributaries to Redwood Creek upstream of Prairie Creek.
- Inventorying cool water refugia on Redwood Creek and determine the distribution of cool water features and cool water volume along the mainstem.

Budget

The Water Resources Division project funding totaled $33,200 over two years (FY 03 and 04) and represents about 40 percent of the total project cost. Total in-kind contributions equaled $41,900 during the project time period. Additional in-kind contributions from other agencies exceeded $120,000 from past stream temperature analyses, temperature probe calibration, Redwood Creek riparian condition assessment.

Budget		
	FY 03	FY 04
Description		
TIR Contract: Watershed Sciences	$ 24,100	------
PERSONNEL		
GIS Technician		$ 4,034
Phys. Sci. Tech (fish surveys)	$ 2,238	
SUPPLIES		
Temperature Data Logger (6- NIST Certified Onset Tidbits & software)	$ 2,762	------
Create DVD's from Digital tapes	------	$ 66
TOTAL	$29,100	$4,100
In-Kind Funding Contributed by RNSP and other Agencies		
PERSONNEL		
NPS staff (fish surveys, discharge measurements, thermal stratification field checking)	$17,250	$7,900
USGS staff (Redwood Creek stream temperature data analysis and synthesis of past data)	$13,750	$3,000
TOTAL	$31,000	$10,900
In-Kind Contributions by other Agencies		
-USGS riparian condition assessment (air photo and field characterization) = $8,000 -USGS temperature data analysis 1997-2002 = $10,000 -Humboldt State University (lab and equipment for calibrating temperature probes 1997-2003) = $2,000 - California Dept of Fish and Game (downstream migrant trapping; stream temperature data for 2003 and 04) = $100,000 - California State Agencies - North Coast Watershed Assessment Project/Redwood Creek Watershed Assessment (analysis of stream temperature data by staff) = $5,000		
PROJECT TOTAL = $50,644		

References

Becker, C.D. and Genoway, R.G. 1979. Evaluation of the critical thermal maximum for determining thermal tolerance of freshwater fish. Envir. Bio. Fishes. v. 4. pp. 245-256.

Bjornn, T.C. and Reiser, D.W. 1991. Habitat requirements of salmonids in streams; In: Influences of Forest and Rangeland Management on Salmonid Fishes and Their Habitats. American Fisheries Society Special Publication 19. pp. 112-133.

Brett, J.R. 1952. Temperature tolerance in young Pacific salmon, genus Oncorhynchus. J. Fish. Res. Board Can. v. 9. no. 6. pp 265-323.

Faux, R.N., Lachowski, H., Maus, P., Torgerson, and C.E., Boyd, M.S. 2001. New approaches for monitoring stream temperature: Airborne thermal infrared remote sensing. In: Project Report Integration of Remote Sensing, Inventory and Monitoring. U.S. Dept. of Agriculture Forest Engineering. Remote Sensing Application Center.

Keller, E.A., Hofstra, T.D., and Moses, C. 1995. Summer "Cold Pools" in Redwood Creek near Orick, California. In: Geomorphic Processes and Aquatic Habitat in the Redwood Creek Basin, Northwestern California. U.S. Geol. Survey Prof. Paper 1454. pp. U1-U9.

McGeer, J.C., L. Baranyi, and G.K. Iwama. 1991. Physiological responses to challenge tests in six stocks of coho salmon (Oncorhynchus kisutch). Can. J. Fish. Aquat. Sci. v.4 8. pp. 1761-1771.

Moses, C.G. 1984. Pool morphology of Redwood Creek, California. M.S. Thesis, University of California, Santa Barbara, California.

Ozaki, V. 1988. Geomorphic and hydrologic conditions for cold pool formation on Redwood Creek, California. Redwood National Park Technical Report 24. Redwood National Park, Arcata, California.

Pacific Coast Fish, Wildlife, and Wetlands Restoration Association (PCFWWRA). 2002. Redwood Creek salmon spawner survey 2000/01 season. Prepared for the California Department of Fish and Game and Redwood Creek Landowners. PCFWWRA, Arcata California. 5p.

Nielsen, J.L., Lisle, T.E., and Ozaki, V. 1994. Thermally stratified pools and their use by steelhead in northern California streams. Tran. Amer. Fish. Soc. v. 123. pp. 613-626.

Sparkman, M.D. 2004. Redwood Creek juvenile salmonid downstream migration study, study year 2004. Calif. Dept. of Fish and Game, Anadromous Fisheries Resource Assessment and Monitoring Program. Annual Report 2i3. 61p.

Stein, R.A., P.E. Reimers, and J.D. Hall. 1972. Social interactions between juvenile coho (Oncorhynchus kisutch) and fall chinook (O. tshawytscha) in Sixes River, Oregon. J. Fish. Res. Board Can. v. 29. no.12. pp. 1737-1748.

Torgerson, C.E., Faux, R.N., McIntosh, B.A., Poage, N.J., and Norton, D.J. 2001. Airborne thermal remote sensing for water temperature assessment in rivers and streams. Remote Sen. Envir. v. 76. pp. 386 – 398.

Watershed Sciences. 2002. Aerial Survey in the Mattole River Basin — Thermal infrared and color videography. Final Report to North Coast Regional Water Quality Control Board. Watershed Sciences, Inc., Corvallis, OR. 24 p.

Watershed Sciences. 2004. Aerial Survey of Redwood Creek — Thermal infrared and color videography. Final Report to Redwood National and State Parks. Watershed Sciences, Inc., Corvallis, OR. 20 p.

Welsh, H.W., Hodgson, G.R., and Harvey, B.C. 2001. Distribution of juvenile coho salmon in relation to water temperatures in tributaries of the Mattole River, California. N. Amer. J. Fish. Man. v. 21. pp. 464-470.

Willey, W.S. 2004. Energetic response of juvenile coho salmon (*Oncorhynchus kisutch*) to varying water temperature regimes in northern California Streams. M.S. Thesis. Humboldt State University, Arcata, CA.

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