

AN ABSTRACT OF THE THESIS OF

Nancy Raskauskas for the degree of Honors Bachelors of Science in Fisheries Science
presented on December 9, 2005

Title: Cool Hideaways: Use of Summer Temperature Refuges by Juvenile Coho Salmon
in the West Fork Smith River

Abstract approved: _____
Judith L. Li

The West Fork Smith River, a 69 km² watershed in the Coast Range of Oregon, is prone to short periods of very high water temperature in mid-summer due to a combination of human and natural influences. In the summers of 2003 and 2004 more than 400 juvenile coho salmon regularly packed themselves into a 4m² area of cooler water near Crane Creek. In the same watershed, other groups of coho salmon and trout were monitored in three other cold refuges where they avoided main channel water temperatures that reached as high as 25°C.

In 2003 we mapped cold refuges and performed snorkel surveys and fish counts at several sites. In 2004 we chose four main refuges as study sites. We installed temperature loggers in each refuge and nearby main channel. We measured (length, weight) and PIT-tagged juvenile coho salmon at each site in early July and recaptured and measured fish in September. We tracked fish movement throughout the summer using a portable PIT-tag reader and snorkel surveyed to count fish numbers in the refuges and nearby pools at various water temperatures and to observe fish behavior. However, of the 178 coho salmon tagged only 50 were recaptured.

Local fidelity to refuge sites, in association with peak temperatures in mid summer best describes juvenile coho use of coldwater refuges at West Fork Smith River. The number of coho salmon in refuges increased with main-channel temperatures from 18°C to 25°C. Coho salmon and other fish congregated in multiple smaller pockets of cold water or “micro refuges” not detected during the initial refuge mapping. Even so, the total number of detected coldwater refuges was less than fifteen areas in over 15 kilometers and total refuge surface area was only 0.00002% of the mainstem surface area searched. At the four study sites differences in peak temperatures, refuge morphology and presence or absence of large trout resulted in variable patterns of use by juvenile coho salmon.

Cool Hideaways:
Use of Temperature Refuges by Juvenile Coho Salmon in the West Fork Smith River

By
Nancy Raskauskas

A THESIS
Submitted to
Oregon State University Honors College

In partial fulfillment of
the requirements for the
degree of

Honors Bachelors of Science

Presented November 22, 2005
Commencement December 2005

Honors Bachelors of Science thesis of Nancy Raskauskas presented on Nov. 22, 2005

APPROVED:

Judith Li Thesis Advisor/Committee Member, OSU Fish and Wildlife Department

Selina Heppell Committee Member, OSU Fish and Wildlife Department

Joseph Ebersole Research Mentor/Committee Member, US EPA NHREEL WED WEB,
OSU Fish and Wildlife Courtesy Professor

Stanley Gregory Acting Head of OSU Fish and Wildlife Department

Joe Hendricks Dean of OSU University Honors College

I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Nancy Raskauskas Author

ACKNOWLEDGEMENTS

My thesis project was made possible from the support of many. Foremost thanks to my mentors at the EPA, **Joan Baker** and **Joe Ebersole**, and to **Judy Li** my thesis advisor at OSU. Joe and Joan make an outstanding research team and I've learned a great deal from their expertise and work ethic in the last three years. Judy Li forced me to plan out logistics, be a critical thinker and hold myself accountable to deadlines. Her support and attention to detail guided me through the thesis process. I am also grateful to **Stephanie Sanford** of CWEST for allowing this research as part of my internship and to **URISC** Research Grant from OSU for providing additional funds for travel and gear. In addition, I was graciously offered advice, temperature data help and the loan of gear from **Micheal Cairns** at the EPA. I was tirelessly assisted in the field by my co-researcher and fellow intern **Stefanie Orlaineta** (CWEST). Further fieldwork help and good natured support came from **Tyler Mintkeski** (EPA) and **Genny Cobarrubias** (CWEST), **Shelia Davis** (EPA), **Dana Devin-Clarke** (EPA), **Kurt Rensmeyer** (CWEST) and **Courtney Shaff** (EPA). **Anthony Olegario** traded work and advice in his quest to finish his graduate thesis on juvenile coho salmon diets in the West Fork Smith River. **Kenneth Rodnick** (ISU) took the time to share information about coho salmon temperature thresholds and physiology. **Mike Colvin** (EPA) helped with data analysis. Finally my parents, brothers, friends, coaches and teammates all had the patience to see me through the stressful deadlines. To all, I am eternally thankful for the help, the gear, the time, the honesty, the enthusiasm, and the inspiration.

TABLE OF CONTENTS

INTRODUCTION.....9

STUDY AREA AND METHODS.....11

Study Areas.....12

Sketches of Sites.....14

Thermal Time Crunch.....18

Refuge Search.....18

Habitat Measurements.....19

PIT-Tagging.....21

Monitoring.....22

Data Analysis.....24

RESULTS.....25

Refuge Search.....25

Temperature.....25

Snorkel Data.....27

Movement.....31

Growth.....32

Behavior.....33

DISCUSSION.....36

Behavioral Trade-off?.....39

Difficulties of Data Collection.....40

CONCLUSION.....42

SOURCES.....43

LIST OF TABLES

1. Habitat characteristics at the four study sites, summer 2004
2. Number of coho salmon tagged at each study site.
3. Dates of snorkel surveys at each study site.
4. Two-way table of starting tagged location and detection locations for PIT-tagged coho salmon at Lower Crane, Crane, Moore and Upper study sites during Summer 2004.

LIST OF FIGURES

1. Location of Study Sites in the West Fork Smith River Watershed
2. Crane Refuge with Off Channel Pool, Summer 2003
3. Crane Refuge, Summer 2004
4. Crane Refuge (photo)
5. Moore Refuge, Summer 2003 & 2004
6. Moore Refuge (photo)
7. Lower Crane Refuge, Summer 2003
8. Lower Crane Refuge, Summer 2004
9. Lower Crane Refuge with portable stationary reader, Summer 2004 (photo)
10. Upper Refuge, Summer 2004
11. Seasonal Change at Upper (photo)
12. 7-day average daily maximum temperature in degrees celcius recorded by temp loggers in the West Fork Smith River in Summers 2002 and 2003.
13. Refuge and mainstem temperatures at Lower Crane Refuge between 8/5/2003 and 8/10/2003
14. PIT-Tagging (photo)

15. Coho salmon being measured to fork length (photo)
16. Total hours over temperature thresholds of 16°, 20°, 22° and 24°C from June 27th to September 4th 2004. *Crane Refuge total hours over from July 27th to September 4th 2004.
17. Total days over temperature thresholds of 16°, 20°, 22° and 24°C from June 27th to September 4th 2004. *Crane Refuge total hours over from July 27th to September 4th 2004.
18. Coho salmon distribution in the area of Crane Refuge transitions from morning to afternoon on July 27 2004. The refuge gained 378 coho salmon and the surrounding area lost 401.
19. Counts of coho salmon in Crane Refuge with time of day and a mainstem water temperature category: hot, warm or cool.
20. Counts of coho salmon in Crane Refuge versus mainstem water
21. Counts of coho salmon in Lower Crane Refuge versus mainstem water temperatures.
22. Counts of coho salmon in Moore Refuge versus mainstem water temperatures.
23. Counts of coho salmon in Upper Refuge versus mainstem water temperatures.
24. Tagged coho salmon recaptured in Moore Refuge versus tagged coho salmon recaptured in Adjoining Pool. Average growth rate during the 57 day study period.
25. Fish behavior in refuges: coho salmon sit close to the bottom in tight ranks. (photo)
26. Above Crane Refuge: wide open bedrock lends a hand to heat the water up. (photo)
27. Two search methods to find cold water refuges.

Cool Hideaways: Use of Temperature Refuges by Juvenile Coho Salmon in the West Fork Smith River

INTRODUCTION

The West Fork Smith River, a 69 km² watershed in the Coast Range of Oregon, is prone to short periods of very high water temperature in mid-summer due to a combination of human and natural influences. In many areas the river channel is scoured to bare bedrock, an artifact of historic splash-damming practices. In addition, the soil composition of the area is shallow and stores very little groundwater. This, compounded with only 4% of annual precipitation and less than 1% of the annual discharge in the summer, creates low flows and high temperatures in the West Fork Smith River (Cairns et al. 2005). Nevertheless, juvenile coho salmon survive and are distributed throughout the entire watershed (Ebersole et al. 2005). This unique situation begs the question: what characteristics of the West Fork Smith River or native coho salmon *Onchorynchus kisutch* allow for survival at high temperatures? During the summers of 2003 and 2004 I examined the use of cold refuges by juveniles, to investigate if this behavior might help explain the persistence of coho salmon in the West Fork Smith River.

According to previous studies on salmonid behavior, coho salmon are likely to use refuges in periods of heat stress (Ebersole et al. 2003; McCullough 1999). A study in tributaries of the Mattole River in California found that streams with temperatures above 18.1°C mean weekly maximum temperature or 16.8°C mean weekly average temperature were unlikely to provide appreciable rearing habitat for coho salmon. However, there was evidence that fish can take advantage of small-scale spatial variations in stream temperature (McCullough 1999).

My general hypothesis was that juvenile coho salmon utilize cold refuges when water temperatures are high. I defined a cold refuge as a patch of water that was at least 2°C cooler than the adjacent main channel temperature during a warm or hot weather event. My two major questions were: *Are cold water refuges used by a relatively larger number of juvenile coho salmon than surrounding habitats during warm periods?* and secondly: *What is the pattern of juvenile coho salmon use in cold water refuges on hot summer days?* I had several associated questions for behavior and growth that I was unable to answer conclusively but gathered enough data and observations to find some interesting patterns and surprises: *What distance do fish travel to use cold refuges? How do the fish that use refuges benefit? And finally, do the same individual fish come back repeatedly to a refuge or are fish in the refuges different individuals over time?*

STUDY AREA & METHODS

The West Fork Smith Basin in the Coast Range of Western Oregon is the site of a collaborative project between the Environmental Protection Agency (EPA), Bureau of Land Management (BLM), United States Forest Service (USFS), National Marine Fisheries Service (NMFS) and independent scientists. The project focuses on coho salmon (*Oncorhynchus kisutch*) and the effects of various habitat factors on coho salmon and several other species over five years. My role in the project has been as a PROMISE/CWEST intern placed at the EPA-Corvallis (2001-2004) and as an EPA-Summer Hire (2005) assisting in a variety of field studies.

The West Fork Smith River is a 69 km² watershed in the Umpqua River basin in the central Oregon Coast Range. The elevation of the basin varies from 60 to 850 meters. The primary source of water in the system is rain water in the Fall, Winter and Spring. The vegetation in the watershed is composed of relatively young multi-aged forest dominated by Douglas fir (*Pseudotsuga mensiezii*), and includes red alder (*Alnus rubra*) and bigleaf maple (*Acer macrophyllum*) in the riparian areas. The dominant geologic material is Tyee sandstone bedrock. In many areas the river bed is scoured down to the bedrock because of splash damming practices during the late 1800's and early 1990's. There are numerous BLM installed boulder-weirs and large wood restoration areas throughout the West Fork Smith River. Other species of fish in the watershed during the summer months include winter steelhead (*O. mykiss*), sea-run and resident cutthroat trout (*O. clarki*), sculpin (*Cottus spp.*), speckled dace (*Rhinichthys osculus*), longnose dace (*R. cataractae*), redbelt shiner (*Richardsonius balteatus*), largescale sucker (*C.*

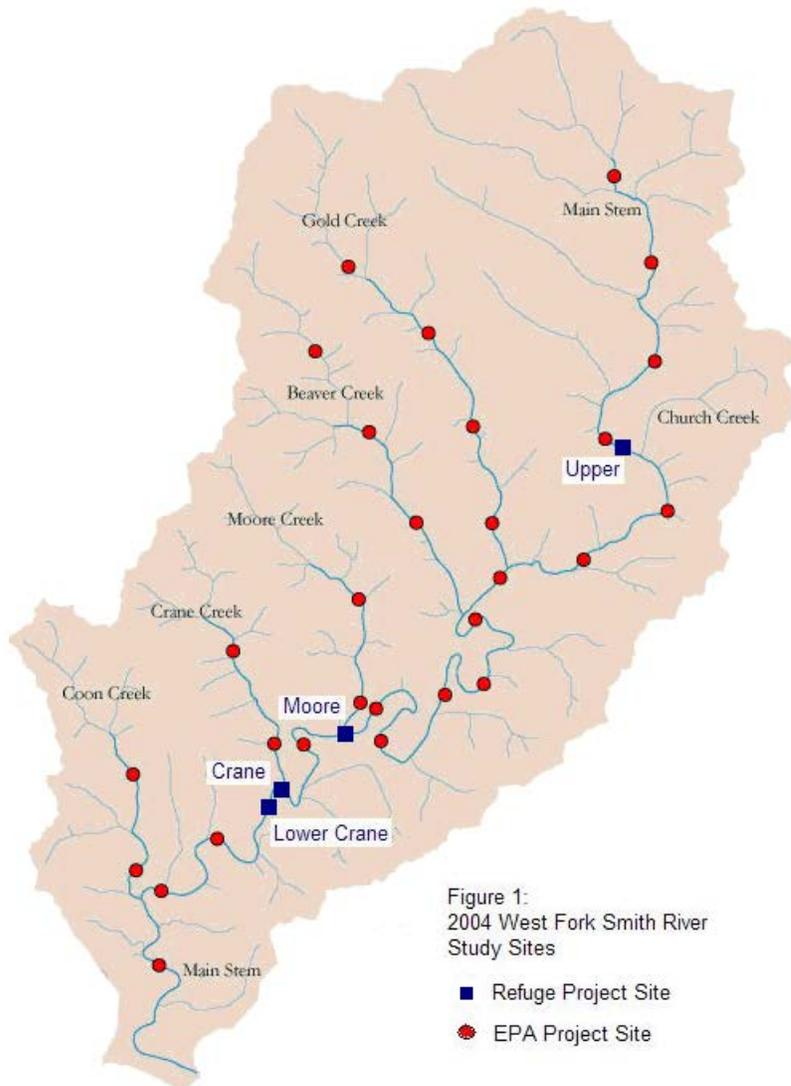
macrocheilus), northern pikeminnow (*Ptychocheilus oregonensis*), western brook lamprey (*Lampetra richardsoni*) and Pacific lamprey (*L. tridentata*) (Ebersole 2005).

The general plan was to monitor movement (with visual counts and periodic snorkel surveys) in and out of at least four cold refuges with an emphasis on surveying during the hottest weeks of the summer. I used Passive Integrated Transponder (PIT) tags to mark fish in my study. I planned to PIT-tag as many of the coho salmon in the refuges as possible and to track their movement throughout the watershed utilizing both the system of PIT-tag readers installed by the EPA project and a portable reader. Extensive West Fork Smith River data gathered by the EPA on physical habitat, temperature over time, juvenile coho salmon movement and juvenile coho salmon populations enhanced my study analysis. The objective of the study in 2003 was to locate cold refuges in the West Fork Smith River and visually monitor a known site at the mouth of Crane Creek. The focus of the study in summer 2004 was to study four of the refuges that had been found the previous year. I monitored coho salmon use of these areas by employing snorkel surveys, PIT-tags and temperature recorders.

Study Areas

The general location in the West Fork Smith River watershed of the four cold refuges that I focused on were (Fig. 1):

1. Crane Creek/WFS Confluence Refuge
2. Across from mouth of Moore Creek Refuge
3. Lower Crane Creek Reach Refuge
4. Upper Reach Refuge



On average, these four sites had a mean surface area of 5.3m² and were easily accessible from the main channel for fish. The four sites were similar in area and daily water temperature variance from the main channel, but differed in habitat features. The source of cold water in each refuge varied, including: stratification of water temperatures because of depth (Moore and Upper), tributary influence (Crane and Moore), overhanging vegetation and underwater seeps and springs (Lower Crane).

Sketches of Sites

1. Crane Refuge- Crane Creek/WFS Confluence

This refuge was a side pool the first summer of the study (2003)(Fig. 2). During that summer the culvert on Crane Creek was replaced. During the second summer (2004) the refuge was simply an area of shallow water in the mainstem at the Crane Creek confluence, there was no side pool (Fig. 3). Subsurface flow from Crane Creek was the reason this area was cooler than the surrounding water.

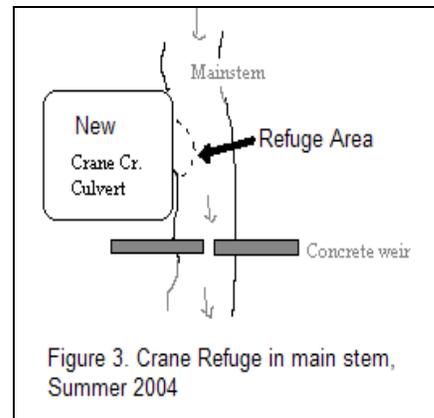
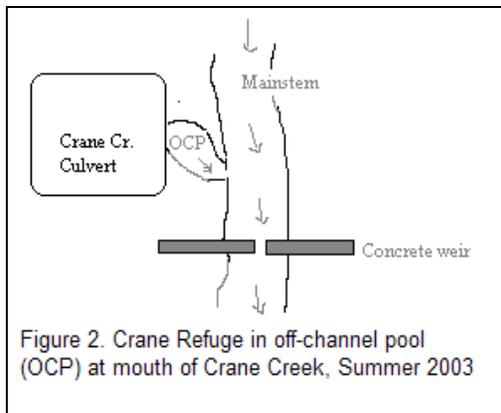




Figure 4. The seine is the limit of the Crane cold refuge area. The brick at lower left is attached to a temperature logger. The edge of the culvert seen in the bottom of the photo hangs over the confluence of Crane Creek and West Fork Smith River.

2. **Moore Refuge-** Across from mouth of Moore Creek Refuge.

Moore Refuge occurred in deep water as a large mainstem pool. The refuge was located across from the confluence of Moore Creek (Fig. 5&6). This refuge was surveyed by snorkeling only.

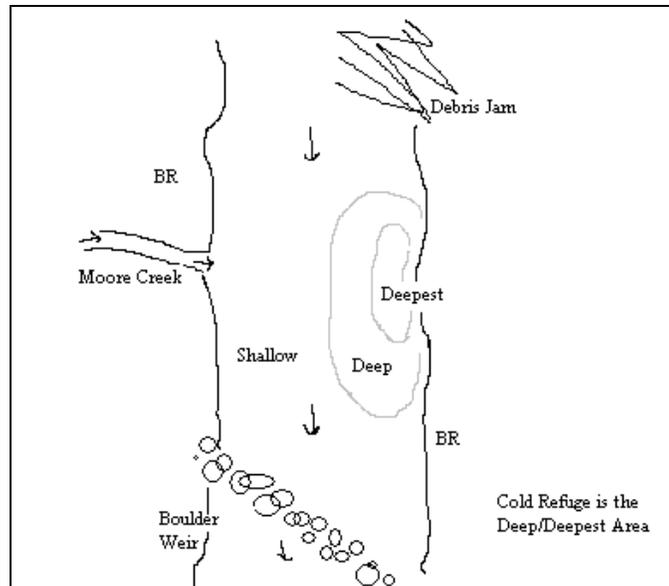


Figure 5. Moore Refuge sketch Summer 2003 and 2004



Figure 6. Moore Refuge Summer 2004

3. **Lower Crane Refuge**-Side pool on main stem below Crane Creek

Lower Crane refuge was the lowest refuge in the watershed. The lower a site was in the watershed, the higher the water temperature. This refuge was unique in that

although it was connected to the main channel, this access was restricted along a side channel. This allowed for the installation of a stationary reader at the mouth of the channel leading to the cold refuge.

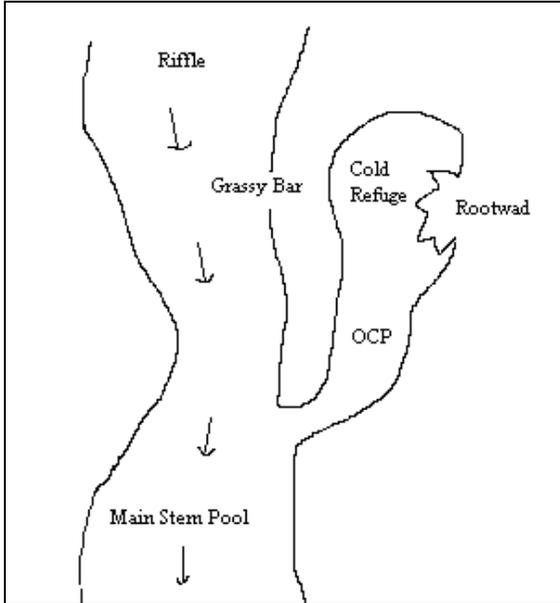


Figure 7. Lower Crane Refuge, Summer 2003

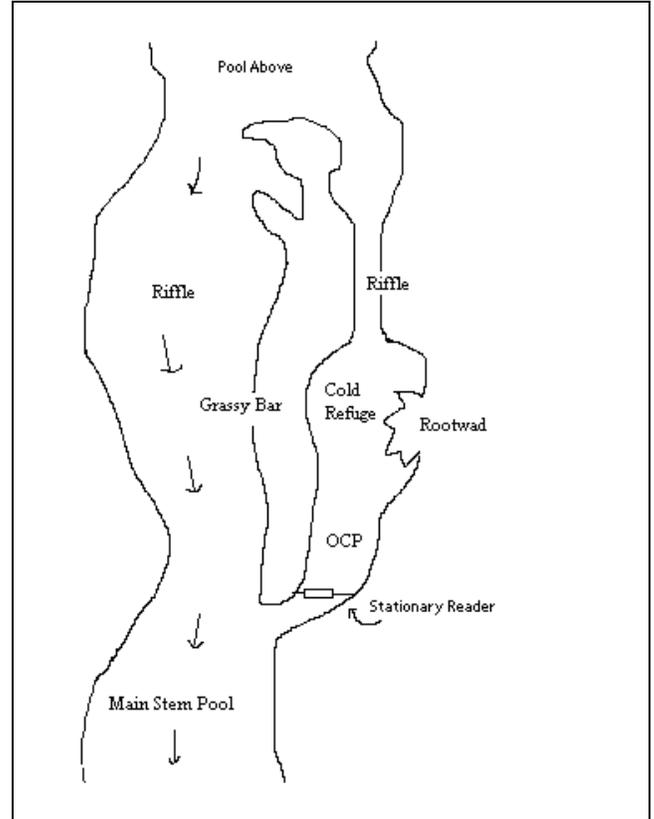


Figure 8. Lower Crane Refuge, Summer 2004



Figure 9. Lower Crane Refuge, Summer 2004. Stationary reader is visible.

4. **Upper Refuge**-500 meters above Church Creek on the mainstem

The Upper refuge also was formed by the stratification of different water temperatures in a calm pool. The water in this refuge mixed quickly if one was not careful how she read the temperature monitor. One problem with this site was that although it was significantly cooler than the water in the adjoining main stem, the water in the main stem never got exceptionally hot. The refuge was a patch of cold water in an area of cool water.

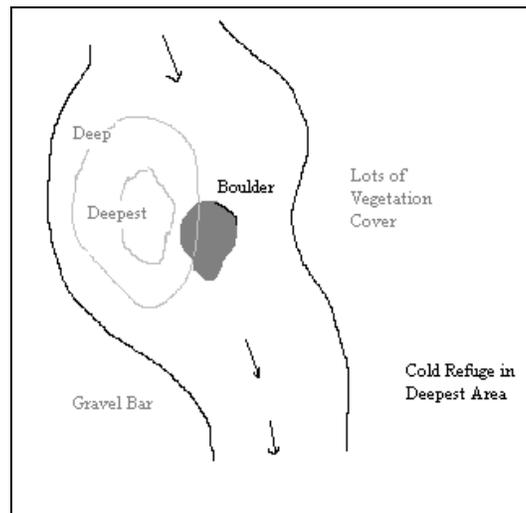


Figure 10. Upper Refuge, Summer 2004



Figure 11. Seasonal Change: Beavers made this dam above the Upper refuge in 2004, perhaps creating another cold refuge above the dam.

Thermal Time Crunch

To address the study questions it was imperative that the cold refuges were monitored during the hottest water temperature days of the summer. I reviewed temperature records from previous years to approximate optimal dates. In 2002, the two hottest days were on July 30 and August 14, but in summer of 2003 temperatures peaked around July 22 (EPA WFS Database). Daily maximum temperatures averaged for week long periods in 2002 was above 22°C in some areas and in 2003 weekly average maximums exceeded 24°C (Fig. 12). Therefore, the cold refuge study was designed to have fish marked and monitoring in place by mid-July 2004, in order to ensure that movements on the hottest days of the summer would be included in the study.

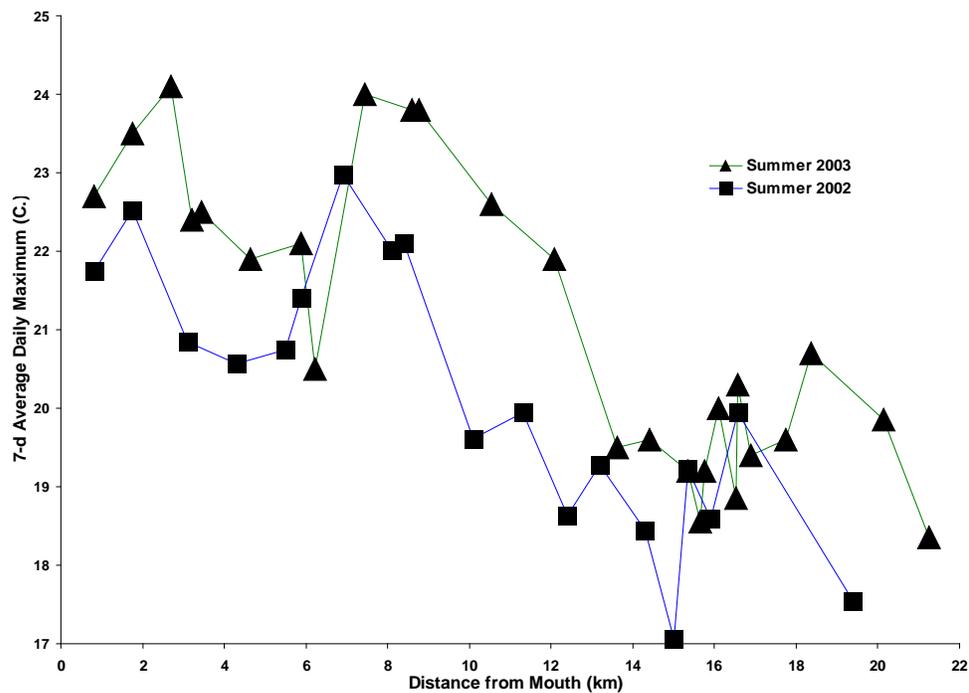


Figure 12. 7-day average daily maximum temperature in degrees celcius recorded by temp-loggers in the West Fork Smith River in summers 2002 and 2003 (Cairns et al. 2005)

Refuge search: In the Summer of 2003 a walking refuge search was made using temperature probes and thermometers and walking upstream to find areas of water that were cooler than the surrounding area on warm afternoons. The 2004 study sites were chosen from the cold refuges that were found. During the summer of 2004 additional “micro refuge” sites were discovered by snorkel surveying. When unusual fish behavior

was noted during a survey, we returned later with a temperature probe and thermometer to determine if the area was a refuge.

Habitat measurements were taken at each of the four sites (Table 1). Location (distance from nearest flasher) was recorded. Flashers are markers set every fifty meters of stream channel on the entire mainstem West Fork Smith River, starting at the mouth. Substrate (cobble, sand, bedrock etc.) was estimated visually as a percentage in each refuge area. For example: “Refuge substrate is 50% bedrock, 25% sand, 15% gravel and 10% detritus.” Dimensions (length, 3 widths, deepest depth, average depth, and pool tail crest) were taken in the refuge, adjoining pool, pool below and pool above. All structural features were recorded (such as boulders, large wood, debris jams, tributaries,). At each site one Onset StowAway TidbiT® temperature logger was deployed in the refuge and one in the adjoining pool (total of 8). The pair of temperature loggers recorded the temperatures in the mainstem and the refuge simultaneously throughout the summer (Fig. 13).

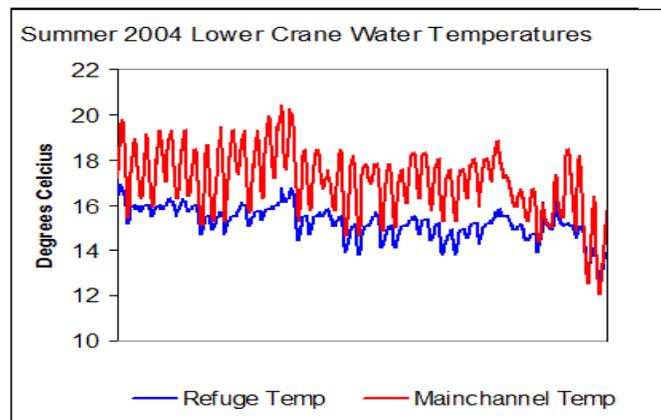


Figure 13. Refuge and Main Stem Temperatures at Lower Crane Creek Refuge between 8/5/2003 and 8/10/2003

Table 1. Habitat characteristics at the four study sites, summer 2004

GENERAL AREA

SITE	UNIT ID	HABITAT TYPE	MAX DEPTH (cm)	PTC DEPTH (cm)	WETTED WIDTH (m)	LENGTH (m)	FEATURES
CRANE	PB	DP	72	33	14.5	20	BR, 2 BW
	ADJ	DP	85	19	13.7	67.8	LW, TR
	PA	GL	29		8.9	31	BW
LOWER CRANE	PB	DP	100	3	20.1	33.5	2BW
	ADJ	DP	90	12	13.3	80.5	BD,LW,TR
	PA	SP/AL	55	15	12	32.2	BR, BD
MOORE	PB	SP	78	2	14.3	60.6	SW
	ADJ	DP	92	4	11.7	66	BW, TR, LW
	PA	DP	110	10	13.1	50.2	BW, LDJ
UPPER	PB	BP	70	2	11.4	41	OV
	ADJ	BP	100	3	8.4	36.5	CB, D
	PA	GL	18	11	3.6	15.1	OV

REFUGES

SITE	HABITAT TYPE	MAX DEPTH (cm)	TOTAL SURFACE AREA (m ²)	FEATURES
CRANE	DP	20	5.2	TR,BD
LOWER CRANE	AL	20	5.0	RW,BR
MOORE	DP	92	6.6	BR,LW
UPPER	BP	100	4.5	CB

Key:

Unit ID-	Habitat Type	Pool Features
PB=Pool Below Refuge	DP=Dammed Pool	BR=Bedrock
ADJ=Pool Adjoining Refuge	GL=Glide	BW=Boulder Weir
PA=Pool Above Refuge	SP=Scour Pool	SW=Small Woody Debris
	AL=Alcove	LW=Large Wood
	BP=Beaver Pond	CB=Cobbles
		TR=Tributaries
		BD=Boulders
		D=Detritus
		OV=Overhanging Vegetation
		LDJ=Large Debris Jam

PIT-tagging took place in early July 2004. At each refuge all the coho salmon that were over 60mm fork length were PIT-tagged as time and water temperatures allowed. No tagging occurred when water temperature exceeded 16°C as dictated by animal care and use permit guidelines for the health of the test subjects (Fig. 14).



Figure 14. PIT-Tagging: coho salmon were measured, weighed, assessed for blackspot parasite and injected with a passive intergrated transponder (PIT) tag.

A total of 226 coho salmon were tagged out of 649 that were processed (Table 2). In some areas few or no fish were tagged because water temperatures over 16°C did not allow tagging according to the project permit. Processing included measuring the fork length, weight, and a blackspot infestation severity. Blackspot is a *Neascus* parasite; severity was

estimated on a scale from zero to three, with zero indicating absence of Neascus parasite and three indicating heavy infestation severity (Cairns et al. 2005). A small PIT-tag reader was set up in the entrance to Lower Crane Creek Refuge. This was the only site with a portable stationary reader because the narrow channel to the refuge allowed for a passage small enough for the reader to be effective.

Table 2. Number of coho salmon tagged at each study site.

	Lower Crane	Crane	Moore	Upper
# tagged in refuge and adjoining pool	17	42	36	17
# tagged in pool below	38	2	0	36
# tagged in pool above	0	18	0	0
total tagged	55	82	36	53
total processed (tagged fish + too small to tag)	145	235	124	145
total tagged for all sites	226			

Monitoring: We visually counted the number of fish (coho salmon and trout) using refuges at morning (8-10AM), mid-day (12-3PM) and late afternoon (4-6:30PM). Generally, this was done by snorkel survey; in the case of Crane Refuge, where the refuge could be viewed from above, counts were made with visual estimation. Counting fish from above was less time-consuming than snorkel surveying. The goal was to check the refuges at least three days per week, and to monitor them at the summer’s peak temperatures as well as at several cooler times. Each refuge was snorkeled at least three times to count juvenile coho salmon in the refuge, adjoining pool, pool below and pool above (Table 3).

Because Crane Refuge was identified in 2002 and was easy to obtain visual counts from without snorkeling, it has more data points. Counts of coho salmon and temperature data were performed at Crane Refuge 35 times: 13 times in the summer of 2003 and 22 times in the summer of 2004.

Table 3. Dates of snorkel surveys at each study site. Each survey included counts of coho salmon in the pool below, refuge, adjoining pool and pool above. Twos Xs indicated that the area was snorkeled twice on one day. Pools were snorkeled with 2-person teams. This table does not include visual counts from above.

	Lower Crane	Crane	Moore	Upper
20-Jul-04			X	X
21-Jul-04		X	X	
23-Jul-04	X	X		
26-Jul-04	X	X	X	
27-Jul-04	XX	XX		X
28-Jul-04			X	
17-Aug-04		X	X	X
18-Aug-04	X	X		

Refuges were seined between at the beginning of summer (July 6, 2004-July 8, 2004) and end of the summer (August 23, 2004-September 2, 2004) to determine growth and condition factor and to check individuals for PIT-tags. In the interim refuge-using individuals were separated out from others in the area by reading the PIT-tagged coho salmon in the refuges during hot times. First, we approached the refuge and en-circled it carefully with block nets to prevent the refuge users from fleeing. Coho salmon in the refuge were scanned with a PIT-tag reader or removed to buckets to be weighed, length measured and blackspot condition

factor recorded (Fig. 15). After this was completed the pools below, above and adjoining were thoroughly seined and the same data was collected for the coho salmon found in them.

Behavior observations at Crane Refuge were collected in two ways. On Wednesday, July 28, 2004 from 15:45-16:27 two snorkelers watching coho salmon in the refuge in four ten-minute observation periods; in alternating periods they watched coho salmon in the main channel. Behavior observations were also collected informally throughout the study period.



Figure 15. Coho salmon being measured to fork length

Data Analysis: I entered the data obtained from habitat surveys, snorkel surveys, PIT-tagging and PIT-tag readers into Excel spreadsheets and used the chart wizard function to make figures of counts of coho salmon versus water temperature. To incorporate the data from the temperature loggers that recorded temperature every 30 minutes for the duration of the study I used the *Hydrostat_Simple_7_2002* macro-spreadsheet designed by Robb Keller of the Oregon Department of Environmental Quality Laboratory Quality Assurance Section. The spreadsheet allowed me to calculate daily or weekly minimum, maximum and average temperatures. It could also be manipulated to show the number of hours or days over various temperature thresholds. Recapture of PIT-tagged individuals at the end of the summer (2004) enabled me to determine differences in specific growth rates between individuals in the refuge and in the adjoining pool for the Moore study site. I used the following equation to calculate daily growth (Busacker et al. 1990):

$$\text{instantaneous growth} = 100 * (\log_e L_2 - \log_e L_1) / (T_2 - T_1)$$

where : L_1 = length at capture (mm)
 L_2 =length at recapture (mm)
 T_2-T_1 =days between tagging and recapture.

RESULTS

Refuge Search

The Summer 2003 walking search of the West Fork Smith River mainstem for cold refuges yielded very few refuges. Less than fifteen areas were found to have the physical characteristics of a cold refuge (water temperature at least 2°C cooler than mainstem water temperature). Cold refuges averaged one every 2.5 kilometers of mainstem. Of this group eight of the areas seemed to be actively used by juvenile coho salmon. The total area of these eight cold refuges was roughly 32 m² compared to 154,922m² total mainstem surface area from the mouth of the West Fork Smith to Beaver Creek. Refuge surface area was 0.00002% of the total mainstem surface area (EPA WFS Database).

Temperature

Typically the temperature in the refuges was at least 2°C cooler than in main channel. One way to summarize temperature data is to determine the number of hours or days over various temperature thresholds. For example, at Lower Crane the refuge never reached temperatures above 22°C from June 27 to September 4 while the adjacent mainstem was over 22°C on 32 days (for a total of 196 hours). Exact hours or days over various thresholds varied at the four sites (Fig. 16 & 17). Upper Refuge diverged from the common pattern because, according to the temperature loggers, it had more hours and days warmer than the nearby mainstem. This may be explained in two possible ways. First the day it was classified as a cold refuge may have been an anomaly, or secondly, the temperature logger may have

spent an unknown number of hours outside of the refuge because nearby beavers repeatedly moved the brick attached to it into a beaver dam structure.

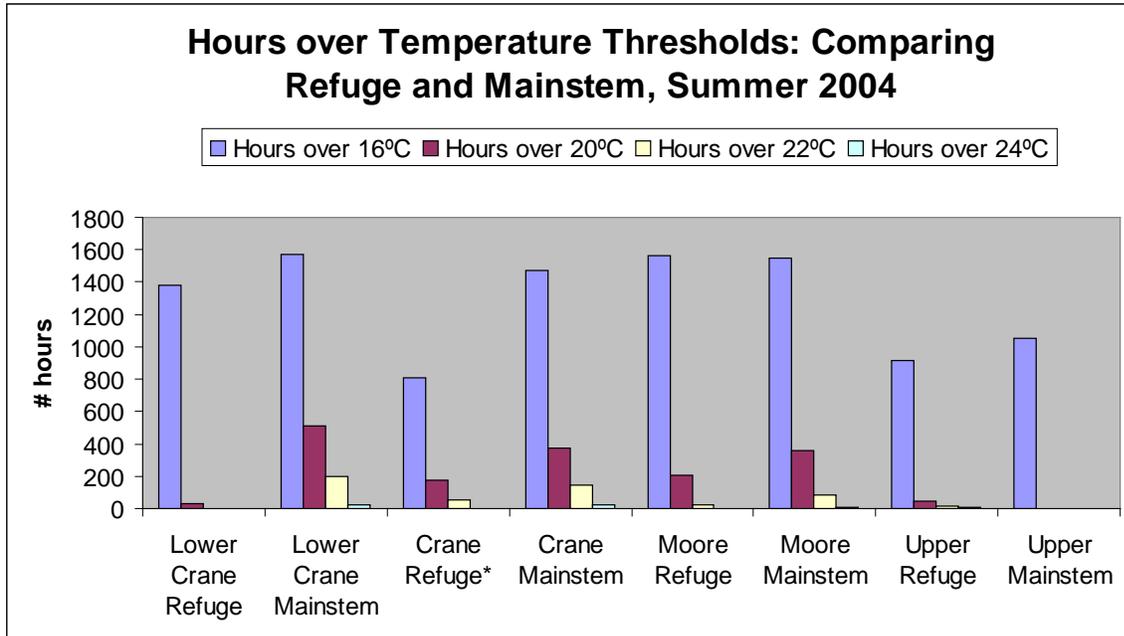


Figure 16. Total hours over temperature thresholds of 16°, 20°, 22° and 24°C from June 27th to September 4th 2004. *Crane Refuge from July 27th to September 4th 2004.

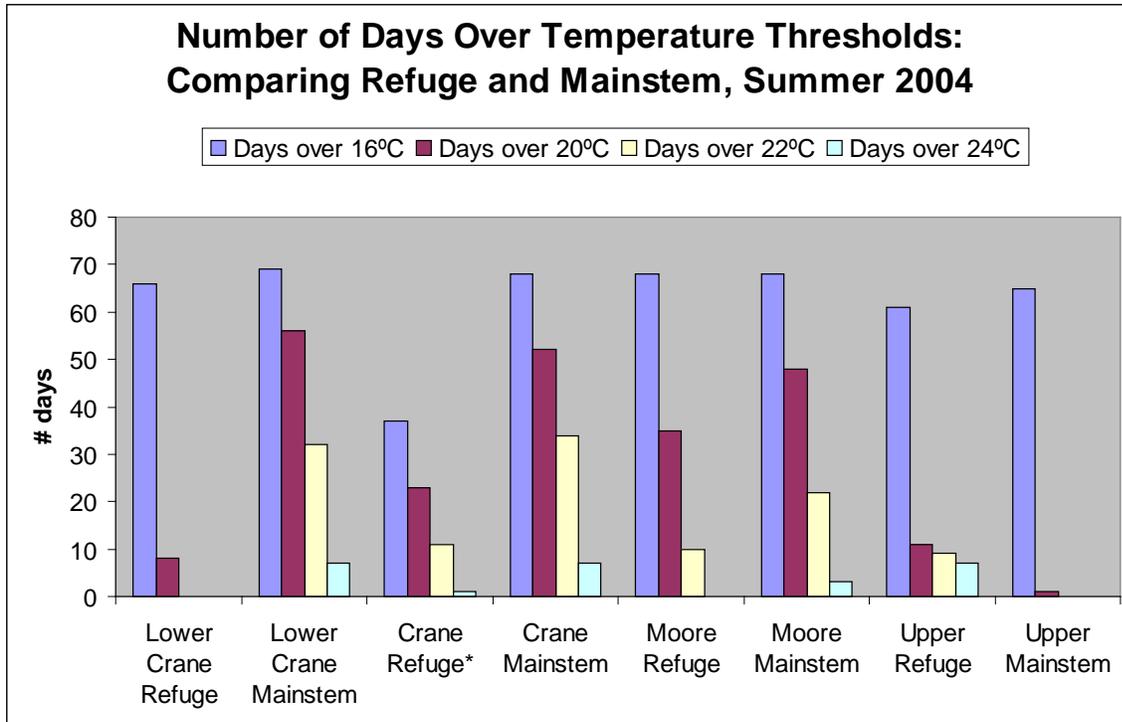


Figure 17. Total days over temperature thresholds of 16°, 20°, 22° and 24°C from June 27th to September 4th 2004. *Crane Refuge from July 27th to September 4th 2004.

Snorkel Data

Compared to other refuges, Crane Creek Refuge had the largest congregations of coho salmon. The number of coho salmon in Crane refuge peaked on hot afternoons around 3PM. Coho salmon stayed close to the bottom in tight ranks; the density of these ranks was greater near the cold source. There were two smaller ephemeral micro refuges in the near vicinity (upstream on left bank) that also reliably had fish when it was hot. There were 512 coho salmon on average in the vicinity (Pool Below, Refuge, Adjacent Pool, Pool Above) of Crane Creek during the 2004 summer. On cold mornings an average of 32 coho salmon could be found in the refuge (6%) of the average total number of coho salmon in vicinity. On average on hot summer afternoons 257 coho salmon were in the refuge (50% of coho salmon in vicinity) (Fig. 18).

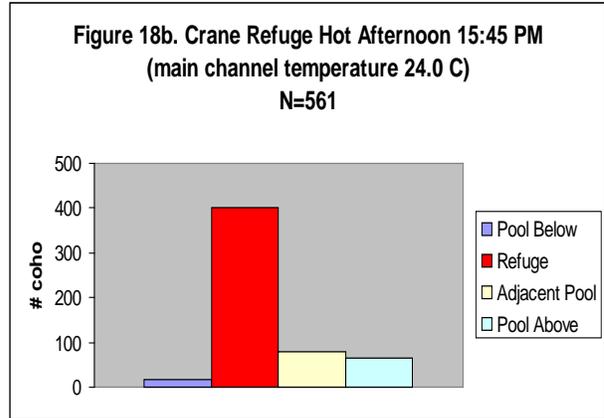
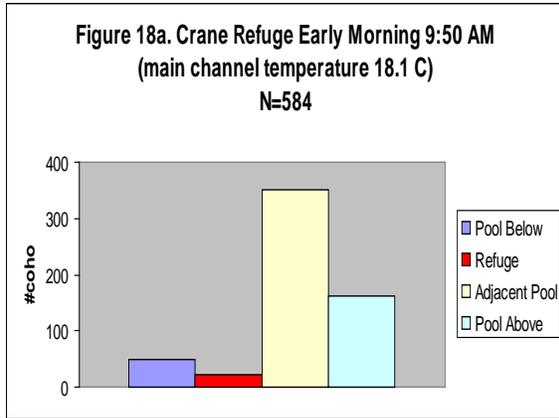


Figure 18. Coho salmon distribution in the area of Crane Refuge transitions from morning to afternoon on July 27 2004. The refuge gained 378 coho salmon and the surrounding area lost 401.

In general, counts of coho salmon in the refuges peaked in mid-afternoon with warmer days yielding the highest counts (Fig. 19).

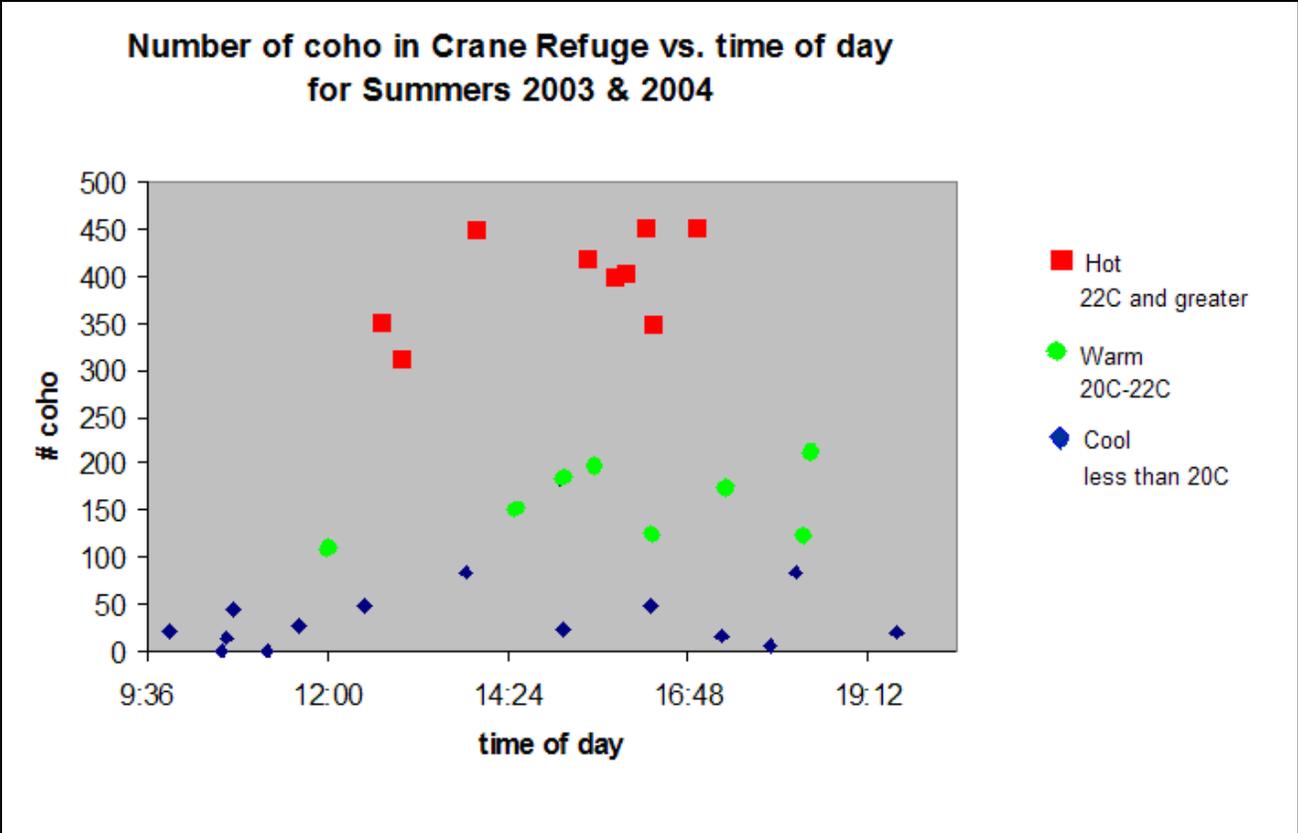


Figure 19. Counts of coho salmon in Crane Refuge with time of day and a mainstem water temperature category: hot, warm or cool.

At Crane Refuge a steady increase in refuge users until late afternoon could often

be observed (e.g. Fig. 20a). Peak refuge use frequently coincided with highest temperature (Fig. 20b).

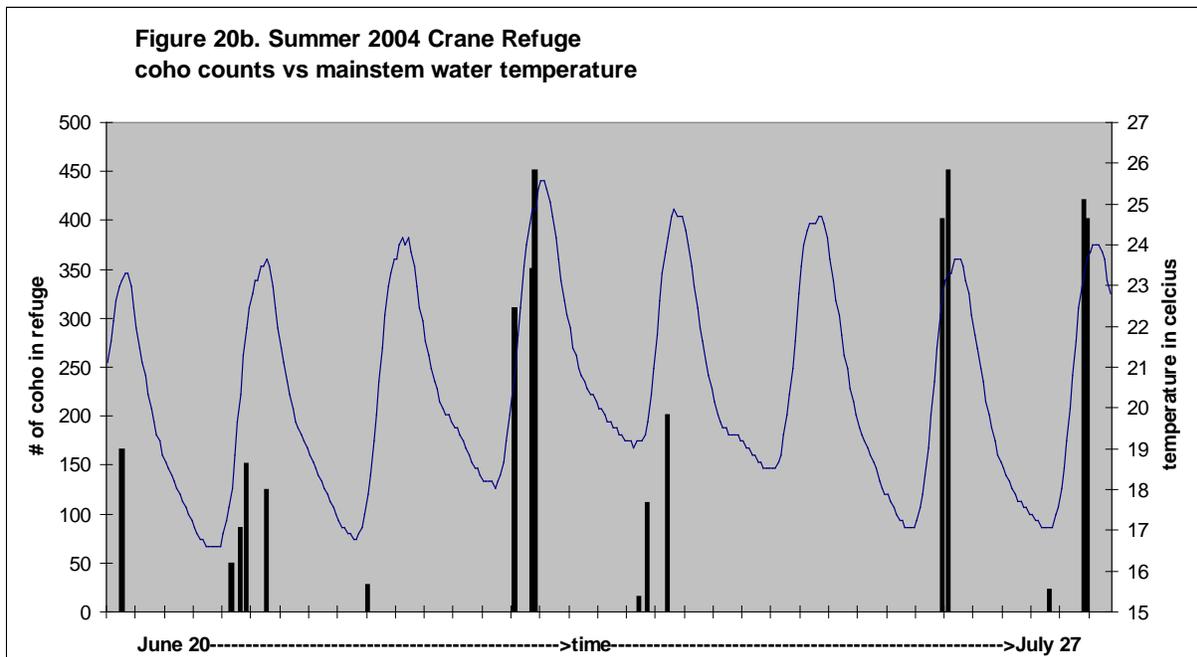
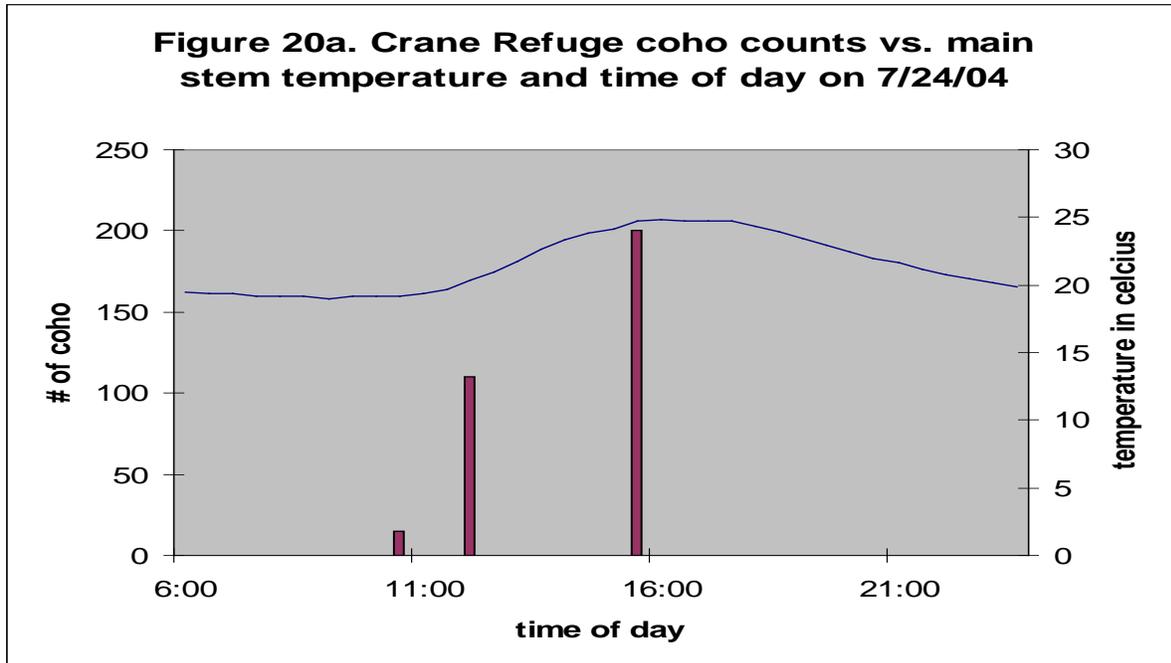


Figure 20. Changes in coho salmon counts at Crane Refuge with mainstem water temperature.

At the other study sites, increase in water temperature generally coincided with increases in refuge use, but the number of coho salmon in the refuges was less (Figs. 21, 22 & 23)

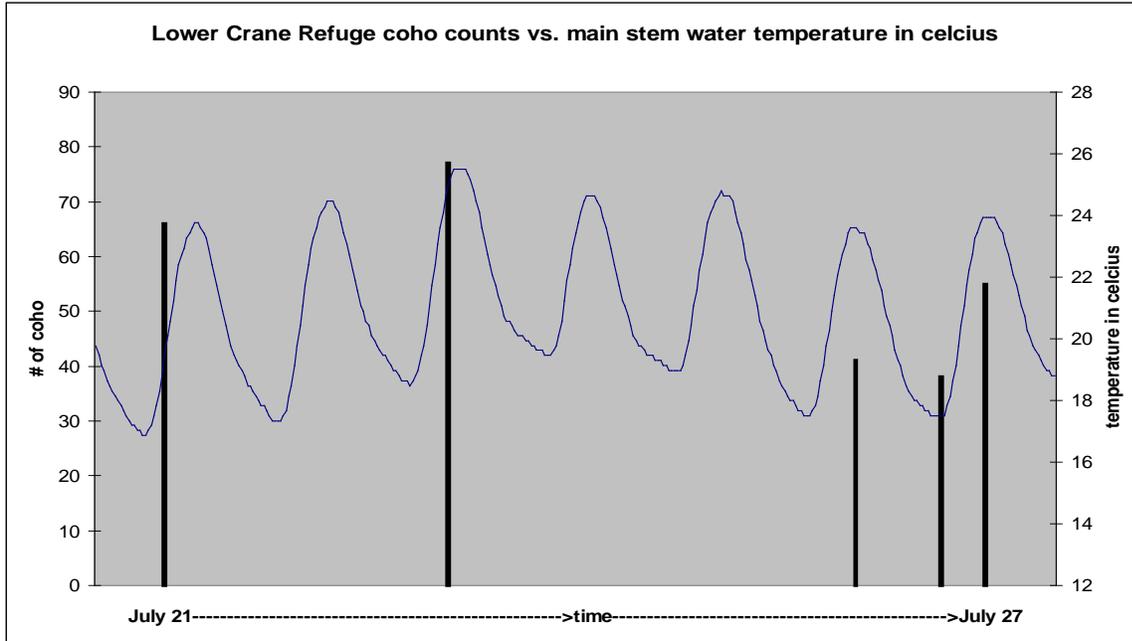


Figure 21. Counts of coho salmon in Lower Crane Refuge versus mainstem water temperatures.

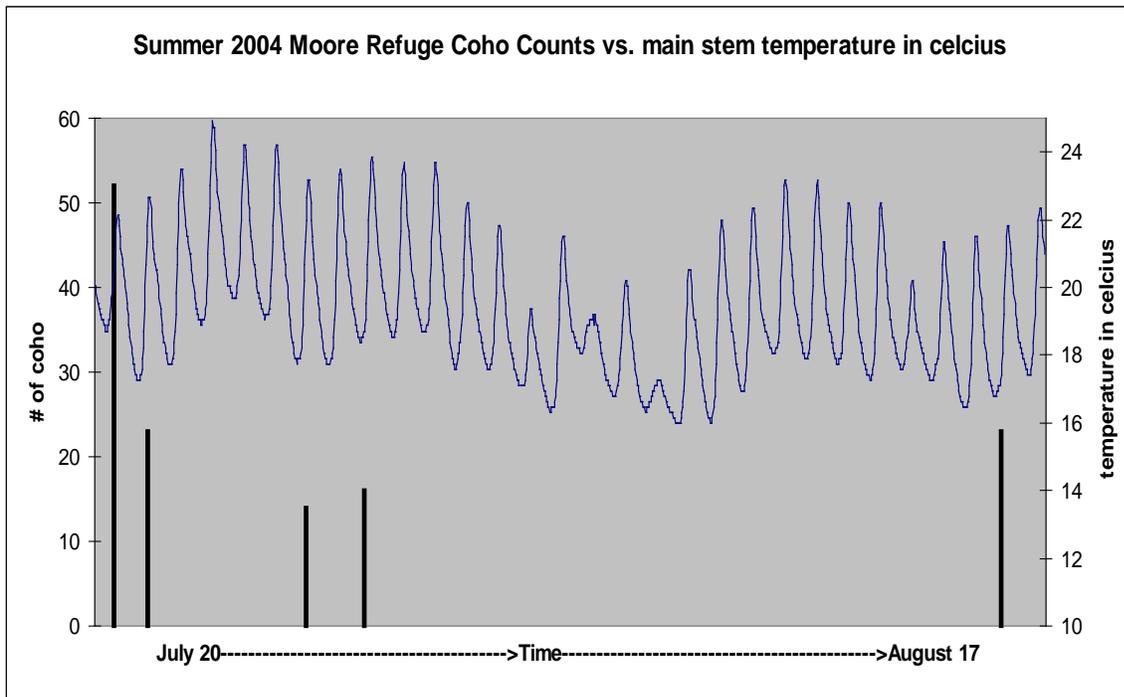


Figure 22. Counts of coho salmon in Moore Refuge versus mainstem water temperatures.

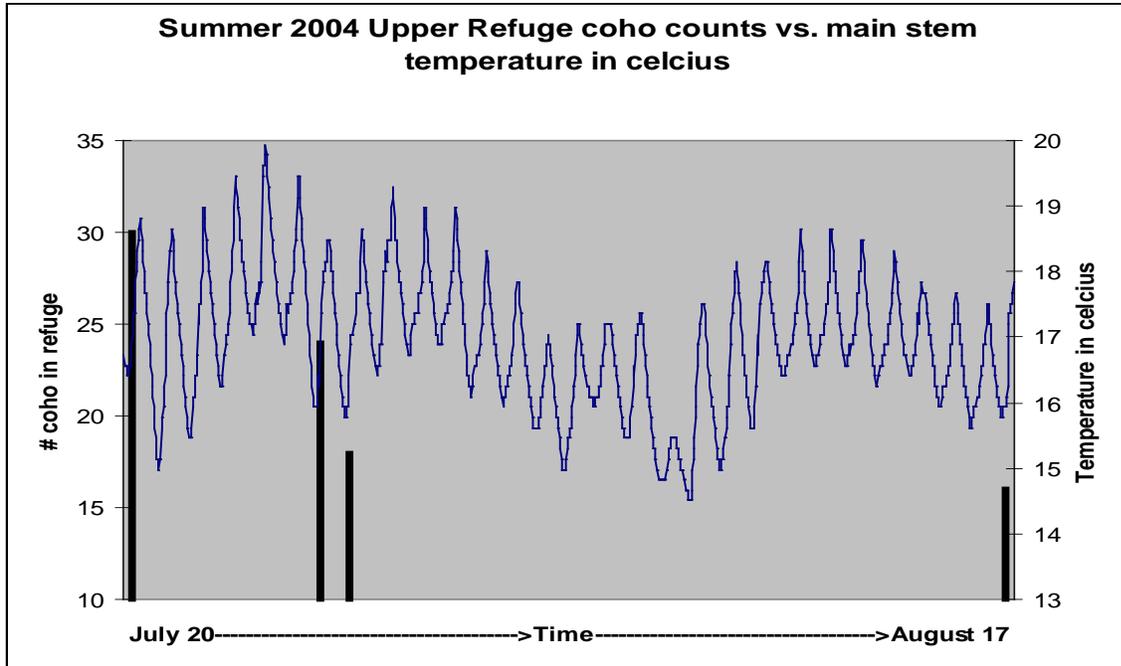


Figure 23. Counts of coho salmon in Upper Refuge versus mainstem water temperatures.

Movement

Of the 178 coho salmon tagged at the start of summer, 50 were identified again at some point during the summer (28%). Lower Crane Refuge had a stationary PIT-tag reader at the entrance. It recorded 84 distinct movements by 6 tagged fish during one week, but no pattern was evident. The remaining 44 tagged fish were detected with the portable reader during walking sweeps or during the end of summer seining to determine length, weight and blackspot condition. Of the 44 individuals that were detected at some point during the summer 35 were detected once and 9 were detected twice for a total of 53 recaptures. Of these 44 individual coho salmon 19 moved into the refuge from a different tagging area and 5 individuals who were tagged in a refuge area were redetected in that refuge area at some point during the summer. Most individuals were detected within one or two pools of the pool that they were tagged in early July (Table 4). However, one individual, traveled from the Crane study site downstream approximately 300 meters to be found in a pool above the Lower Crane site.

Table 4. Two-way table of starting tagged location and detection locations for 52 of the 53 PIT-tagged coho salmon detections at Lower Crane, Crane, Moore and Upper study sites during Summer 2004. PB=Pool Below, AP=Adjoining Pool, PA=Pool Above, REF=Refuge.

		Recapture Location											
		Crane AP	Crane PB	Crane REF	L. Crane AP	L. Crane REF	Moore AP	Moore PB	Moore REF	Upper PA	Upper PB	Upper REF	Grand Total
Tagged Location	Crane AP	1		4									5
	Crane PB		1										1
	Crane REF			1									1
	L. Crane AP				1	3							4
	L. Crane REF					5							5
	Moore AP						7	2	9				18
	Upper AP										1		1
	Upper PA									8		3	11
	Upper PB									2			2
	Upper REF									2		2	4
	Grand Total	1	1	5	1	8	7	2	9	12	1	5	52

Growth

Very few fish were successfully recaptured to measure growth. At Moore Refuge tagged coho salmon that were recaptured in the refuge and tagged coho salmon that were recaptured in the adjoining pool grew at similar rates over the summer. A t-test showed no significant difference in growth rates. Moore Refuge was used to compare growth because it was the only site with a sufficient number of recaptured fish in the refuge at the end of the summer. In general, there was little change in size over the study period and four out of five of the coho salmon recaptured outside the refuge either lost length or did not add length (Fig. 24).

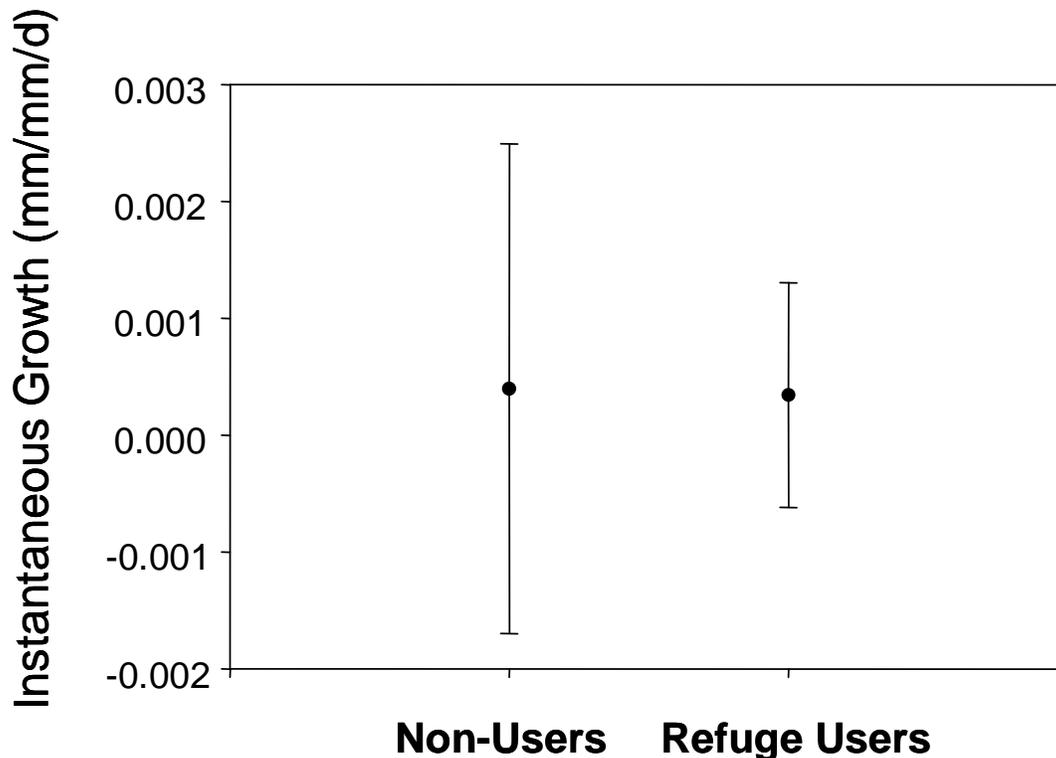


Figure 24. Tagged coho salmon recaptured in Moore Refuge versus tagged coho salmon recaptured in Adjoining Pool. Average growth rate during the 57 day study period. Non-Users n=5, Refuge Users n=4.

Behavior

When two observers rotated ten minute observations of juvenile coho salmon in a refuge and in the main stem on a hot afternoon, fish in the refuge displayed characteristic “refuge” behavior. They sat in tight ranks on the bottom, sharing space with adult trout and reforming ranks after disturbances. In the main stem coho salmon were observed bucking the current, swimming up and down in the water column, and snatching at possible food particles. They did not appear “stressed,” and seemed very active despite the warm water. The divergent behavior of the coho salmon in the refuge and the coho salmon in the main stem suggested a physiological trade-off was occurring.

The coho salmon also used smaller “micro refuges” in vicinity of the larger refuges. The micro refuges were on average 0.5m² and shared the same general temperature

properties of a cold refuge compared to the main channel temperature. Micro refuges were defined as areas that were at least 2°C cooler than the main stem where fish were localized. The refuges and micro refuges were used by fish in the same manner, but less fish could fit into micro refuges. The micro refuges in the study were actually discovered because of fish behavior observed while snorkel surveying in the study site pools. When fish were observed acting like they do in refuges (tight ranks, near the bottom, facing a bank instead of upstream) the area was checked afterward with a thermometer and compared to the main channel temperature. A key difference between micro refuges and cold refuges was the ephemeral nature of micro refuges.

On hot afternoons (main channel water temperature greater than 23°C) juvenile coho salmon shared refuge space with adult cutthroat trout; the deeper refuges (Moore and Upper) were dominated by large trout. For example in Moore Refuge trout regularly used up to 80% of the refuge space while coho salmon consistently used 15% or less. In the deep refuges trout used most of the available space. They seemed to crowd out the juvenile coho salmon which either did not settle in the area or stayed to one corner of the available cold space. In shallower refuges (Crane and Lower Crane), the juvenile coho salmon and adult trout sat together in tight ranks during the hot part of the day (Fig. 25). However, the coho salmon would leave a small buffered zone of free space between the adult trout and themselves.





Figure 25. Fish behavior in refuges: coho salmon sit close to the bottom in tight ranks.

DISCUSSION

Local fidelity to mainstem sites, in association with peak temperatures in mid summer, best describes juvenile coho use of coldwater refuges at West Fork Smith River (Table 4, Figs. 20, 21, 22 & 23).

Crane Refuge was from start to finish of the project, the most impressive refuge in terms of the numbers of juvenile coho salmon and adult trout that reliably gathered in a small area. This refuge is within a large pool with a large number of coho salmon that have the

opportunity to utilize the refuge. Because the area above and below the refuge for several hundred meters is dominated by shallow water over open bedrock and little shade cover (Fig. 26) water surrounding the refuge heats quickly when the sun is out. Fish in this location do not seem to have alternative refuges. They may linger in the area hoping to go up Crane Creek, but the mouth of Crane Creek is usually subsurface under gravel during the majority of the summer, making it impassible. Crane Refuge became the key study location for behavioral observations because it was so consistent.



Figure 26. Above Crane Refuge: wide open bedrock lends a hand to heat the water up.

The other refuge sites did not attract fish in the same numbers as Crane Refuge. Crane Refuge was located where the average stream temperatures were warmest. Habitat conditions that contributed to high peak temperatures, size of the refuge, and local fidelity to the site may all contribute to the relative higher fish numbers at this site. In contrast, the Upper refuge was a patch of cold water in an area of cool water. Coho salmon in the Upper Refuge did not experience as many hours at high water temperatures as fish at the lower three

sites (Lower Crane, Crane and Moore). Surveys at the Upper refuge were complicated by a low number of PIT-tag detections until the final seining effort. Nevertheless, I never saw coho salmon in this refuge using the area in the same way as juvenile coho salmon at the lower three refuges. Instead of sitting in tight ranks on the bottom, they always seemed to be swimming at various depths.

Kenneth Rodnick (Idaho State University) came to study juvenile coho salmon physiology in 2004 and 2005. His crew found some interesting differences between coho salmon who lived in the lower main stem near Lower Crane refuge (hottest average main stem temperatures) and an upper main stem site near the Upper refuge (coolest average main stem temperatures). In their 2004 sample of 25 coho salmon from each of the two sites they found that body weight was on average greater at the Upper site as was length (fork length). They also found a higher rate of blackspot infection at the Lower Crane site. Five blood parameters were measured: hemoglobin, hematocrit, free fatty acids, triglycerides and glucose. Coho salmon at the upper site had more hemoglobin and a higher percentage on their hematocrit on average. These two indices of oxygen carrying-capacity were higher in the cold water environment. Coho salmon at the Upper site also had much higher triglycerides and free fatty acids which may reflect better nutritional input for fish in cold water or higher metabolic rate and energy demands for the coho salmon at the Lower Crane site. This may explain some of the behavior that was observed near Crane Refuge where coho salmon were observed feeding in the main channel or sitting still in the refuge or micro refuges during high mainstem water temperatures.

Of the study refuges, Moore refuge had the most refuge space available (Table 1). It tended to be dominated by several large trout. When coho salmon juveniles used the refuge they aggregated together in one corner of the cold water and were easily spooked. Perhaps,

more aggressive fish that can monopolize an area, making deeper cold refuges less useful to juvenile coho.

Initially, I believed that only the larger refuges were providing colder habitat for the juvenile coho salmon at maximum summer water temperatures. Because refuge space was not abundant, it seemed impossible that the entire juvenile coho salmon population of the West Fork Smith River could be benefiting from the refuges because of the lack of space. However, I found four micro refuges in the study area. I was able to find them because of the repetitive snorkel surveying areas on the very hottest days of the year. When the initial search of the entire main stem was performed in Summer 2003 it was impossible to be everywhere in the watershed on the hottest days; consequently we searched on any warm days, and it was harder to distinguish areas that could be cooler at high temperatures. In Summer 2004, I realized that there could be many more micro refuges (possibly larger refuges too) that were missed in the 2003 search or that became micro refuges in 2004. Comparing walking surveys with temperature probes to snorkel surveying, I think the more thorough way to find refuges and micro refuges is snorkeling or a combination of snorkeling and temperature probes. A surveyor with a temperature probe must bring the probe close to all areas of a pool, which can be time-consuming and can cause accidental mixing of water ahead that has not yet been surveyed. In contrast, a snorkeler in the West Fork Smith River can work up a pool quickly looking for fish behavior that indicates a cold refuge because of the good water clarity, without having to go to every sector of the pool (Fig. 27).

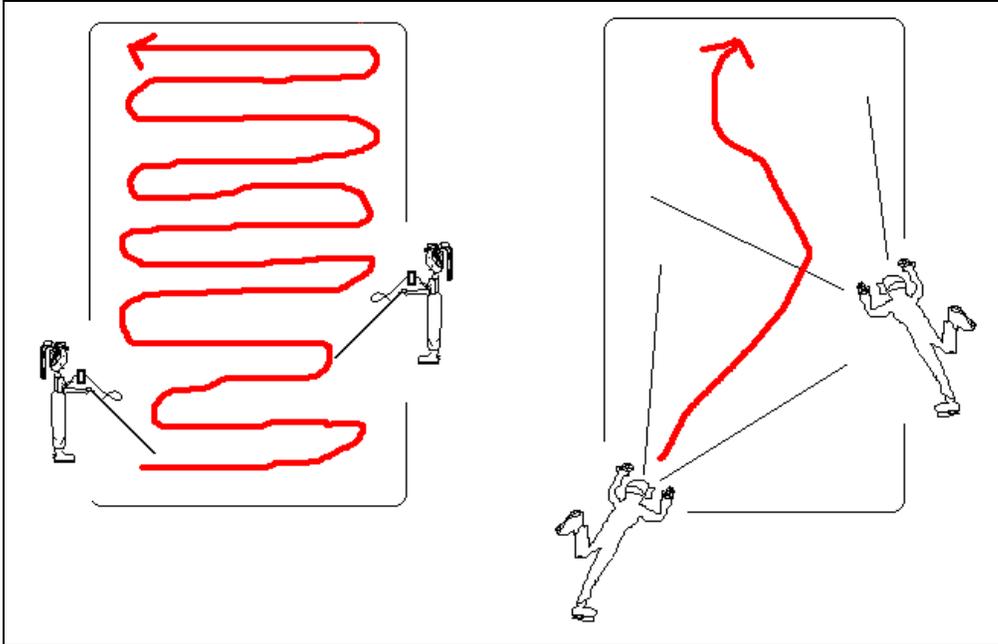


Figure 27. Two search methods to find cold water refuges: Temperature probing every part of the pool or snorkel surveying to search for typical cold refuge fish behavior.

Behavioral Trade-off?

The overall energy balance of ectothermic animals such as coho salmon is dependent on certain environmental variables. Temperature and food are associated with net energy gain and growth in fishes (Crowder et al. 1983). In the behavior observations we noted that when main channel water temperatures were high coho salmon tended to either be hunkered down in refuges or foraging for food in the main channel. Two survival strategies seem evident: either coho salmon can sit still in the refuge and minimize heat stress while conserving energy or coho salmon can expose themselves to heat stress and gain energy by constantly feeding. This could be pursued in future studies.

Difficulties of data collection

A general difficulty for making timely observations during the entire project was the logistical problem of watching fish at multiple places in a limited time when refuges were at the very hottest.

Another major problem I encountered was not being able to PIT-tag enough juvenile coho salmon at the beginning of the summer. This occurred for several reasons. There were not very many coho salmon that were long enough (greater than or equal to 60mm) to tag at the start of the summer. Coho salmon generally begin to use the refuges when the water temperature exceeds 20-24° degrees, however, because the project permit required tagging to cease at temperatures above 16°C, when coho salmon were not yet using the refuges. This meant that I was forced to tag as many individuals as possible in each refuge area and then count on later portable PIT- tag reader hits to determine which of the tagged fish were refuge-users. Also, I encountered problems with the accuracy of the balance and for some of the tagged fish only lengths were recorded. Another problem was that I was unable to tell the direction that tagged fish swam through the stationary reader at the Lower Crane site. I had to assume whether they were swimming into or out of the refuge at the recorded times.

Perhaps the greatest problem that I encountered was that I did not recapture or re-find many of my original tagged fish. I think this occurred for various reasons. First, we encountered frequent problems getting the portable PIT-tag reader to have a wide enough range to get it near enough to fish to read their tag. Secondly, as mentioned above the number of PIT-tagged fish was limited. Finally, the day we attempted to recapture at Crane Refuge, was immediately following an end of summer rain storm that made seining difficult.

After collecting the end of summer weight length and condition data for my tagged fish in August/September 2004, the research I had proposed for this project was finished. However, the fish that were tagged were still at large. I was curious if the system of

stationary readers that is in place in the West Fork Smith had picked up any of these fish or if the periodic portable PIT-tag reader sweeps throughout the winter months had found any of the tagged fish. Unfortunately, when the recapture database was searched for my tags in the time period from the end of the refuge project until September 2005, none were found. Some possible explanations are that the project coho salmon suffered a high mortality rate, possibly due to being tagged just before the hot period of the summer. Another possibility is periodic malfunctions in stationary PIT-Tag readers, or the removal of the smolt trap during high flow when many juveniles leave the watershed. Detecting project coho salmon leaving the system was limited and none of the coho salmon tagged in this project were detected.

CONCLUSION

At temperatures above 20°C in midsummer, juvenile coho salmon use both refuges and micro refuges at West Fork Smith River. Because of the dynamic nature of refuges and micro refuges and the difficulty in locating and monitoring them, it is debatable whether the West Fork Smith River has enough area in refuges and micro refuges during the summer to make an impact on basin wide juvenile survival rates. Differences in peak temperatures, refuge morphology (such as depth) and presence or absence of large trout resulted in highly variable patterns of use by juvenile coho salmon at the four cold refuge sites in this study. Because of the large number of juvenile coho salmon in the adjoining pool, the open bedrock morphology with little cover and the lack of access to Crane Creek during the summer Crane Refuge had a set of conditions that resulted in the largest coho salmon aggregations throughout the summer. Over half of the coho salmon in the local area (257 out of 512 total in the pools above, below and adjoining the refuge) could be found in Crane Refuge at peak mainstem temperature.

SOURCES

- Busacker, G.P., Adelman, I.R., Goolish, E.M. 1990. Growth. Pages 363-387 in C.C. Schreck and P.B. Moyle, editors. *Methods for Fish Biology*. American Fisheries Society, Bethesda, Maryland.
- Cairns, M.A., Ebersole, J.L., Baker, J.P., LaVigne, H.R., Davis, S.M., Wigington, P.J. Jr.. 2005. Influence of Summer Stream Temperatures on Black Spot Infestation of Juvenile Coho Salmon in the Oregon Coast Range. (in press)
- Crowder, L.B. and Magnuson, J.J. 1983, Cost-benefit analysis of temperature and food resource use: a synthesis with examples from the fishes. Pages 189-221 in W.P. Aspey and S.I. Lusic, editors. *Behavioral Energetics: The Cost of Survival in Vertebrates*. Ohio State University Press, Columbus.
- Ebersole, J.L., Wigington, J.L. Jr., Baker, J.P., Cairns, M.A., Church, M.R., Compton, J.E., Leibowitz, S., Hansen, B., Miller, B.. 2005. Juvenile coho salmon growth and survival across stream network seasonal habitats. (in review)
- Ebersole, J.L., Liss W.J. and Frissel C.A. 2001. Relationship between stream temperature, thermal refugia and rainbow trout *Oncorhynchus mykiss* abundance in arid-land streams in the northwestern United States. *Ecology of Freshwater Fish* 10:1-10.
- Ebersole, J.L., Liss W.J. and Frissel C.A. 2003. Thermal heterogeneity, stream channel

Morphology and salmonid abundance in northeastern Oregon streams. *Canadian Journal of Fisheries and Aquatic Sciences* 60:1266-1280.

McCullough, D.A. 1999. A review and synthesis of effects of alterations to the water temperature regime on freshwater life stages of salmonids, with special reference to chinook salmon. US Environmental Protection Agency, Region 10 No. 910-R 010. Seattle, WA.

Welsh, H.H., Jr., Hodgson, G.R., Harvey, B.C. 2001. Distribution of juvenile coho salmon in relation to water temperature in tributaries of the Mattole River, California. *North American Journal of Fisheries Management* 21:464-470.

Some information for background and figures was obtained from the United States Environmental Protection Agency National Health and Environmental Effects Research Laboratory Western Ecology Division Watershed Ecology Branch (US EPA NHEERL WED WEB), Corvallis, OR unpublished database of temperature, habitat and coho salmon movement information for the West Fork Smith River. This information is cited as "EPA WFS Database" in the text.

All photos are property of the author.