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JUVENILE COHO SALMON BEHAVIOURAL CHARACTERISTICS IN KLAMATH RIVER SUMMER THERMAL REFUGIA

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ABSTRACT

During the summer in the main-stem Klamath River, juvenile salmonids respond positively to cooler tributary temperatures by congregating in large schools at the mouths of these tributaries, referred to as thermal refugia. The purpose of this paper is to summarize results from coho salmon (*Oncorhynchus kisutch*) thermal refugia studies conducted since 2006 in the Klamath River. Results showed that juvenile coho salmon started using thermal refugia when the Klamath River main-stem temperature approached approximately 19 °C. The majority of the juvenile coho salmon within the studied thermal refugia were found in the slower velocity habitat associated with cover. Juvenile coho salmon counts in the studied thermal refugia dramatically decreased at temperatures >22–23 °C, suggesting that this approximates their upper thermal tolerance level. Although some juvenile coho salmon were very mobile, others chose, until smoltification, to rear in the mouths and lower reaches of non-natal tributaries where thermal refugia occurred, apparently because of suitable habitat conditions. Information gained from these investigations will improve our knowledge of the life history of coho salmon in the Klamath River drainage and how they use the main-stem river. Copyright © 2010 John Wiley & Sons, Ltd.

KEY WORDS: coho; salmon; Klamath River; thermal refugia

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INTRODUCTION

Juvenile salmonids within the main-stem of the Klamath River respond positively to cooler tributary temperatures by congregating in large schools at the mouths of these tributaries, referred to as thermal refugia. The Bureau of Reclamation (Reclamation), in cooperation with the Karuk and Yurok Tribes, has conducted summer thermal refugia studies in the main-stem of the Klamath River since 2003, with emphasis on the use of refugia by juvenile coho salmon (*Oncorhynchus kisutch*) (Sutton *et al.*, 2004, 2007). This manuscript summarizes observational behaviour data obtained from these studies conducted during 2006 through 2008 with the following objectives:

(1) 2006: Investigate coho salmon juvenile thermal refugia temperature tolerances and microhabitat requirements.
(2) 2007: Determine spring onset of thermal refugia use by juvenile coho salmon.
(3) 2008: Continue to investigate thermal refugia microhabitat suitability requirements and assess juvenile coho salmon mobility in late summer and fall.

Previous observations showed that juvenile salmonids generally selected habitats commensurate with species-specific behavioural needs within their thermal tolerance range (Bisson *et al.*, 1988; Hampton, 1988; Sutton *et al.*, 2007). Information gained from these investigations will improve our knowledge of the life history of salmonids, and particularly coho salmon, in the Klamath River drainage and how they use the main-stem river.

Study area

This paper analyzes 3 years of studies conducted at various tributary confluences with the Klamath River (Figure 1). Based on past observations, these sites contained juvenile coho salmon. Beaver Creek originates in the Siskiyou Mountains of southern Oregon and flows southward into the Klamath River at approximately river kilometre (RKM) 261. The refuge in the main-stem Klamath River generally can be described as a long, shallow area dominated by alluvial outwash from Beaver Creek. The local gradient of Beaver Creek is about a 1% slope, and access to the main-stem Klamath River is unrestricted at typical summer flows (i.e. fish can readily move from tributary to main-stem and back) (Sutton, 2007). Summer flows in Beaver Creek are about 1.4 cubic metres per second (cms) compared to about 28.3 cms in the main-stem.

Tom Martin Creek originates from a high elevation and is the first major tributary that enters the Klamath River downstream from the Scott River confluence. This is a relatively small stream that flows northward, creating a

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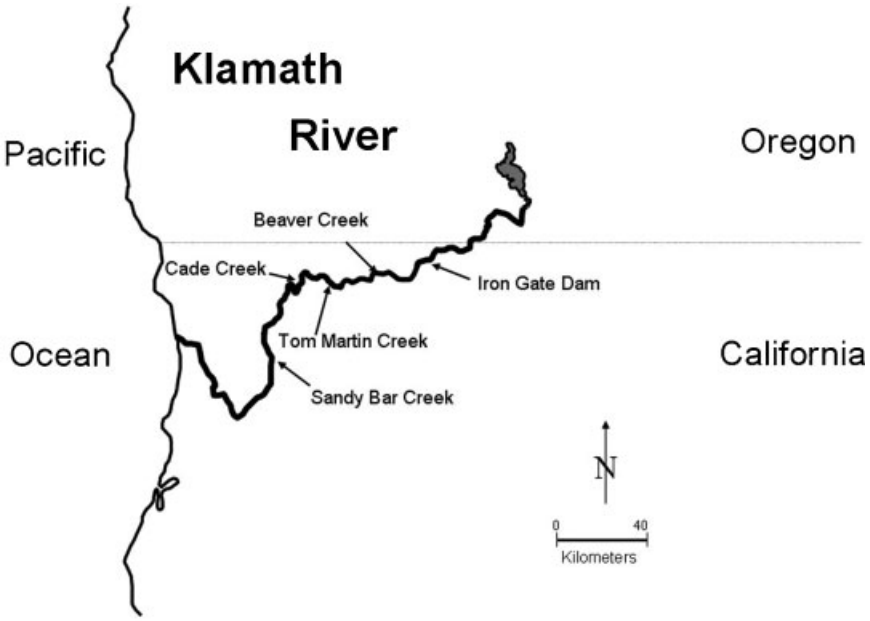

Figure 1. Map of study area for conducting thermal refugia studies in Klamath River.

small thermal plume at its confluence with the Klamath River at approximately RKM 230. Tom Martin Creek mouth enters into a backwater habitat unit that is used by a few juvenile coho salmon. Beechie *et al.* (2005) and Soto *et al.* (2008) found these areas are used for overwintering. The gradient of Tom Martin Creek is a moderate slope. Tom Martin Creek is used by most juvenile salmonids as a refuge, although the upstream distribution of salmon is restricted by a culvert located a short distance upstream from the tributary mouth. Summer flows in Tom Martin Creek are <0.1 cms compared to about 28.3 cms in the main-stem.

Cade Creek is a small tributary that enters the Klamath River upstream of Happy Camp, California at RKM 177. Like Tom Martin Creek, most juvenile salmonids use Cade Creek as a refuge, not the small plume at the confluence. At low base main-stem flows (<0.1 cms), Cade Creek is perched above the Klamath main-stem with flows about 28.3 cms, resulting in a very steep slope at the confluence. As a result, there is a dramatic water surface elevation difference (>0.5 m) between the top of the slope at the mouth of Cade Creek and the Klamath River. During a survey at Cade Creek on 11 July 2007, juvenile salmonids were observed attempting to jump into the tributary from the main-stem, possibly trying to escape the warm main-stem water temperatures. The main-stem water temperature was 25.7 °C while the Cade Creek temperature was 17.0 °C at 13:00 h. This behaviour has been seen in other creek mouths and it usually occurs early in the summer when fish are starting to redistribute in response to rising temperature.

Sandy Bar Creek enters the Klamath River at RKM 126 near Somes Bar. The Karuk tribe has been trapping, marking and recapturing coho salmon in Sandy Bar Creek near a backwater area as part of a study to assess seasonal movement patterns. The Sandy Bar Creek site is defined as 'a tributary fed-floodplain channel' (Soto *et al.*, 2008). Similar to Cade Creek at base flow, Sandy Bar Creek is perched above the Klamath River and enters the main-stem at a very steep slope. This steep drop in elevation at the confluence makes passage improbable for juvenile salmonids during the summer when flows are low in Sandy Bar Creek (<0.1 cms) and the Klamath River (about 50 cms). Young-of-the-year coho salmon can access the site in search of rearing habitat during late spring when flows are higher and the floodplain channel connects to the main-stem at multiple locations on its upstream end. Like Tom Martin Creek and Cade Creek, there is very little refugia area within the main-stem at the confluence. Sandy Bar has a relatively large refuge within the flood plain channel, but fish likely have trouble locating it during the period when fish seek refugia because of the small thermal plume where it meets the main-stem. In addition, Sandy Bar Creek water warms as it moves across the open bar, which also limits the refugia value at the confluence. Minor stream restoration efforts have been used to create pocketwater habitat by the Karuk Tribe in cooperation with the Middle Klamath Watershed Council (MKWC) to allow easier access for juvenile salmonids entering Cade Creek and Sandy Bar Creek.

METHODS

Methods varied among Klamath River thermal refugia, depending on the objectives of the study and year (Table I).

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Table I. Methods used at Klamath River thermal refugia, 2006–2008

Technique	2006	2007	2008
Beaver Creek			
Intensive fish counts (snorkeling)	x	x	x
Microhabitat use	x		x
Temperature monitoring in tributary and main-stem	x	x	x
Tributary flow measurements	x		x
Mark and recapture (seining-freeze branding)			x
Tom Martin Creek			
Intensive fish counts (snorkeling)	x	x	x
Microhabitat use	x		x
Temperature monitoring in tributary and main-stem	x	x	x
Mark and recapture [seining-passive integrated transponder (PIT) tagging and freeze branding]		x	x
Tributary flow measurements	x		x
Cade Creek			
Mark and recapture (minnow trapping—PIT tagging and freeze branding)		x	
Temperature monitoring in tributary and main-stem		x	
Tributary flow measurements		x	
Sandy Bar Creek			
Temperature monitoring in tributary and main-stem		x	x
Mark and recapture (fyke netting—PIT tagging and freeze branding)		x	x
Microhabitat use			x
Tributary flow measurements		x	x

Instantaneous flow measurements were taken in Beaver Creek and Tom Martin Creek each day that fish counts were conducted in 2006 and 2008. Flow measurements in the Klamath River were retrieved from the United States Geological Survey (USGS) gauge site below Iron Gate Dam. A global water pressure transducer was deployed in Beaver Creek to monitor water levels at 15-min intervals in 2006 and 2008. Temperatures were monitored at all tributaries using Onset Computer Corporation TidBit data loggers.

Reclamation and Karuk tribal personnel monitored 0+ coho salmon juveniles each summer in the Beaver Creek and Tom Martin thermal refugia from late July to late August. One objective of this intensive monitoring effort was to determine microhabitat use, including temperature, by coho salmon in the refugia. Monitoring involved using direct observations through snorkeling. Deviations in 2007 and 2008 from the 2006 intensive fish counting methods include: daytime counts were adjusted to every other hour from 09:00 to 17:00 h, not from 07:00 to 19:00 h; fish counts in 2008 were conducted on 2 days, not 3 days; and temperature monitoring at Beaver Creek and Tom Martin Creek was extended in 2007 and 2008 to include the spring and early fall season.

Fyke net and minnow traps were deployed in Sandy Bar Creek and Cade Creek between March and June 2007 to capture juvenile coho salmon. Juvenile traps were monitored a minimum of once daily by tribal biologists. Traps were removed or secured during high streamflows. Tribal biologists closely observed fish behaviour (at the traps as well as upstream of and downstream from the trap sites) to ensure that the traps did not block passage to migrating adult salmonids. Seining was conducted between March 2008 and April 2009 to capture juvenile coho salmon at the Tom Martin Creek refuge. Seining involved a minimum of two tribal researchers pulling the seine through shallow waters along the shoreline of the main-stem Klamath River and Tom Martin Creek.

Juvenile coho salmon were handled by tribal biologists for marking and also to determine species, length, weight and condition. All surfaces which came into contact with coho salmon during handling (i.e. measuring boards, weight scales, nets, etc.) were kept clean and wet to avoid excessive scale or mucus abrasion. When necessary, juvenile coho salmon were nonlethally anaesthetized using Alka-Seltzer® Gold (potassium and sodium bicarbonate) or tricaine methanesulfonate (MS-222). Tribal researchers determined the appropriate dose of anaesthetic considering the research needs as well as the species, size and condition of the juvenile coho salmon to be nonlethally anaesthetized. Air bubblers were used to oxygenate the holding buckets.

Juvenile coho salmon marked using passive integrated transponder (PIT) tags were over 65 mm in length or freeze-branded if <65 mm. For freeze brands, care was taken to ensure that a mark selection design was used to avoid confusion (upon mark recovery) about the location of where marks were applied. Marking and tagging only occurred when water temperatures were $<18\,^{\circ}C$.

Juvenile coho salmon were released back into the habitat unit from which they were taken as soon as possible following research procedures. Coho salmon were allowed

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to recover fully and observed carefully for injury prior to release. Fish with clinical signs of disease or other injury were not tagged or marked.

RESULTS

Temperatures and discharges

In 2006, the hottest day at Beaver Creek occurred on 26 July and 27 July when the air temperature reached 38.5 °C. Coincidentally, snorkeling occurred at Beaver Creek on 26 July. In 2007, the hottest day occurred on 31 July (air temperature = 38.2 °C) and in 2008, the hottest day occurred on 9 July and 15 August (air temperature = 38.6 °C). The average air temperature experienced considerable diel variability during each year; and as the study progressed each summer, the air temperatures generally showed a cooling trend primarily in response to reduced solar radiation (reduced solar altitude and day length). Air temperatures strongly influenced water temperatures. The average water temperatures in the Klamath River reflected this cooling trend. Otherwise, meteorological conditions were relatively stable during the study period.

Figure 2 compares hourly water temperatures in main-stem Klamath River just upstream of Tom Martin Creek and in Tom Martin Creek, illustrating seasonal variability from 25 April 2007 to 26 March 2009. The break in the Tom Martin Creek plot reflects a period of time where water temperatures were not being monitored. More seasonal variability occurs in the Klamath River than in Tom Martin Creek, and Tom Martin Creek remains relatively cool year-round compared to the Klamath River. For example, between 3 April 2008 and 26 March 2009, the average temperature in the Klamath River was 12.6 °C (range 3.2–25.7 °C). The average temperature in Tom Martin Creek during this same time period was 9.4 °C (range 2.9–18.3 °C).

The main-stem Klamath River release from Iron Gate Dam was 28.3 cms during July and August each year. Tom Martin Creek, Cade Creek and Sandy Bar flows were relatively stable during the summer with instantaneous readings near 0.03 cms; substantially lower than in Beaver Creek. Discharge in Beaver Creek near the confluence with the Klamath River showed diel variation and a general decline during the summer. For example, average discharge in Beaver Creek declined from 2.5 cms (range 2.3–2.6 cms) on 30 June 2008 to 1.3 cms (range 1.2–1.4 cms) on 1 August 2008.

Intensive juvenile coho salmon counts

Table II summarizes 0+ coho salmon counts at the Beaver Creek refuge between 2006 and 2008. In 2006, coho salmon numbers at the Beaver Creek refuge were low compared to counts made in 2005, but higher than those in 2004, and reflected relatively moderate year class strength. Based on past observations and the 3-year cycle for coho salmon, it was expected that summer, 2007 would be a weak year class. However, very high coho salmon counts were recorded on 28 June 2007, after which numbers dropped dramatically. Relatively few coho salmon were observed at Beaver Creek refuge in 2008. The most coho salmon observed in the refuge during the 3-year period was 63 at 09:00 h on 28 June 2007 (Table II). At Beaver Creek, where most coho salmon were observed within the main-stem Klamath River thermal refugia in slow velocity water with extensive cover, only two coho salmon observations occurred in the creek

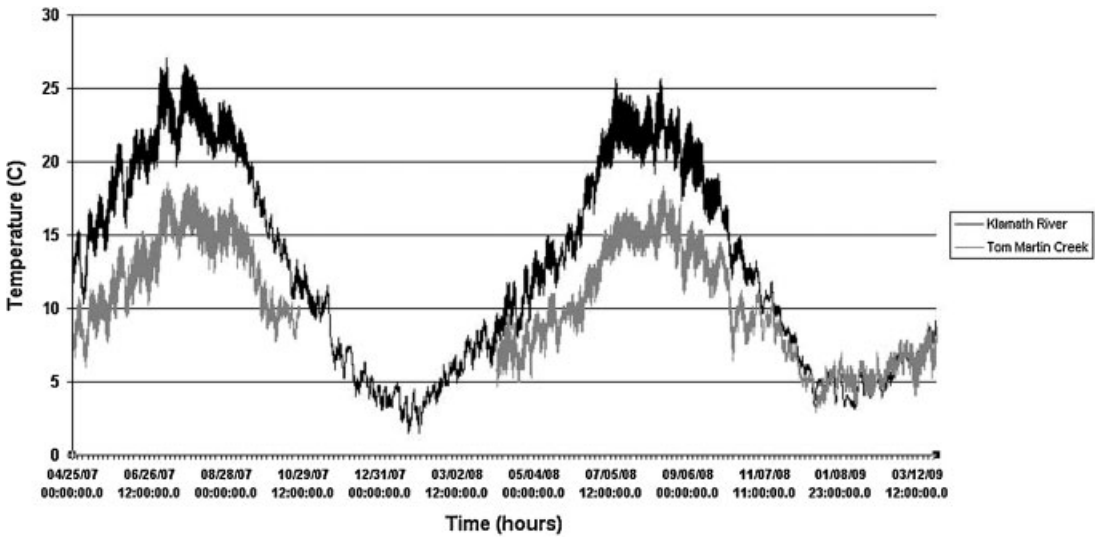

Figure 2. Water temperatures in main-stem Klamath River at Tom Martin Creek and in Tom Martin Creek, 25 April 2007 to 26 March 2009.

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Table II. Coho salmon counts at Beaver Creek refuge and creek, 2006–2008

Time (h)	Date					
	Refuge	Creek	Refuge	Creek	Refuge	Creek
2006	July 26		August 1		August 29	
07:00	17	0	13	0	0	0
09:00	19	0	7	0	0	0
11:00	20	0	16	0	4	0
13:00	25	0	15	0	6	0
15:00	18	0	9	0	8	0
17:00	9	0	9	0	8	0
19:00	8	0	12	0	5	0
2007	June 28		July 23		August 8	
09:00	63	0	4	0	1	0
11:00	62	0	8	0	7	0
13:00	46	0	9	0	3	0
15:00	54	0	7	0	0	0
17:00	50	0	7	0	0	0
2008	July 30		August 12			
09:00	2	0	0	0		
11:00	4	0	4	0		
13:00	4	0	1	0		
15:00	5	0	0	1		
17:00	4	0	1	1		

Table III. Coho salmon counts at Tom Martin refuge and creek, 2006–2008

Time	Date					
	Refuge	Creek	Refuge	Creek	Refuge	Creek
2006	July 27		August 2		August 29	
07:00	0	12	1	27	0	33
09:00	0	21	0	19	0	29
11:00	2	20	0	25	0	26
13:00	8	15	0	20	0	23
15:00	7	17	1	21	0	25
17:00	14	24	1	21	0	26
19:00	7	21	1	23	0	28
2007	June 26		August 2		August 10	
09:00	9	18	0	28	0	55
11:00	9	18	0	78	0	67
13:00	12	24	0	116	0	65
15:00	14	21	0	70	0	62
17:00	11	24	0	74	0	61
2008	July 29		August 13			
09:00	2	107	9	20		
11:00	11	135	7	23		
13:00	12	127	17	24		
15:00	13	116	10	26		
17:00	12	121	15	26		

(12 August 2008; Table II). Similar to past summers, the number of fish counted in the refuge generally increased as each day progressed.

Unlike Beaver Creek, most juvenile salmonids used Tom Martin Creek as a refuge; not the small plume at the confluence (Table III). This observation demonstrates that coho salmon use the main-stem Klamath River and the tributaries to escape warm summer temperatures. Similar to Beaver Creek, the number of fish counted in the refuge generally increased as each day progressed.

Juvenile coho salmon temperature tolerance

Figures 3 and 4 show plots of temperatures and juvenile coho salmon counts during 1 day each in 2006 and 2007, respectively, at the Beaver Creek refuge. These plots represent coho salmon counts in areas (cells) with the most fish. The 2006 plot occurred on the hottest day of the year. Examination of these plots shows that coho salmon numbers increased as temperatures increased up to about 22–23 °C and declined dramatically as temperatures exceeded 23 °C. It was uncertain whether the refuge coho salmon numbers declined in late afternoon because they were dying from chronic lethal high temperatures or because they moved to cooler locations, such as Beaver Creek. Divers reported seeing some very dark coho that looked stressed and lacked the normal flight response when encountered. It should be noted that we were unable to mark and tag fish at the Beaver Creek refuge to track movements because water temperatures were >18 °C.

Mobility of coho salmon using thermal refugia

Mark and recapture results from Tom Martin Creek provided some information on the mobility of juvenile coho salmon that utilized thermal refugia in the Klamath River (Table IV). Personnel from the Karuk Tribe PIT tagged a total of 174 juvenile coho salmon at Tom Martin Creek between August 2007 and April 2009 and recaptured 78 during that same period using seines and fyke nets. Fish initially marked averaged 73 mm in length (55–103 mm range). No juvenile coho salmon were captured in Tom Martin Creek that exhibited clinical signs of disease (swollen abdomen, lesions and pale gills), although one fish captured on 4 August 2008 displayed a physical injury from a suspected avian predator attack and was not tagged. None of the 16 fish tagged in the main-stem Klamath River near the mouth of Tom Martin Creek were recaptured with subsequent sampling. Of those fish recaptured within Tom Martin Creek, most were located where they initially were tagged. However, four marked fish were recaptured further downstream—one by seine 24 RKM downstream at Fort

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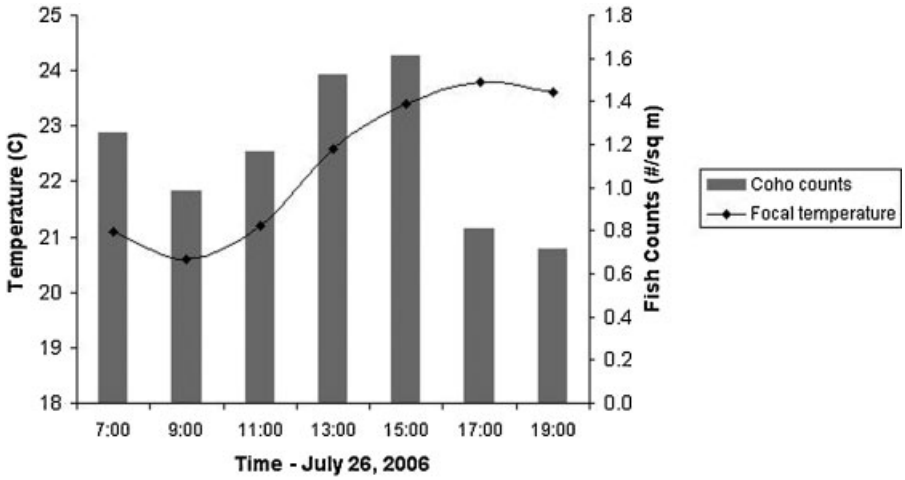

Figure 3. Juvenile coho salmon counts in Beaver Creek thermal refuge as temperatures increased during 1 day in 2006.

Goff Creek in September 2007 (Table IV) (Hillemeier *et al.,* 2009). Two coho salmon that were marked in Tom Martin Creek on 15 September 2008 were detected using a remote PIT tag detection antenna array 55 RKM downstream near Happy Camp at the Bulk Plant; one on 2 January 2009 and the other on 28 April 2009. The Yurok Tribe recaptured one Tom Martin fish that was tagged on 4 August 2008. The coho salmon was caught in lower Waukell Creek, a tributary of the Klamath River near the ocean, using a fyke net on 29 April 2009.

It is interesting to note that juvenile coho salmon from the 2008-year class were still being recaptured in April 2009 at the same location where they were initially tagged in Tom Martin Creek. For example, two juvenile coho salmon were recaptured multiple times at the same location in Tom Martin Creek between 15 September 2008 and 8 April 2009 (205 days). Growth rate between the two fish averaged 0.11 mm/day. Past data suggests fall/winter movements are tied closely to peak flows (Karuk Tribe database). It should be noted that 2008/2009 peak flows in the Klamath River were much lower than normal: (http://waterdata.usgs.gov/ca/nwis/dv/?site_no=11520500&agency_cd=USGS&referred_module=sw).

Juvenile coho salmon microhabitat utilization

Pooled juvenile 0+ coho salmon observation data taken from Beaver Creek and Tom Martin Creek main-stem thermal refugia and Tom Martin Creek and Sandy Bar Creek in 2006 and 2008 showed highest use for mean column velocities ranged between 0.07 and 0.21 metres per second (mps) and depths ranged between 0.61 and 1.00 m. Comparatively, habitat suitability criteria developed by Hardy *et al.* (2006a) indicated that most juvenile coho

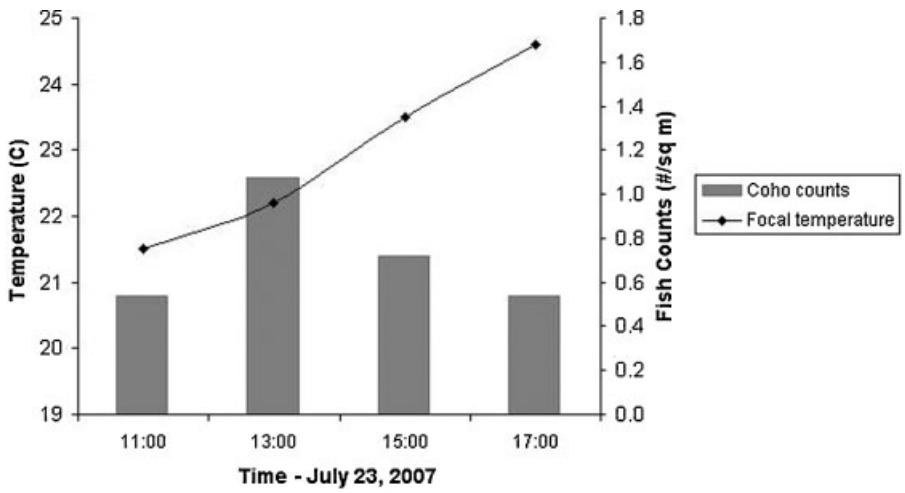

Figure 4. Juvenile coho salmon counts in Beaver Creek thermal refuge as temperatures increased during 1 day in 2007.

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Table IV. Summary of coho salmon juvenile PIT tag mark and recapture results at Tom Martin Creek, 2007–2009

Date	Method	Number of marked	Number of recaptures	Recapture location
Klamath River at mouth of Tom Martin Creek—RKM 230				
4 August 2008	Seine	9	0	
22 January 2009	Fyke	4	0	
12 February 2009	Fyke	1	0	
12 March 2009	Fyke	1	0	
15 April 09	Fyke	1	0	
Tom Martin Creek below Highway 96 culvert				
16 August 2007	Seine	55	0	
18 September 2007	Seine		1	Fort Goff Creek-RKM 206
4 August 2008	Seine	14	0	
15 September 2008	Seine	73	5	Tom Martin Creek below culvert
1 December 2008	Seine	13	38	Tom Martin Creek below culvert
2 January 2009	Antennae		1	Bulk Plant-RKM 175
14 January 2009	Seine	1	10	Tom Martin Creek below culvert
10 February 2009	Fyke	2	17	Tom Martin Creek below culvert
12 February 2009	Fyke		3	Tom Martin Creek below culvert
8 April 2009	Fyke		2	Tom Martin Creek below culvert
9 April 2009	Fyke		1	Tom Martin Creek below culvert
28 April 2009	Antennae		1	Bulk Plant-RKM 175
29 April 2009	Fyke		1	Waukell Creek-RKM 1
Total		174	80	

salmon utilized mean column velocities of about 0.09–0.18 mps and depth about 0.46–0.76 m.

Our observations showed that juvenile coho salmon mostly utilized overhead cover, followed by rootwad/undercut and wood. Approximately 98% of observed juvenile coho salmon were located within 2 m of escape cover in the Beaver Creek, Tom Martin Creek and Sandy Bar Creek refugia in 2006 and 2008.

Timing of coho salmon use of thermal refugia

Figure 5 illustrates when juvenile coho salmon entered Cade Creek relative to main-stem Klamath River and Cade Creek water temperatures in 2007. The horizontal line represents the 22 °C level where we start to see stress on coho salmon. The vertical bar represents numbers of coho salmon captured by minnow traps in Cade Creek. Minnow

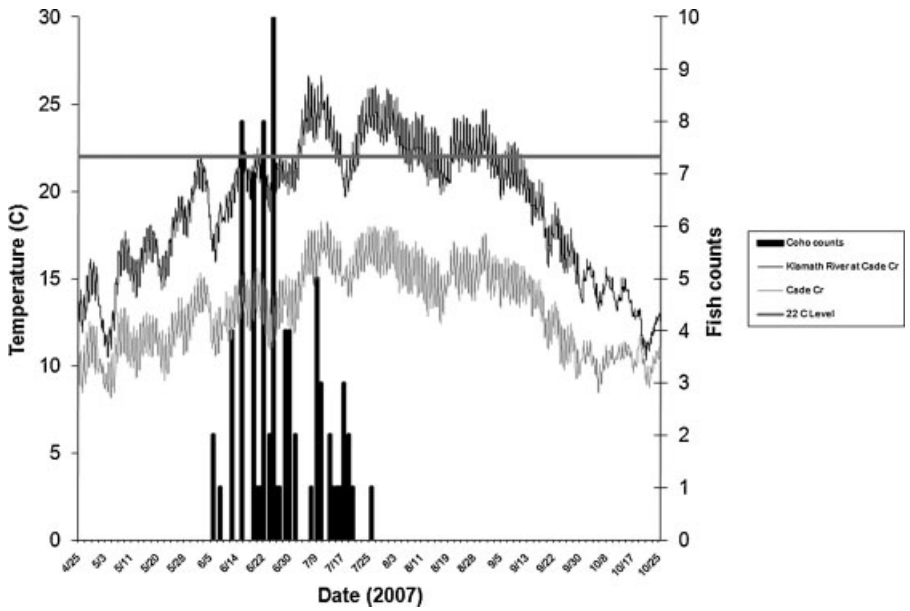

Figure 5. Timing of juvenile coho salmon use of Cade Creek relative to main-stem Klamath and tributary temperatures in 2007 (minnow trap data).

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trap data were used because these traps were fished downstream from the highway culvert. It appears that coho salmon started entering Cade Creek when main-stem Klamath River temperatures exceeded about 19 °C. Coho salmon numbers peaked and declined in late July, possibly in response to a cold front that allowed them to exit Cade Creek and redistribute to additional thermal refugia located downstream or move further upstream in Cade Creek.

The temperature trace in Figure 6 shows Sandy Bar Creek temperatures and main-stem Klamath River temperatures, along with a horizontal line at 22 °C in 2007. Fewer coho salmon were observed in Sandy Bar Creek than Cade Creek. Upstream migrant trap (modified fyke net) data were used at Sandy Bar Creek because minnow traps did not catch any coho salmon at this location. Again, coho numbers in Sandy Bar Creek tended to decline after a cold front in late July.

DISCUSSION

Juvenile coho salmon counts in the studied thermal refugia significantly decreased at temperatures >22–23 °C, suggesting that this is approximately the upper thermal tolerance level. This is similar to the observations made by Sutton *et al.* (2007). Juvenile coho salmon started to use the studied thermal refugia when the Klamath River main-stem temperature approached approximately 19 °C. It appears that salmonids only seek thermal refugia after their thermal comfort level is exceeded; otherwise, they seem to be either dying from lethal main-stem temperatures, constantly moving between tributaries when main-stem temperatures allow them to move, or moving further up the tributaries.

It is well-documented that cover plays a significant role in determining habitat preference for rearing coho salmon (Peters, 1996; Moyle, 2002; Lestelle, 2007). Escape cover is one issue that has been addressed in detail in the Klamath River for Chinook salmon fry (Hardy *et al.*, 2006a, 2006b). Escape cover is defined as the riverine component that is used, or that could be used, for protection or concealment when fleeing from predators or a threat. Thus, it was not surprising that we found the majority of juvenile coho salmon within thermal refugia in the slower velocity habitat closely associated with cover, such as Tom Martin Creek. The lack of juvenile coho salmon use in lower Beaver Creek was possibly because velocities were too high or some other habitat features were not suitable for coho salmon use.

Although some juvenile coho salmon were very mobile, others chose to rear, until smoltification, in the mouths and lower reaches of non-natal tributaries where thermal refugia occur. This kind of life history strategy has been observed at various locations in the Klamath River. For example, Tom Martin Creek and Sandy Bar Creek are tributaries to the Klamath River where all of the juvenile coho salmon that inhabit the creeks are non-natal fish (i.e. no coho salmon spawning occurs in the creeks). Past sampling has shown that juvenile coho salmon utilize Tom Martin Creek and the Sandy Bar channel in the Klamath River floodplain during summer and fall, apparently because of suitable physical and thermal characteristics (Soto *et al.*, 2008).

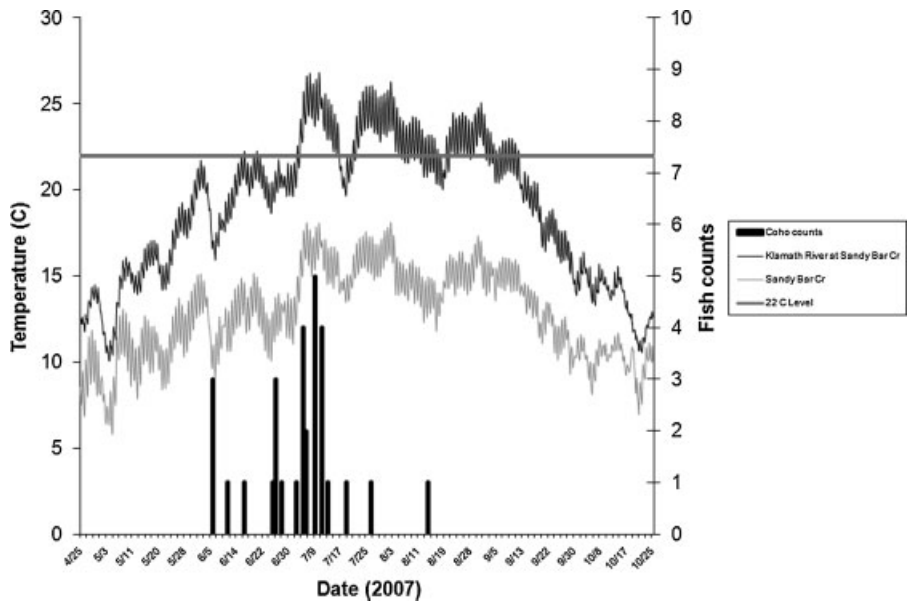

Figure 6. Timing of juvenile coho salmon use of Sandy Bar Creek relative to main-stem Klamath and tributary temperatures in 2007 (upstream migrant trap data).

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Although we demonstrated mobility of juvenile coho salmon on a broad geographic scale, we were not successful using PIT tags to determine mobility during the summer within thermal refugia. For example, although coho salmon were marked and recaptured in Tom Martin Creek in 2008, there was no evidence they moved in and out of the creek during low summer base flow conditions. Also, we were unable to determine why numbers of juvenile coho salmon declined in late afternoon of hot days at Beaver Creek. It is important to understand what conditions are necessary to allow coho salmon to move freely among habitats (i.e. connectivity) to meet their life history requirements (e.g. late summer downstream movements to overwintering habitats). Also, it is unknown what per cent of juvenile coho salmon rear until smoltification in tributaries (e.g. Tom Martin Creek) and what per cent is transient. Thus, one option would be to deploy a fixed PIT tag detector station at the mouth of a cold tributary, such as Tom Martin Creek, that would detect passage of tagged fish in and out of the creek. Also, installation of remote PIT tag detection antenna arrays within thermal refugia would increase recapture effort and detection probability.

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REFERENCES

Beechie TJ, Liermann M, Beamer EM, Henderson R. 2005. A classification of habitat types in a large river and their use by juvenile salmonids. *Transactions of the American Fisheries Society* **134**: 717–729.

Bisson PA, Nielsen JL, Ward JW. 1988. Summer production of coho salmon stocked in Mount St. Helens streams 3–6 years after the 1980 eruption. *Transactions of the American Fisheries Society* **117**: 322–335.

Hampton M. 1988. *Development of Habitat Preference Criteria for Anadromous Salmonids of the Trinity River*. U.S. Dept. Int., Fish Wildlife Serv., Div. Ecol. Serv: Sacramento, CA; 93.

Hardy TB, Addley RC, Saraeva E. 2006a. Evaluation of instream flow needs in the lower Klamath River – Phase II Final Report. Prepared for U.S. Department of the Interior, 229 pp.

Hardy TB, Shaw T, Addley RC, Smith GE, Rode M, Belchik M. 2006b. Validation of Chinook fry behavior-based escape cover modeling in the lower Klamath River. *International Journal of River Basin Management* **4**(3): 169–178.

Hillemeier D, Soto T, Silloway S, Corum A, Kleeman M, Lestelle L. 2009. The role of the Klamath River main-stem corridor in the life history and performance of juvenile coho salmon (*Oncorhynchus kisutch*). Period Covered: May 2007–May 2008. Prepared for Bureau of Reclamation, Mid-Pacific Region, Klamath Area Office, 95 pp.

Lestelle LC. 2007. Coho salmon (*Oncorhynchus kisutch*) life history patterns in the Pacific Northwest and California. Final Report. Biostream Environmental, 122 pp.

Moyle PB. 2002. *Inland fishes of California*. University of California Press: Berkeley and Los Angeles, California; 502.

Peters RJ. 1996. An evaluation of habitat enhancement and wild fry supplementation as a means of increasing coho salmon production of the Clearwater River, Washington, PhD Thesis, University of Washington: Seattle, Washington.

Soto T, Corum A, Voight H, Hillemeier D, Lestelle L. 2008. The role of the Klamath River main-stem corridor in the life history and performance of juvenile coho salmon (*Oncorhynchus kisutch*). Phase 1 Report 2006–07 Winter. Prepared for Bureau of Reclamation, Mid-Pacific Region, Klamath Area Office, 96 pp.

Sutton R. 2007. Klamath River Tributary Fish Passage Surveys. Bureau of Reclamation Technical Memorandum No. 86-68290-03-07. Denver, Colorado, 29 pp.

Sutton R, Deas M, Faux R, Corum RA, Soto TL, Belchik M, Holt JE, McCovey BW Jr, Myers FJ. 2004. Klamath River thermal refugia study, summer 2003. Prepared for Bureau of Reclamation, Klamath Area Office, 143 pp.

Sutton RJ, Deas ML, Tanaka SK, Soto T, Corum RA. 2007. Salmonid observations at a Klamath River thermal refuge under various hydrological and meteorological conditions. *River Research and Applications* **23**(7): 775–785. DOI:10.1002/rra.1026.

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