Salmonid Use of Thermal Refuges in the Klamath River: 2009 Annual Monitoring Results

Final Technical Memorandum
April 2010

Joshua Strange

Yurok Tribal Fisheries Program
Klamath River Division
Hwy. 96, Weitchpec Route Box 196
Hoopa, CA 95546

Introduction

Elevated water temperatures in river systems and the associated thermal stress on their biota is an increasingly serious and widespread problem. Substantial changes in water quantity, quality, and timing and associated thermal shifts have been noted in major salmon producing river systems such as the Columbia (Quinn and Adams 1996; Quinn et al. 1997) and Sacramento (Deas et al. 1997; Gleick and Chalecki 1999). Projections of future hydrological and thermal conditions under various global warming scenarios for the Pacific Northwest region and California suggest an acceleration of thermal problems in salmon producing river systems (Chatters et al 1991; Gleick and Chalecki 1999; Hamlet and Lettenmaier 1999; Kim 2001; Maurer and Duffy 2005; Stewart et al. 2005; Maurer et al. 2007), on top of assumptions of continued human population growth and resource development. Given these facts, old questions remain and new areas of uncertainty have arisen in terms of the biological capacity for populations of salmonids to tolerate and adapt to elevated thermal regimes. Providing information relevant to this area of uncertainty is a necessary step in determining best management practices that can successfully ameliorate the impacts of water diversions and flow alterations in the context of increasingly compromised thermal regimes without causing unintended problems.

One primary line of questioning focuses on the role of thermal refuges to sustain salmonid populations, both during discrete time periods and locations in addition to whole river systems over longer time scales. The importance of thermal refuges to poikilothermic salmonids, both adults and juveniles, in the face of stressfully high water temperatures in a variety of settings has been repeatedly demonstrated. Use of thermal refuges by adult salmonids has been demonstrated during upriver migration (Nielsen et al. 1994; Goniea et al. 2006; High et al. 2006) and upon arrival to prespawn holding areas in rivers (Berman and Quinn 1991; Torgersen et al. 1999), lakes (Newell and Quinn 2005), and heated streams (Kaya et al. 1977; Kaeding 1996). Thermal refuges can increase the carrying capacity of juveniles in thermally compromised streams (Burns 1971; Ebersole et al. 2001) and can allow the presence of salmonids in otherwise inhospitable habitats (Matthews and Berg 1997; Biro 1998; Torgersen et al. 1999; Sutton et al. 2007). In a review, McCullough (1999) found that most thermal refuge use generally occurred above temperatures of 20ºC for juvenile and adult Chinook salmon.

Thermal refuges in lotic habitats are generally formed by cool water tributaries, cold springs and seeps, inter-gravel and hyporheic flow, pool stratification, and hypolimnetic releases from impoundments (Bilby 1984; Neilson 1994). Within the Klamath River of California, thermal refuges are formed almost exclusively by cool water tributaries. McIntosh and Li (1998) failed to document any stratified pools during a 180 km survey of the Klamath River mainstem in 1996. Above Iron Gate Dam, which currently limits the distribution of anadromous fishes, the Klamath River cuts through the Cascade mountain range wherein changes in geology and hydrology create a relative abundance of groundwater springs and seeps. Below Iron Gate Dam, surveys by a variety of research teams have documented thermal refuges only at the confluences of cool water tributaries (Belchik 2003; Deas et al. 2006; Sutton et al. 2007; Yurok Tribal Fisheries Program (YTFP) unpublished data). These thermal refuges receive significant use by adult and juvenile salmonids (e.g. Chinook salmon, coho, and steelhead) during the warm summer months when the Klamath River regularly exceeds daily maxima of 25ºC (Bartholow 2005; YTFP unpublished data); and thereby exceeding the thermal tolerances of juvenile (Brett 1952; Brett et al. 1982) and adult salmonids (Strange *in press*). The elevated thermal regime, altered hydrograph, artificially restricted connectivity, and degraded water quality conditions (i.e., high pH, low dissolved oxygen, and un-ionized ammonia; NCRWQCB 2003; Flint et al. 2004) of the mainstem Klamath River generally preclude uninterrupted summer rearing of juvenile salmonids in the absence of thermal refuges (National Research Council (NRC) 2004). For this reason, understanding, protecting, and enhancing thermal refuges within the mainstem Klamath River is an important sub-task within the overarching goal of maintaining and restoring anadromous fish runs within the Klamath River watershed.

In past summers (1998, 2002-2008), the YTFP has extensively monitored the use of thermal refuge by salmonids at tributary confluences in the mainstem Klamath River. In addition to adding to a valuable long term data set, which is required to determine subtle and complex patterns in fish use, there is a need for annual monitoring of thermal refuges in order to provide real-time indicators of fish health and diseases risk in the Klamath River. This real-time information is useful to the Klamath Fish Health Assessment Team and to multiple agencies in the event of an unusual mortality episode. The objective of this study is to annually monitor the summer abundance of salmonids using thermal refuges at four index tributaries within the lower mainstem Klamath River (Red Cap, Bluff, Cappel, and Tully creeks). This technical memorandum presents our research findings from the summer of 2009.

Study Area Description

The Klamath River drains approximately 31,000 km^2 in southern Oregon and northwestern California and flows 386 km from the outlet of Upper Klamath Lake, a hyper-eutrophic regulated natural lake, to its confluence with the Pacific Ocean (Figure 1). Under the Köppen classification (Köppen 1931), climate in the basin is considered Mediterranean with hot dry summers, high winter rainfall, and coastal summer fog trending inland towards progressively drier and more continental climates. The transition from a coastal Mediterranean climate to a high elevation Mediterranean climate occurs within approximately 40 km of the ocean. The United States Bureau of Reclamation (USBR) operates the Klamath Project, which diverts water from the Klamath River for the purpose of irrigated agriculture. Annual diversions in a typical year have ranged from 43,172 to 55,507 hectare meters (350,000 to 450,000 acre feet) in comparison to an estimated natural, undepleted outflow at Keno Dam of 161,093 hectare meters (1,306,000 acre feet) (USBR 2005). Upriver movement of anadromous fish populations is currently restricted by Iron Gate Dam at river kilometer (rkm) 310 (as measured from the mouth of the Klamath River; Figure 1). Although Iron Gate Dam is part of the Klamath Hydroelectric Project owned by Pacificorp, flow releases from Iron Gate Dam are controlled by the USBR with water withdrawn from the metalimnion, which is cooler in the spring and warmer in the fall than ambient water temperatures (Bartholow 2005). A mitigation hatchery is operated by the California Department of Fish and Game at Iron

Gate Dam, with hatchery origin fish dominating anadromous fish runs within the Klamath River basin.

Methods

We observed fish approximately once per week at the four index thermal refuges from approximately mid-June to mid-August, which corresponds to the typically period of fish use of thermal refuges in the lower Klamath River annually (YTFP unpublished data). Fish were enumerated by snorkeling through the confluence pool and the first upstream pool in the creek (Figure 2) and counting or estimating, by life stage and species, all fish observed. Fish counts were conducted using a block method. Divers counted fish in blocks or groups and worked their way through the survey area using a counting hierarchy that assisted in counting large numbers of fish in a confined area. Snorkel divers swam from the lower end of the refuge to the upper end with each diver staying within designated lanes. We classified fish as follows: Chinook and coho salmon as 0+, 1+, jack, or adult; steelhead as 0+, 1+, 2+/half pounder, and adult. Illnesses, injuries, and mortalities to fish were recorded. Horizontal and vertical visibilities were estimated using arm lengths, with one arm length equaling approximately 1 m of visibility. After completing each snorkel survey, water temperatures in the river, creek, and refuge were recorded to within 0.1°C with a temperature meter, calibrated according to company directions. We conducted snorkel surveys during afternoon hours only for consistency. Access to index sites was by road or jet boat. The index thermal refuges that we surveyed during the summer of 2009 were Red Cap (rkm 85), Bluff (rkm 80), Tully (rkm 61.5), and Cappel (rkm 53) creeks. We compiled river flow data from United States Geological Survey (USGS) gauging stations. Klamath River water temperature and flow data used for this analysis were compiled from the United States Geological Survey's (USGS) gauging station at Klamath Glen (rkm 13 USGS site no. 11530500).

Results

A total of 35 snorkel surveys were conducted at the four index thermal refuges from June 18th to August 14th 2009 between the hours of 12:00 and 16:30. Instantaneous river temperatures ranged from 20.0 to 25.8°C with instantaneous creek temperatures ranging from 14.8 to 19.5°C resulting in an associated maximum thermal gradient of 9.9°C. Total salmonid abundance ranged from 10 to 9,050 fish of which 99% were juveniles on average. Adult salmonids were present concurrently with juveniles and generally co-mingled in the same specific areas of the thermal refuges (Figure 3). Chinook salmon dominated counts of fish using thermal refuges, accounting for 94% of all fish. No coho were observed using the index thermal refuges during the 2009 study, consistent with previous study years' results. Of the four index sites, Bluff Creek (Figure 4) had the highest abundance of juvenile and adults salmonids on average, and Red Cap Creek had the lowest. The mouth configuration of Red Cap Creek in 2009 created poor quality holding habitat (i.e. shallow and swift) in comparison to the other thermal refuges. Estimated total abundance of all species of salmonids for juveniles versus adults along with instantaneous water temperature by site and date is summarized in Table 1. Estimated abundance by species and age class by site and date is summarized in Table 2.

Salmonid abundance at all sites except for Red Cap Creek peaked in late July in conjunction with the seasonal peak in river temperatures and the seasonal progression of juvenile Chinook salmon out-migration (Figure 5). This relationship between fish abundance in thermal refuges and date, driven by the correlation of date with river temperature and the number of juvenile salmonids in the system, has been consistent at all study sites for all prior study years (Figure 6). The numbers of dead and clinically sick fish (i.e. ceratomyxosis) observed at the index thermal refuges corresponded to the total abundance of fish and thereby showed the same relationship with date (Figure 7). The highest number of dead and sick fish observed during the study was 155 individuals at Bluff Creek on July 27th 2009 (Table 1). Fish abundance in thermal refuges increased with increasing river temperatures (Figure 8), and approximately 23°C appears to be an important threshold for obligatory use of thermal refuges by salmonids (Figures 5 and 8). Fish abundance in thermal refuges appeared to be positively correlated with the associated thermal gradient (Figure 9), however, this data is auto-correlated with daily maxima in the river and thus neither metric alone is an appropriate predictor of fish abundance in a given thermal refuge. Water temperature and flow of the lower Klamath River during the summer of 2009 are presented in Figure 10.

Acknowledgments

We would like to thank the following field personnel for their work conducting snorkel surveys: Rocky Erickson, Jamie Holt, Barry McCovey Jr., and Troy Fletcher Jr. This study was funded by the USBR's Klamath Basin Area Office and NOAA Fisheries Pacific Coast Salmon Recovery Funds.

References

Bartholow JR. 2005. Recent water temperature trends in the lower Klamath River, California. *North American Journal of Fisheries Management* 25:152-162.

Belchik MR. 2003. Use of thermal refugial areas on the Klamath River by juvenile salmonids; Summer 1998. Yurok Tribal Fisheries Program Technical Report. 36pp.

Berman CH, Quinn TP. 1991. Behavioural thermoregulation and homing by spring chinook salmon, *Oncorhynchus tshawytscha* (Walbum), in the Yakima River. *Journal of Fish Biology* 39:301-312.

Bilby RE. 1984. Characteristics and frequency of cool-water areas in a western Washington stream. *Journal of Freshwater Ecology* 2:593-602.

Biro PA. 1998. Staying cool: behavioral thermoregulation during summer by young-of-the-year brook trout in a lake. *Transactions of the American Fisheries Society* 127: 212-222.

Brett JR. 1952. Temperature tolerance in young Pacific salmon, genus *Oncorhynchus*. *Journal of the Fisheries Research Board of Canada*. 9:265-325.

Brett JR, Clarke WC, Shelbourne JE. 1982. Experiments on thermal requirements for growth and food conversion efficiency of juvenile Chinook salmon, *Oncorhynchus tshawytscha*. Can. Tech. Rep. Fish. Aquat. Sci. 1122: 29pp.

Burns JW. 1971. The carrying capacity for juvenile salmonids in some northern California streams. *California Fish and Game* 57:44-57.

Chatters JC, Neitzel DA, Scott MJ, Shankle SA. 1991. Potential impacts of global climate change on Pacific Northwest spring chinook salmon (*Oncorhynchus tshawytscha*): an exploratory case study. *The Northwest Environmental Journal* 7:71-92.

Deas ML, Cook CB, Lowney CL, Meyer GK, Orlob GT. 1997. Sacramento River Temperature Modeling Project Report. Center for Environmental and Water Resources Engineering. Department of Civil and Environmental Engineering, University of California, Davis. Report 96-1.

Deas ML, Tanaka SK, Vaughn JC. 2006. Klamath River Thermal Refugia Study: Flow and Temperature Characterization. Final Project Report. Report of Watercourse Engineering, Inc. to the US Bureau of Reclamation, Klamath Area Office, Klamath Falls, OR.

Ebersole JL, Liss WJ, Frissell CA. 2001. Relationship between stream temperature, thermal refugia and reainbow trout *Oncorhynchus mykiss* abundance in arid-land streams in the northwestern United States. *Ecology of Freshwater Fishes* 10:1-10.

Flint LE, Flint AL, Curry DS, Rounds SA, Doyle MC. 2004. Water-Quality Data from 2002 to 2003 and Analysis of Data Gaps for Development of Total Maximum Daily Loads in the Lower Klamath River Basin, California. U.S. Geological Survey, Scientific Investigations Report 2004-5255.

Gleick PH, Chalecki EL. 1999. The impacts of climatic changes for water resources of the Colorado and Sacremento-San Joaquin river basins. *Journal of the American Water Resources Association* 35: 429-1441.

Goniea TM, Keefer ML, Bjornn TC, Peery CA, Bennett DH, Stuehrenberg LC. 2006. Behavioral thermoregulation and slowed migration by adult fall Chinook salmon in response to high Columbia River water temperatures. *Transactions of the American Fisheries Society* 135:408-419.

Hamlet AF, Lettenmaier DP. 1999. Effects of climate change on hydrology and water resources in the Columbia River basin. *Journal of the American Water Resources Association* 35:1597-1623.

High B, Peery CA, Bennett DH. 2006. Temporary staging of Columbia River summer steelhead in coolwater areas and its effect on migration rates. *Transactions of the American Fisheries Society* 135:519-528.

Kaya CM, Caddying LR, Burkhalter DE. 1977. Use of cold-water refuge by rainbow and brown trout in a geothermally heated stream. *Progressive Fish-Culturist* 39:37-39.

Kaeding LR. 1996. Summer use of coolwater tributaries of a geothermally heated stream by rainbow and brown trout, *Oncorhynchus mykiss* and *Salmo trutta*. *American Midland Naturalist* 135:283-292.

Kim J. 2001. A nested modeling study of elevation-dependent climate change signals in California induced by increased atmospheric CO_2. *Geophysical Research Letters* 28:2951-2954.

Köppen W. 1931. ‘Grundriss der Klimakunde’. Walter de Gruyter, Berlin.

Matthews KR, Berg NH. 1997. Rainbow trout responses to water temp and dissolved oxygen stress in two southern California stream pools. *Journal of Fish Biology* 50:50-67.

Maurer EP, Duffy PB. 2005. Uncertainty in projections of streamflow changes due to climate change in California. *Geophysical Research Letters* 32.

Maurer EP, Stewart IT, Bonfils C, Duffy PB, Cayan D. 2007. Detection, attribution, and sensitivity of trends toward earlier streamflow in the Sierra Nevada. *Journal of Geophysical Research-Atmospheres* 112.

McCullough DA. 1999. A review and synthesis of effects of alteration to the water temperature regime on freshwater life stages of salmonids, with special reference to Chinook salmon. EPA 910-R-010. pp 74-76.

McIntosh BA, Li HW. 1998. Final Report - Klamath Basin pilot project: coldwater refugia study and videography. Oregon State University, Corvallis, OR.

National Research Council (NRC). 2004. Endangered and threatened fishes in the Klamath River Basin, causes of decline and strategies for recovery. The National Academies Press, Washington, D.C. 398 pp.

Newell JC, Quinn TP. 2005. Behavioral thermoregulation by maturing sockeye salmon (*Oncorhynchus nerka*) in a stratified lake prior to spawning. *Canadian Journal of Zoology* 83:1232-1239.

Nielsen JL, Lisle TE, Ozaki V. 1994. Thermally stratified pools and their use by steelhead in northern California streams. *Transactions of the American Fisheries Society* 123:613-626.

NCRWQCB (North Coast Regional Water Quality Control Board). July 2003. 2002 CWA section 303(d) list of water quality limited segment. Available http://www.waterboards.ca.gov/tmdl/docs/2002reg1303dlist.pdf.

Quinn TP, Adams DJ. 1996. Environmental changes affecting the migratory timing of American shad and sockeye salmon. *Ecology* 77:1151-1162.

Quinn TP, Hodgson S, Peven C. 1997. Temperature, flow, and the migration of adult sockeye salmon (*Oncorhynchus nerka*) in the Columbia River. *Canadian Journal of Fisheries and Aquatic Sciences* 54:1349-1360.

Stewart IT, Cayan DR, Dettinger MD. 2005. Changes toward earlier streamflow timing across western North America. *Journal of Climate* 18:1136-1155.

Strange JS. *In press*. Upper thermal limits to migration in adult Chinook salmon: evidence from the Klamath River basin. *Transactions of the American Fisheries Society*.

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* 23:775-785.

Torgersen CE, Price DM, Li HW, McIntoch BA. 1999. Multiscale thermal refugia and stream habitat associations of Chinook salmon in northeastern Oregon. *Ecological Appications* 9:301-319.

United State Bureau of Reclamation (USBR). 2005. Natural flow of the Klamath River. Unites State Department of the Interior. 115pp.

Tables and Figures

Table 1. Summary of total fish estimates at the four index thermal refuges during the summer of 2009 with temperature.

Location	Date	Time	River Temp. C	Creek Temp. C	Delta Temp C	TOTAL Juveniles	TOTAL Adults	TOTAL Fish	Sick Juveniles	Total Sick/Mort Fish
Red Cap	6/18/2009	14:00	20.0	18.0	2.0	50	0	50	0	0
Red Cap	6/25/2009	14:15	21.0	17.5	3.5	93	0	93	1	1
Red Cap	6/29/2009	13:30	22.1	17.0	5.1	37	0	37	2	2
Red Cap	7/13/2009	12:00	20.5	17.0	3.5	10	0	10	0	0
Red Cap	7/16/2009	13:10	23.0	18.0	5.0	10	0	10	3	3
Red Cap	7/20/2009	13:40	23.9	18.0	5.9	16	0	16	13	13
Red Cap	7/30/2009	14:10	25.5	19.0	6.5	76	0	76	6	6
Red Cap	8/5/2009	12:50	23.0	19.0	4.0	49	0	49	1	1
Red Cap	8/18/2009	15:00	22.9	17.0	5.9	87	0	87	10	10
Red Cap	8/14/2009	13:25	22.0	17.0	5.0	31	0	31	6	6
Bluff	6/18/2009	15:00	20.0	17.0	3.0	20	0	20	0	0
Bluff	6/25/2009	16:30	21.0	18.0	3.0	140	0	140	20	20
Bluff	6/29/2009	12:45	22.3	16.0	6.3	1310	2	1312	10	10
Bluff	7/8/2009	15:00	21.0	18.0	3.0	630	0	630	20	20
Bluff	7/15/2009	12:20	23.0	16.0	7.0	4000	3	4003	76	77
Bluff	7/20/2009	12:00	23.9	16.8	7.1	3564	1	3565	101	102
Bluff	7/27/2009	13:30	25.8	19.2	6.6	8950	100	9050	150	155
Bluff	8/5/2009	15:10	23.5	19.5	4.0	3410	19	3429	70	71
Bluff	8/13/2009	14:20	22.0	19.0	3.0	516	0	516	0	0
Tully	6/21/2009	14:30	20.0	18.0	2.0	25	0	25	0	0
Tully	6/29/2009	15:40	22.3	16.0	6.3	206	0	206	6	6
Tully	7/7/2009	14:30	21.5	15.1	6.4	638	0	638	50	50
Tully	7/23/2009	12:00	22.9	16.2	6.7	1008	0	1008	50	50
Tully	7/28/2009	12:45	25.7	18.0	7.7	5500	2	5502	150	150
Tully	8/6/2009	13:45	22.1	15.1	7.0	443	0	443	7	7
Tully	8/11/2009	15:10	23.0	18.0	5.0	50	0	50	0	0
Cappel	6/21/2009	15:05	20.0	15.5	4.5	17	0	17	0	0
Cappel	6/26/2009	15:00	21.5	15.5	6.0	150	0	150	5	5
Cappel	7/2/2009	13:25	22.5	15.5	7.0	922	0	922	20	20
Cappel	7/10/2009	14:10	21.0	13.5	7.5	177	0	177	12	12
Cappel	7/17/2009	13:50	23.5	15.5	8.0	515	0	515	30	30
Cappel	7/20/2009	13:50	24.1	15.0	9.1	737	0	737	0	0
Cappel	7/29/2009	13:00	25.8	15.9	9.9	5045	6	5051	35	35
Cappel	8/5/2009	15:30	24.0	14.8	9.2	2755	5	2760	15	16
Cappel	8/11/2009	13:40	23.0	15.4	7.6	700	0	700	20	20

Table 2. Fish estimates with species and age classes at the four index thermal refuges during the summer of 2009. CHNK = Chinook salmon, STHD = steelhead.

Location	Date	Time	0+ CHNK	1+ CHNK	JACK CHNK	ADLT CHNK	0+ COHO	1+COHO	ADLT COHO	0+ STLH	1+ STLH	2+/HP STLH	ADLT STLH
Red Cap	6/18/2009	14:00	25	0	0	0	0	0	0	25	0	0	0
Red Cap	6/25/2009	14:15	45	0	0	0	0	0	0	45	3	0	0
Red Cap	6/29/2009	13:30	25	0	0	0	1	0	0	2	8	1	0
Red Cap	7/13/2009	12:00	1	0	0	0	1	0	0	0	6	2	0
Red Cap	7/16/2009	13:10	8	0	0	0	0	0	0	0	0	2	0
Red Cap	7/20/2009	13:40	13	0	0	0	0	0	0	0	3	0	0
Red Cap	7/30/2009	14:10	40	0	0	0	0	0	0	15	15	6	0
Red Cap	8/5/2009	12:50	24	0	0	0	0	0	0	8	15	2	0
Red Cap	8/18/2009	15:00	70	0	0	0	0	0	0	5	10	2	0
Red Cap	8/14/2009	13:25	25	0	0	0	0	0	0	3	1	2	0
Bluff	6/18/2009	15:00	15	0	0	0	0	0	0	0	0	5	0
Bluff	6/25/2009	16:30	110	0	0	0	0	0	0	10	20	0	0
Bluff	6/29/2009	12:45	1200	0	0	2	0	0	0	60	30	20	0
Bluff	7/8/2009	15:00	600	0	0	0	0	0	0	0	25	5	0
Bluff	7/15/2009	12:20	4000	0	0	3	0	0	0	0	0	0	0
Bluff	7/20/2009	12:00	3500	0	0	1	0	0	0	0	60	4	0
Bluff	7/27/2009	13:30	8000	0	0	60	0	0	0	100	350	500	40
Bluff	8/5/2009	15:10	3000	0	0	9	0	0	0	10	200	200	10
Bluff	8/13/2009	14:20	500	0	0	0	0	0	0	0	15	1	0
Tully	6/21/2009	14:30	5	0	0	0	0	0	0	15	5	0	0
Tully	6/29/2009	15:40	180	0	0	0	0	0	0	20	6	0	0
Tully	7/7/2009	14:30	600	0	0	0	0	0	0	25	12	1	0
Tully	7/23/2009	12:00	1000	0	0	0	0	0	0	2	6	0	0
Tully	7/28/2009	12:45	5500	0	0	0	0	0	0	0	0	0	2
Tully	8/6/2009	13:45	400	0	0	0	0	0	0	30	13	0	0
Tully	8/11/2009	15:10	50	0	0	0	0	0	0	0	0	0	0
Cappel	6/21/2009	15:05	0	0	0	0	0	0	0	15	2	0	0
Cappel	6/26/2009	15:00	120	0	0	0	0	0	0	20	10	0	0
Cappel	7/2/2009	13:25	900	0	0	0	0	0	0	6	15	1	0
Cappel	7/10/2009	14:10	150	0	0	0	0	0	0	15	10	2	0
Cappel	7/17/2009	13:50	500	0	0	0	0	0	0	0	15	0	0
Cappel	7/20/2009	13:50	700	0	0	0	0	0	0	30	7	0	0
Cappel	7/29/2009	13:00	5000	0	0	2	0	0	0	0	25	20	4
Cappel	8/5/2009	15:30	2500	0	0	5	0	0	0	5	200	50	0
Cappel	8/11/2009	13:40	650	0	0	0	0	0	0	0	25	25	0

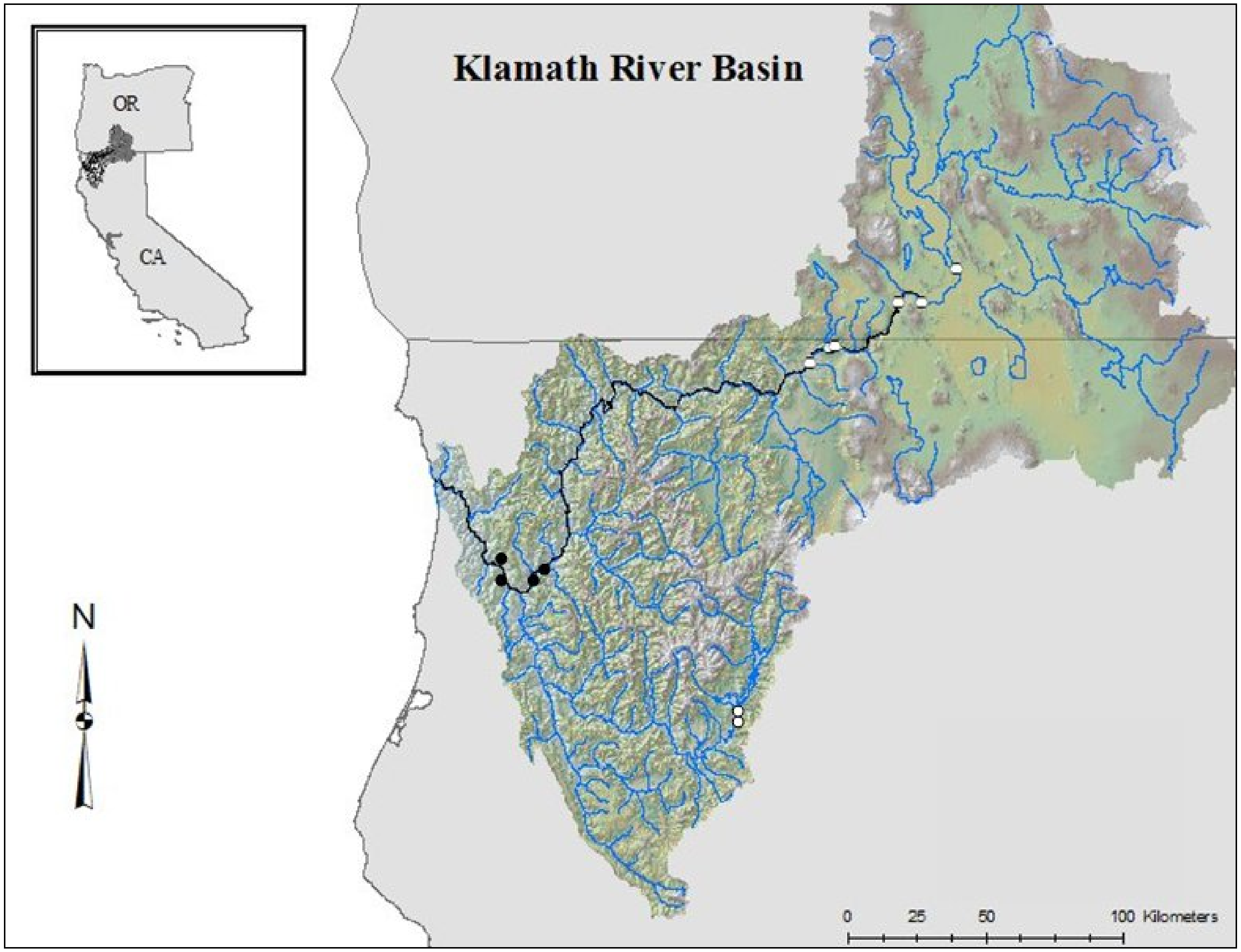

Figure 1. Map of the Klamath River basin with the mainstem designated by a black line. White dots indicate the location of dams. Black dots indicate the location of the index thermal refuges monitored during the summer of 2009 as part of this study, which moving from downstream to upstream were Cappel, Tully, Bluff, and Red Cap creeks.

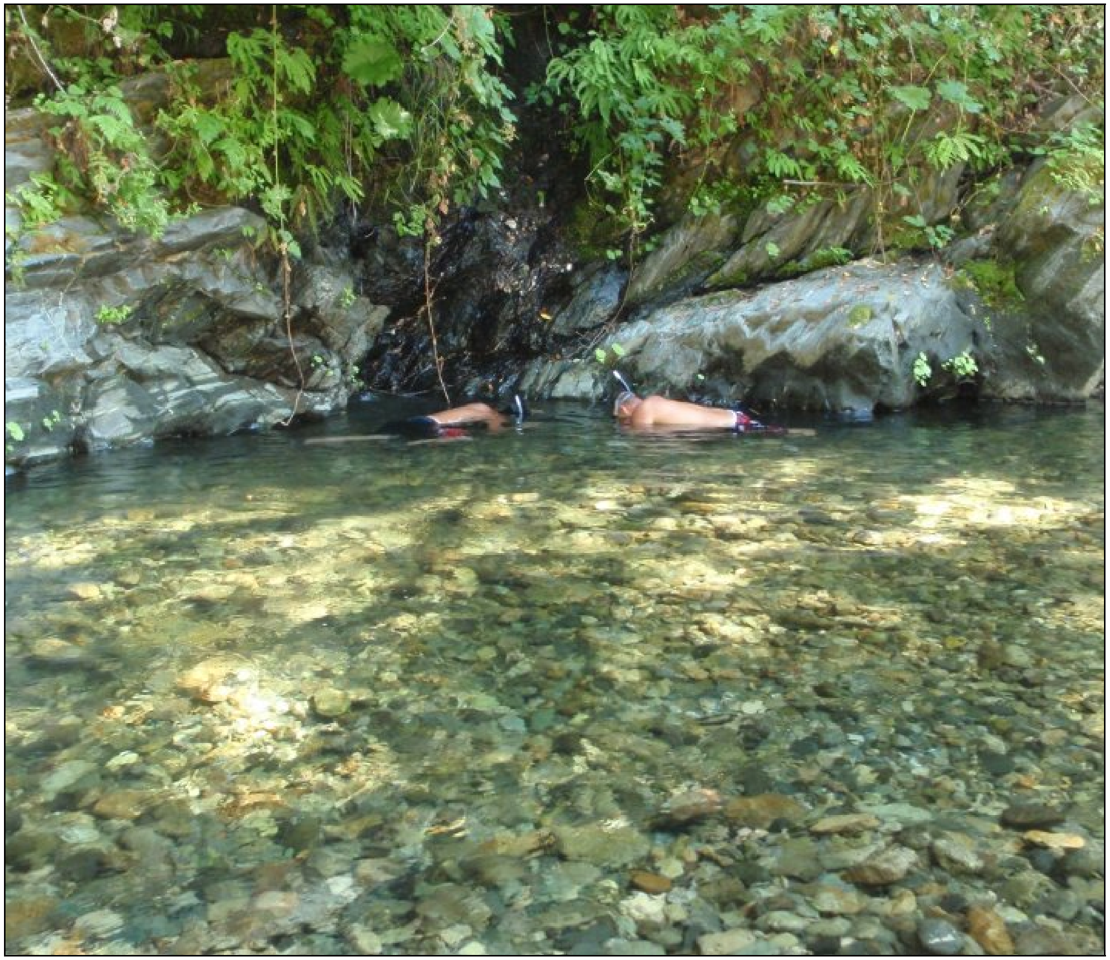

Figure 2. Photograph showing snorkel divers surveying the tail-out of the first pool in the creek above the confluence refuge with the mainstem Klamath River (Red Cap Creek 2009). Juvenile and adult salmonids often swim into non-natal tributaries for temporary rearing and thermal refuge use, especially if the quality of holding habitat is poor at the confluence such as at Red Cap Creek in 2009.

Figure 3. Photograph showing a typical mix of fish species (Chinook salmon, steelhead, suckers) and age classes (YOY, 1+, and adult) that use thermal refuges in the mainstem Klamath River annually (Bluff Creek, summer 2009).

Figure 4. Photograph showing the high abundance of juvenile Chinook salmon and steelhead that typically dominate counts in thermal refuges along the mainstem Klamath River annually (Bluff Creek 2009). Note the position of the fishes facing upstream within the cold water plume of the creek but also within sight of drifting invertebrates contained in the warmer and more turbid waters of the Klamath River (to the right).

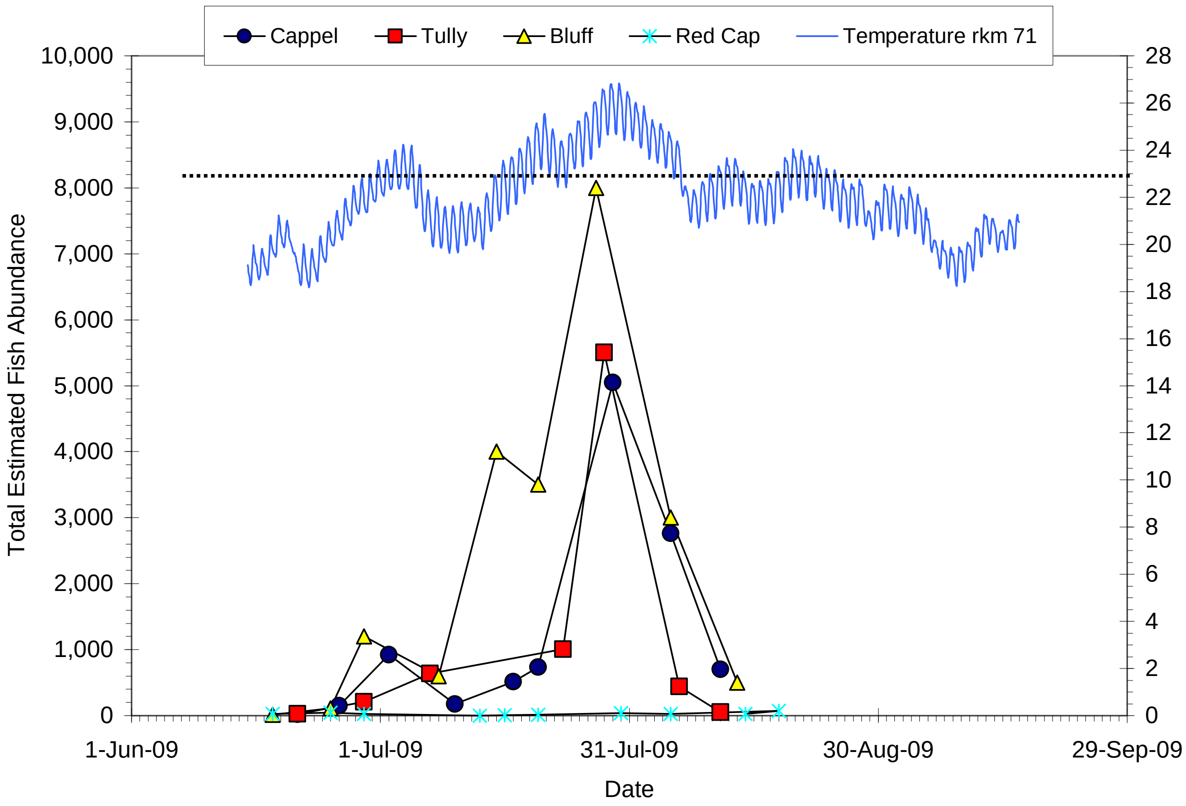

Figure 5. Estimated total fish abundance for all age classes and species of salmonids observed at the four index sites during the summer of 2009 as a function of date illustrating the seasonal progression of thermal refuge use as driven by water temperatures and the outmigration of juveniles. The Red Cap Creek thermal refuge had negligible use by salmonid because the configuration of the mouth resulted in poor quality holding habitat (i.e. shallow and swift). River temperatures at rkm 71 on the Klamath River (above the confluence of the Trinity River) were equivalent to river temperatures at rkm 57 based on visual inspection.

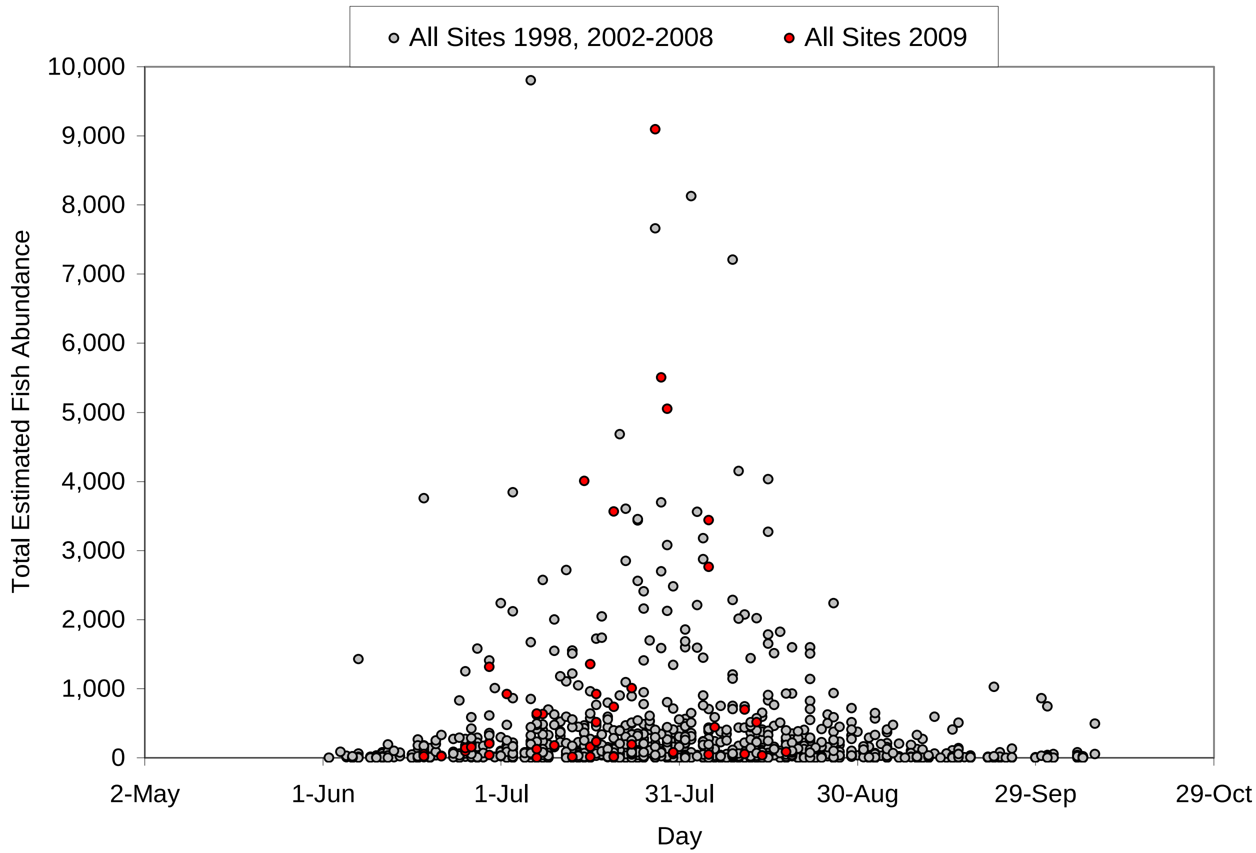

Figure 6. Estimated total fish abundance for all age classes and species of salmonids as a function of day of the year at all sites during previous study years (1998, 2002-2008) in comparison to the 2009 study year. This graph illustrates the consistent seasonal progression of salmonid use of thermal refuges in the Klamath River basin as a function of water temperature and out-migration, both of which are auto-correlated with date. Three data points above 10,000 fish (max of 14,180) were omitted to keep the y-axis scale the same as for other graphs.

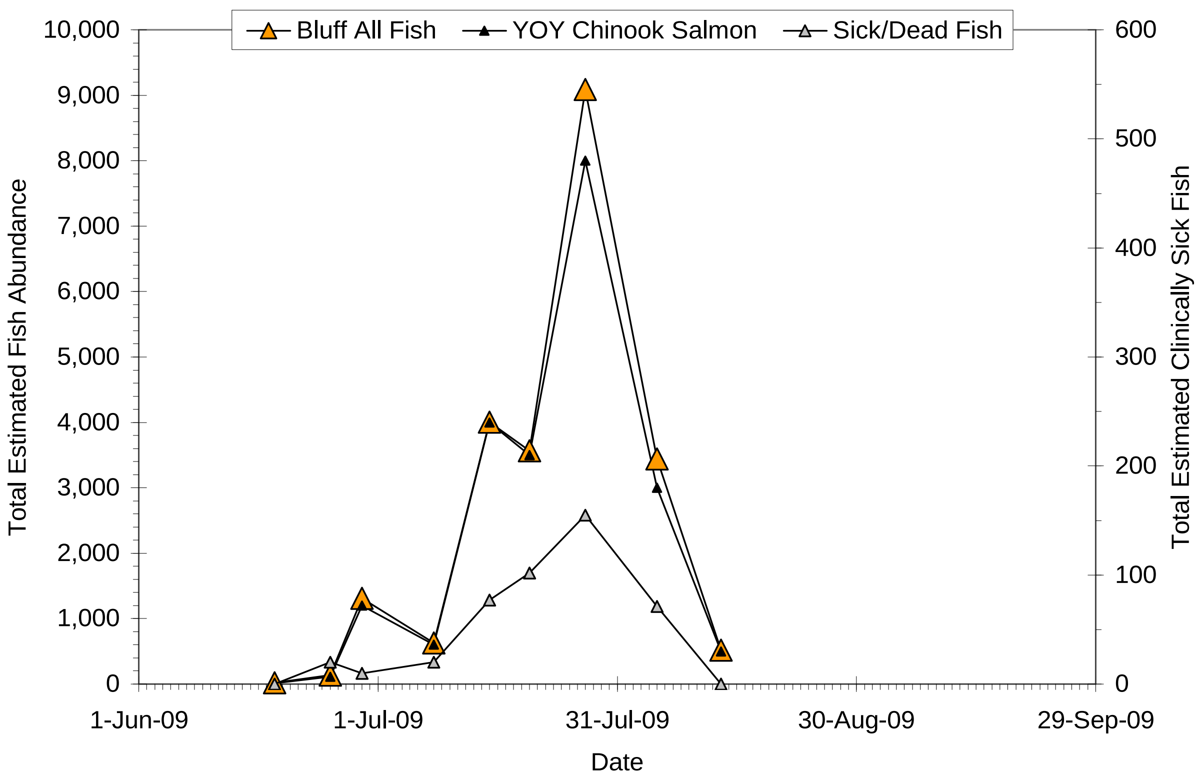

Figure 7. Total estimates salmonid abundance at the Bluff Creek thermal refuge in 2009 compared to total young-of-the-year (YOY) Chinook salmon abundance, illustrating the typical dominance of juvenile Chinook in thermal refuge in the lower Klamath River annually. The total number of sick and dead fish counted closely follows the trend in abundance with date, which is also correlated with water temperature. Clinically sick fish displayed symptoms of *Ceratomyxa shasta* infection (not contagious from fish to fish due to its two host life-cycle) visible with the unaided eye and these fish almost certainly eventually perished.

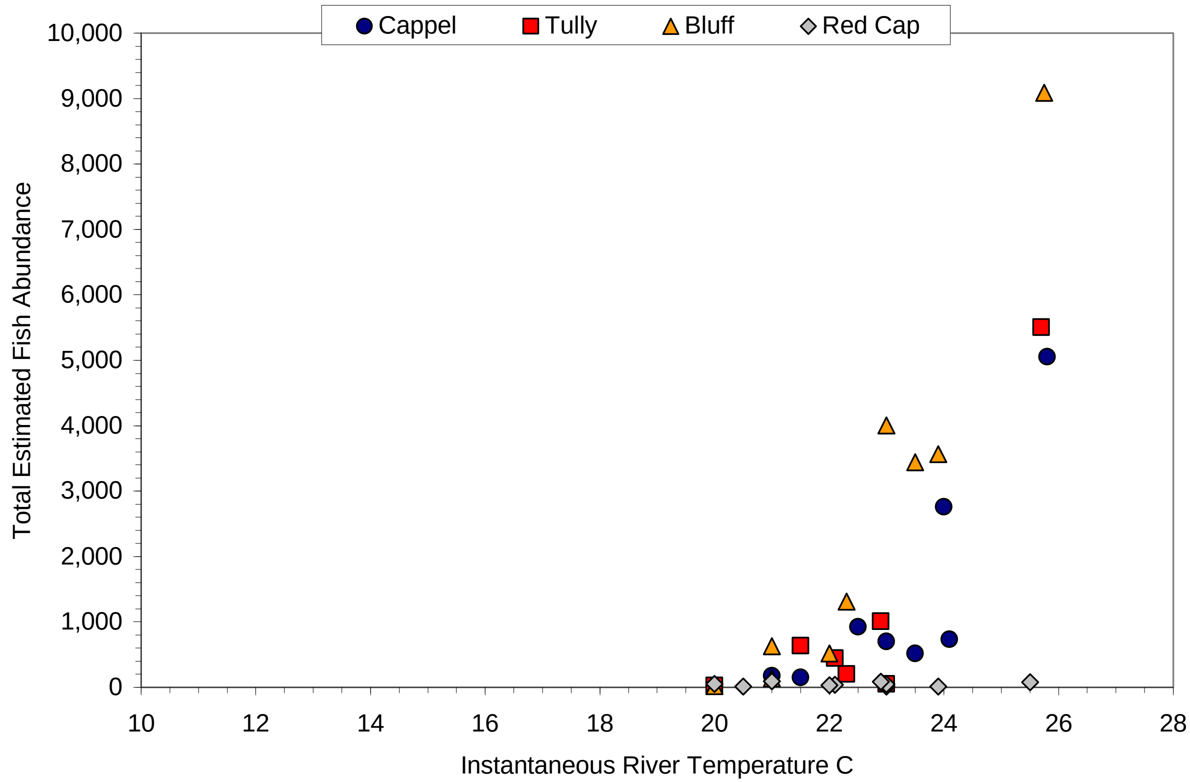

Figure 8. Estimated total fish abundance for all age classes and species of salmonids observed at the four index sites during the summer of 2009 as a function water temperature of the adjacent mainstem Klamath River. Based on this graph and previous years' study results, 23ºC appears to be an important threshold for obligatory thermal refuge use for juvenile salmonids in the Klamath River basin. The Red Cap Creek thermal refuge had negligible use by salmonid because the configuration of the mouth resulted in poor holding habitat (i.e. shallow and swift).

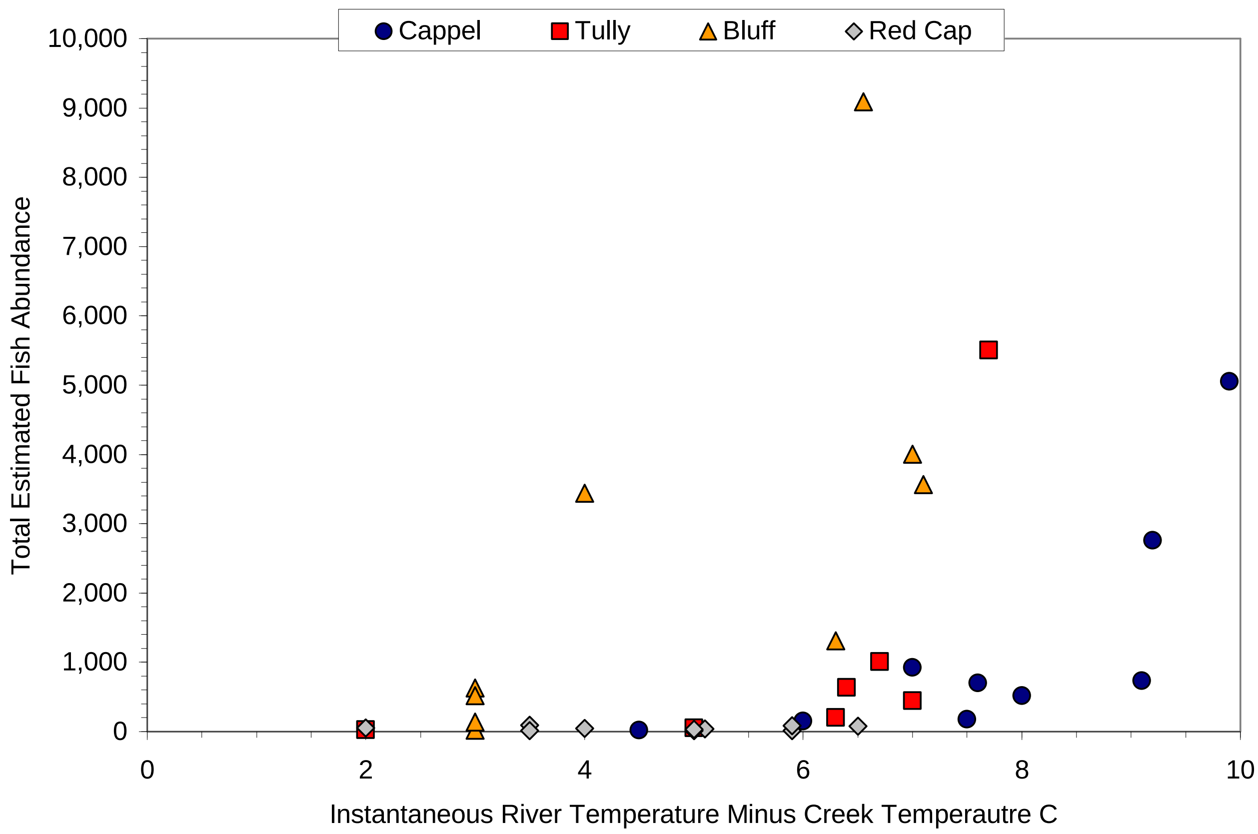

Figure 9. Estimated total fish abundance for all age classes and species of salmonids observed at the four index sites during the summer of 2009 as a function the difference in water temperatures between the refuge forming creek and the adjacent mainstem Klamath River. This graph illustrates the correlation between the abundance of salmonids using thermal refuges and the associated thermal gradient, however, this data is auto-correlated with daily maxima in the river and thus neither metric alone is an appropriate predictor.

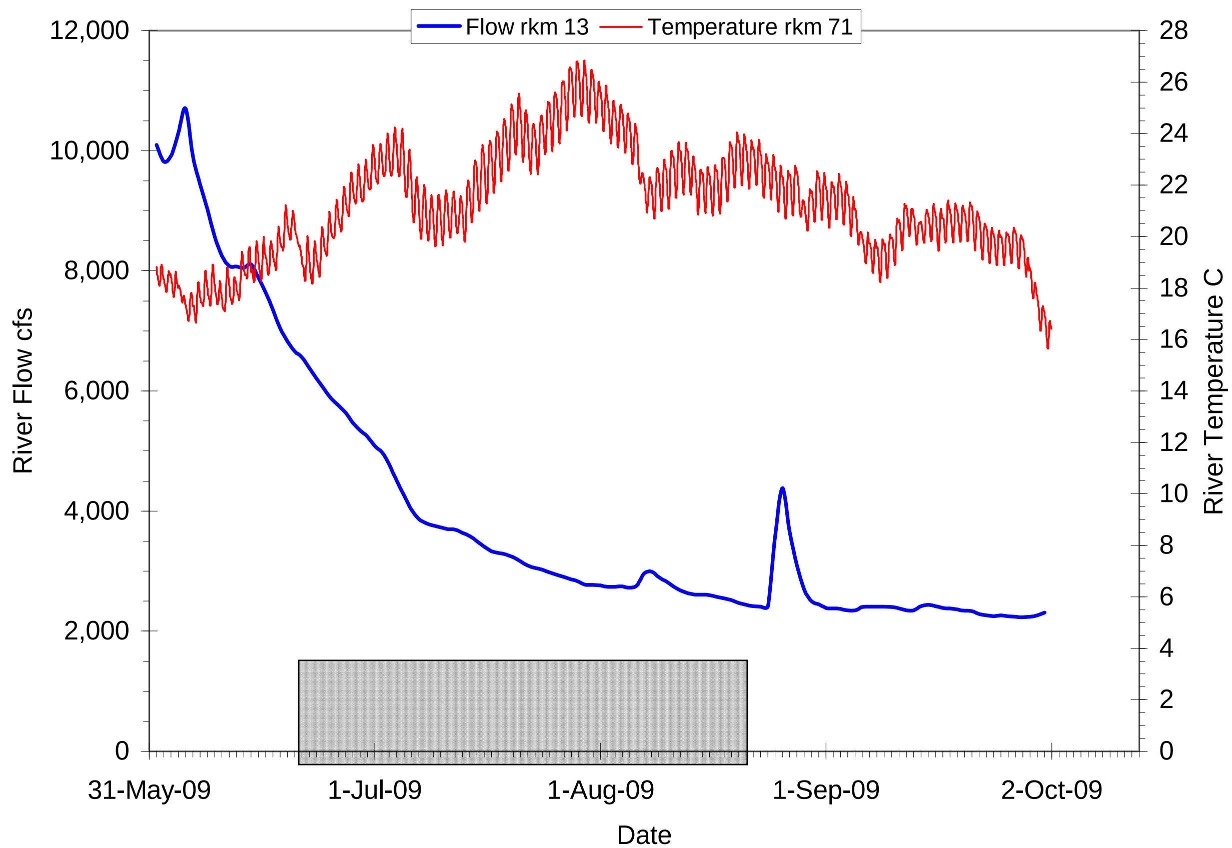

Figure 10. Water temperature and flow of the lower Klamath River during the summer of 2009 to provide. The shaded box indicates the period when surveys of thermal refuges were conducted. The spike in flow during late August was from a dam release on the Trinity River to meet ceremonial obligations to the Hupa Tribe (boat dance flow).