Salmonid Use of Thermal Refuges in the Klamath River: 2010 Annual Monitoring Study

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Joshua S. Strange

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

Photo: Juvenile Chinook salmon in the Bluff Creek thermal refuge (credit: Jamie Holt).

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), the Klamath (NRC 2005; Bartholow 2005), and the 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; Strange 2010a) 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; Strange 2010b). In a thorough literature review, McCullough (1999) found that thermal refuge use generally did not occur until water temperatures reached or exceeded 20ºC for juvenile and adult Chinook salmon, although questions remain about temperature thresholds that distinguish between facultative and obligatory thermal refuge use.

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 inflows from tributaries with the lower reaches of the tributaries also providing thermal refuge habitat for juveniles and adults. 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; Strange 2010b). 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; Yurok Tribal Fisheries Program (YTFP) unpublished data); and thereby exceeding the thermal tolerances of juvenile (Brett 1952; Brett et al. 1982) and adult salmonids (Strange 2010a). The ultimate upper incipient lethal level of water temperature for Chinook salmon is 25ºC (Brett 1952). 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 and their contributing watersheds 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, 2002-2009), 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 disease 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 report presents and discusses our research findings from the summer of 2010.

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 July through August, which corresponds to warm water temperatures and 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 counting or estimating, by life stage and species, all fish observed. Fish counts were conducted using a block method. The diver 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 as needed. 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 2010 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 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). Temperature data for this study was collected by hand held thermometers (accurate to 0.1°C) for instantaneous data and by Onset Hobo Pro v2 temperature loggers (accurate to 0.2°C) for hourly data. Hourly water temperature data was collected by the YTFP and by the US Forest Service - Orleans Ranger District.

RESULTS

A total of 32 snorkel surveys were conducted at the four index thermal refuges from June 30th to August 23rd 2010. Instantaneous river temperatures ranged from 16.5 to 24.5°C with instantaneous creek temperatures ranging from 13.5 to 20.0°C resulting in an associated maximum thermal gradient of 11.0°C. Total salmonid abundance ranged from 10 to 8,000 fish of which almost all 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). Bluff Creek had the highest abundances of fish observed among all sites sampled in 2010 with fish abundances at all sites having counts that were highest when river temperatures were high (Figure 4). Young of the year Chinook salmon dominated counts of fish using thermal refuges (Figure 5). No coho were observed using the index thermal refuges during the 2010 study, consistent with previous study years' results. Of the four index sites, Bluff Creek had the highest abundance of juvenile and adults salmonids on average, and Red Cap Creek had the lowest (Figure 4). The mouth configuration of Red Cap Creek in 2010 again 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 August in conjunction with the latest seasonal peak in river temperatures and the seasonal progression of juvenile Chinook salmon out-migration (Figure 4). 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 (Figures 6 and 7). 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 5). The highest number of dead and sick fish observed during the study was an estimated 800 individuals at Bluff Creek on Aug 4th (Table 1). Fish abundance in thermal refuges increased with increasing river temperatures (Figure 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 2010 are presented along with water temperature in Bluff Creek in Figure 10.

DISCUSSION

The findings of the 2010 thermal refuge monitoring study in the mainstem Klamath River was consistent with findings in previous study years showing a positive but non-linear correlation between the abundance of juvenile salmonids using thermal refuges and mainstem river temperatures. This finding is also consistent with studies in the literature regarding juvenile salmonid use of thermal refuges in the Klamath River and elsewhere (Belchik 2003; Benson and Holt 2006; Sutton et al. 2007; see references in introduction). Thermal refuge use was not documented below instantaneous river temperatures of 20°C, which is consistent with findings from other studies illustrating that the threshold for facultative thermal refuge use occurs around 20°C for juvenile salmonids (see review by McCullough 1999).

Summer is an essential season of active feeding and growth for juvenile salmonids with body size generally being strongly positively correlated with early marine survival. Based on the bioenergetics of basal metabolism and the costs of prey capture and digestion as a function of temperature versus the energy gained from prey, active feeding becomes too energetically costly as temperatures rise above thermal tolerances (Brett et al. 1982), and juvenile salmonids must maximize energy conservation by tactics such as residing in the coldest water possible and minimizing movement. These behaviors were observed in 2010 and previous study years during periods of maximum mainstem river temperatures and peak abundance of fish in thermal refuges. Presumably these behaviors occur when river temperatures have exceeded the threshold for obligatory thermal refuge use. Previous work by the YTFP monitoring thermal refuges continually over the course of a day (Benson and Holt 2006) or a full day and night cycle (Belchick 2003) have revealed that juvenile salmonids will venture into the mainstem Klamath River, presumably to take advantage of the higher food resources, during the night and early morning hours when mainstem water temperature are at their diel minimums, with the converse also being true. As daily minimum river temperatures increased above the threshold for obligatory thermal refuge use, however, this foraging behavior was not observed and fish stayed entirely within the thermal refuge. While there is of course variation in the data, there is enough consistency in the relationship between fish abundance in thermal refuges and mainstem river temperatures to propose a hypothesis that the threshold for obligatory thermal refuge use occurs when mean daily temperatures exceed 22°C. This hypothesis is consistent with the steep decline in growth rates around 22°C for juvenile Chinook salmon depending on food ration levels as determined by Brett et al. (1982) and is also consistent with other notable studies of thermal refuge use by juvenile salmonids in the Klamath River (Belchik 2003; Benson and Holt 2006; Sutton et al. 2007).

It is important to note that there are minor but important differences in thermal tolerances between steelhead (higher) and Chinook and coho salmon (lower), which presumably propagates through their thresholds for facultative and obligatory thermal refuge use. The width of the difference between facultative and obligatory threshold values, combined with absolute water temperatures and the diel variation experienced in a given setting, is important for determining the extent to which individual fish or species of fish are able to use the presumably richer food resources of the mainstem Klamath River compared to those of the creek inflow. The dynamic described above has important survival implications for individual fish over the course of days or weeks and populations over the course of years and decades.

Other factors besides mainstem river temperatures have been observed to influence the abundance of juvenile salmonids using thermal refuges in the Klamath River in 2010 and previous study years. Depth, velocities, velocity cover, escape cover, and levels of human visitation are all notable features of thermal refuges that have been observed to strongly influence the use of a given thermal refuge by salmonids. The water temperature and flow rate of the thermal refuge forming tributary are also important, but in the collective experience of YTFP researchers, the features listed above tend to override the influence of the tributary inflow. For example, the Red Cap Creek thermal refuge had very low observed counts of salmonids in 2010 and featured shallow depth, relatively high velocities, and poor cover quality. In contrast, during previous study years the mouth of Red Cap Creek was configured differently resulting in great depth and low velocities with consistently high abundances of salmonids (Benson and Holt 2006). As another example, Elk Creek has a large volume of cool water inflow but very low observed abundances of salmonid use (Belchik 2003), which corresponds with its consistent extreme lack of cover, relatively high velocities, and shallow depth. YTFP researchers have also observed reduced fish counts and fish leaving thermal refuges with high quality features that also had heavy human visitation and use (typically for swimming and fishing), such as at Horse Linto Creek on the Trinity River and Indian Creek on the Klamath River.

Human interventions to modify the configuration of creek mouths to facilitate these high quality features use are possible and beneficial, as are restrictions of human visitation and disturbance, but such interventions are also logistically challenging and require annual maintenance and adequate enforcement. The Karuk Tribe and the Mid-Klamath Watershed Council (MKWC) have been leading successful efforts to configure creek mouths for the benefit of thermal refuge seeking salmonids on an annual basis as inspired by traditional Karuk practices of salmonid husbandry. These efforts have displayed impressive results and warrant further implementation in the opinion of this author based on personal inspection and monitoring data. Research led by the Karuk Tribe has also highlighted the importance of thermal refuge use that occurs when non-natal fish swim considerable distances up into tributaries for extended periods during the summer when the mainstem Klamath River is inhospitable. This behavioral tactic has been especially notable for juvenile coho salmon, which are otherwise rarely observed in thermal refuges in both the Klamath and Trinity rivers. These observations have led to initial efforts to create off-channel ponds to greatly increase the quantity and quality of rearing habitat for juvenile salmonids seeking refuge from the mainstem Klamath River in the summer. In addition to scientific literature from the Pacific Northwest, the magnitude of the potential benefits of this type of restoration and enhancement is demonstrated by the extensive beaver pond network at Boise Creek, which held impressive numbers and sizes of juvenile salmonids in 2010 including coho (personal communication: Toz Soto, Karuk Tribe; Will Harling, MKWC). In terms of protecting and improving thermal refuges, it is also important not to overlook the imperative of protecting the water quality and quantity of thermal refuge forming tributaries by way of watershed management and restoration. In the opinion of this author, this topic needs much greater research and application within the Klamath River basin (although there is a surprising amount of literature available on this topic throughout the Pacific Northwest, which is beyond the scope of this discussion to review here).

During the 2010 thermal refuge monitoring study, unseasonably late high flows and cold temperatures resulted in the delay of the onset of substantial thermal refuge use by salmonids by approximately three weeks. This delay highlights the overriding influence of water temperature on thermal refuge use as opposed to date based on day length or other indicators of season. One question arising from this metrological situation is whether a greater proportion of emigrating juvenile salmonids were able to migrate to the estuary and ocean as compared to average conditions and to what extent this may have been offset by protracted rearing in the mainstem Klamath River due to hospitable conditions combined with the incentive provided by the rich food resources available in the Klamath River. Regardless of the answer to that question for 2010, thermal refuge counts were high exceptionally late into the summer and hence had not dropped to negligible levels by the end of the monitoring period at the end of August as usual.

In general the dynamic between out-migration progression, population size, environmental conditions, thermal refuge use, and survival of all cohorts and behavioral groups is an important topic of investigation that will influence thermal refuge use, out-migration dynamics, and the success of juvenile salmonids in emigrating through the mainstem Klamath River. At a basic level of inquiry, the progression of the seasonal outmigration of salmonids and the contributing population sizes will influence the observed abundances of fish using thermal refuges. However, the data to determine the answer to this basic line of inquiry is less than ideal at this time and consists of using rotary screw trap catches as a surrogate. Even with the weaknesses involved in using such data, this would be a useful analysis to complete on an annual basis to pair with thermal refuge monitoring data in future years as possible. This might allow for initial testing of the hypothesis that the success of outmigrants in a given year is strongly influenced by the timing and rate of onset of inhospitable temperature and flow conditions in the mainstem Klamath River. Such an analysis would also need to include annual measures of ceratomyxosis to evaluate the likely amount of disease mortality as part of the overall evaluation of outmigration success in a given year. The utility of such an analysis would be hampered by the standard difficulty in measuring actual survival rates of juvenile salmon through freshwater emigration and early marine survival.

Salmonid use of thermal refuges during 2010 at the index sites was dominated by young-of-the-year Chinook salmon and 1+ steelhead as typical. Bluff Creek continued to dominate counts consistent with its large and cold inflow, great depth, and relative abundance of cover. Fish health was overall considered good by divers in 2010 subjectively, but total counts of sick fish based on visual observation of symptoms of ceratomyxois and columnaris were high relative to other study years. Despite several previous and ongoing attempts by various researchers, questions remain about the proportions of natal fish at a given thermal refuge, the duration of residency of natal and non-natal fish, and the ultimate survival of both groups. Even though data to conclusively answer such questions are not available, various lines of evidence confirm that natal and non-natal fish use thermal refuges and can display considerable residence times while also using brief periods of weather-induced cooling to move downstream to the estuary, the ocean, or to other thermal refuges. The YTFP will continue its annual monitoring study of these index thermal refuges for the purposes of real-time information about fish health and outmigration progression, and to build a long-term data set with a sufficiently large sample size to accurately analyze the contributions of the various factors that influence the use of thermal refuges by salmonids in the Klamath River and to discern the resulting implications for fish survival and river management.

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TABLES AND FIGURES

Table 1. Summary of total fish estimates at the four index thermal refuges during the summer of 2010 with temperature.

Location	Date	River Temp. C	Creek Temp. C	Delta Temp C	TOTAL Juveniles	TOTAL Adults	TOTAL Fish	Sick Juveniles	Total Sick/Mort Fish
Bluff	2-Jul	17.0	15.0	2.0	0	0	0	0	0
Bluff	10-Jul	21.0	17.0	4.0	335	5	340	0	0
Bluff	16-Jul	21.5	17.0	4.5	680	0	680	20	20
Bluff	20-Jul	23.0	17.0	6.0	481	3	484	10	10
Bluff	30-Jul	24.0	19.8	4.2	1575	10	1585	36	36
Bluff	4-Aug	24.5	19.5	5.0	4600	10	4610	800	800
Bluff	12-Aug	22.5	17.5	5.0	8120	30	8150	100	100
Bluff	20-Aug	22.5	17.5	5.0	8850	25	8875	600	600
Bluff	23-Aug	21.5	17.5	4.0	6450	40	6490	500	500
Cappell	2-Jul	17.0	15.0	2.0	0	0	0	0	0
Cappell	7-Jul	20.1	15.0	5.1	125	0	125	0	1
Cappell	14-Jul	22.0	14.0	8.0	83	0	83	0	0
Cappell	15-Jul	22.0	15.0	7.0	286	0	286	50	50
Cappell	20-Jul	22.0	15.0	7.0	151	0	151	0	0
Cappell	29-Jul	24.5	13.5	11.0	430	0	430	20	20
Cappell	4-Aug	24.0	15.0	9.0	620	5	625	50	50
Cappell	11-Aug	23.0	14.0	9.0	290	10	300	25	25
Cappell	16-Aug	22.5	15.0	7.5	2592	0	2592	100	100
Cappell	23-Aug	21.5	15.5	6.0	545	15	560	30	30
Red Cap	30-Jun	17.5	16.0	1.5	0	0	0	0	0
Red Cap	30-Jul	24.0	20.0	4.0	21	4	25	0	0
Red Cap	12-Aug	22.5	17.0	5.5	30	0	30	5	5
Tully	2-Jul	16.5	15.5	1.0	0	0	0	0	0
Tully	10-Jul	21.0	17.5	3.5	141	0	141	0	0
Tully	12-Jul	22.0	16.0	6.0	8	0	8	0	0
Tully	15-Jul	21.5	16.5	5.0	42	0	42	0	0
Tully	20-Jul	22.0	17.0	5.0	35	2	37	0	0
Tully	29-Jul	24.5	16.0	8.5	375	0	375	11	11
Tully	4-Aug	24.0	16.5	7.5	350	0	350	45	45
Tully	11-Aug	23.0	17.0	6.0	150	0	150	20	20
Tully	16-Aug	22.5	16.0	6.5	44	0	44	0	0
Tully	23-Aug	21.5	18.0	3.5	140	10	150	25	25

Table 2. Fish estimates with species and age classes at the four index thermal refuges during the summer of 2010. CHNK = Chinook salmon, STHD = steelhead.

Location	Date	0+ CHNK	1+ CHNK	JACK CHNK	ADLT CHNK	0+ COHO	1+COHO	ADLT COHO	0+ STLH	1+ STLH	2+/HP STLH	ADLT STH
Bluff	2-Jul	0	0	0	0	0	0	0	0	0	0	0
Bluff	10-Jul	250	0	0	5	0	0	0	30	50	5	0
Bluff	16-Jul	440	0	0	0	0	0	0	120	100	20	0
Bluff	20-Jul	370	0	0	0	0	0	0	20	80	11	3
Bluff	30-Jul	1500	0	0	0	0	0	0	0	40	35	10
Bluff	4-Aug	4100	0	0	0	0	0	0	0	300	200	10
Bluff	12-Aug	8000	0	0	15	0	0	0	0	100	20	15
Bluff	20-Aug	7500	0	0	10	0	0	0	0	1000	350	15
Bluff	23-Aug	6000	0	0	30	0	0	0	150	100	200	10
Cappell	2-Jul	0	0	0	0	0	0	0	0	0	0	0
Cappell	7-Jul	70	0	0	0	0	0	0	30	20	5	0
Cappell	14-Jul	70	0	0	0	0	0	0	13	0	0	0
Cappell	15-Jul	150	0	0	0	0	0	0	30	100	6	0
Cappell	20-Jul	120	0	0	0	0	0	0	10	20	1	0
Cappell	29-Jul	400	0	0	0	0	0	0	15	0	15	0
Cappell	4-Aug	500	0	0	0	0	0	0	0	100	20	5
Cappell	11-Aug	250	0	0	0	0	0	0	0	30	10	10
Cappell	16-Aug	2500	0	0	0	0	0	0	40	50	2	0
Cappell	23-Aug	500	0	0	5	0	0	0	20	20	5	10
Red Cap	30-Jun	0	0	0	0	0	0	0	0	0	0	0
Red Cap	30-Jul	10	0	0	0	0	0	0	6	0	5	4
Red Cap	12-Aug	25	0	0	0	0	0	0	0	5	0	0
Tully	2-Jul	0	0	0	0	0	0	0	0	0	0	0
Tully	10-Jul	110	0	0	0	0	0	0	10	20	1	0
Tully	12-Jul	0	0	0	0	3	0	0	4	1	0	0
Tully	15-Jul	30	0	0	0	2	0	0	0	10	0	0
Tully	20-Jul	15	0	0	0	0	0	0	5	10	5	2
Tully	29-Jul	350	0	0	0	0	0	0	0	20	5	0
Tully	4-Aug	350	0	0	0	0	0	0	0	0	0	0
Tully	11-Aug	150	0	0	0	0	0	0	0	0	0	0
Tully	16-Aug	25	0	0	0	0	0	0	4	15	0	0
Tully	23-Aug	100	0	0	5	0	0	0	0	30	10	5

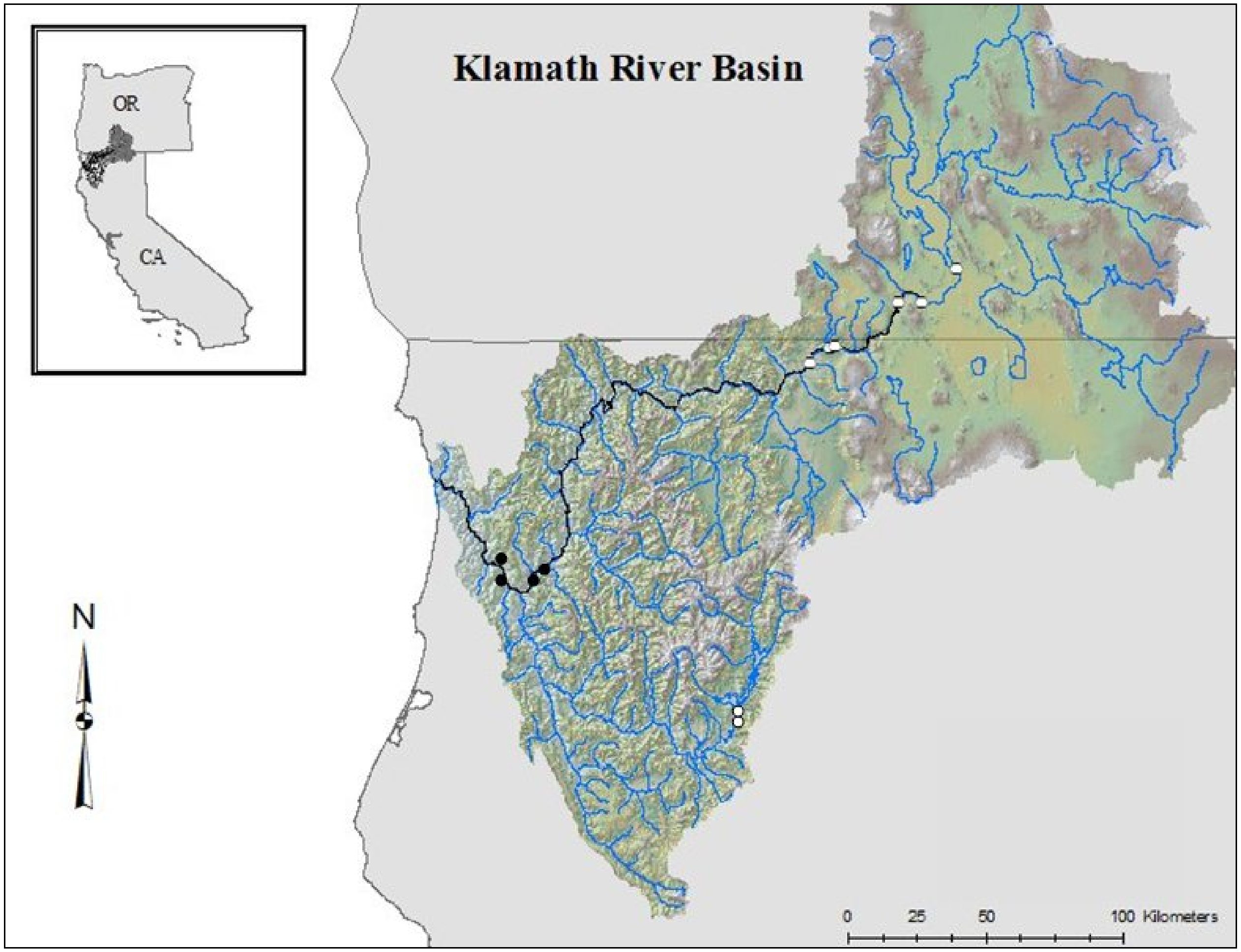

Figure 1. Map of the Klamath River basin with the mainstem designated by a black line. White dots indicate the location of dams. Black dots indicate the location of the index thermal refuges monitored during the summer of 2010 as part of this study, which moving from downstream to upstream were Cappel, Tully, Bluff, and Red Cap creeks.

Figure 2. 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 3. 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).

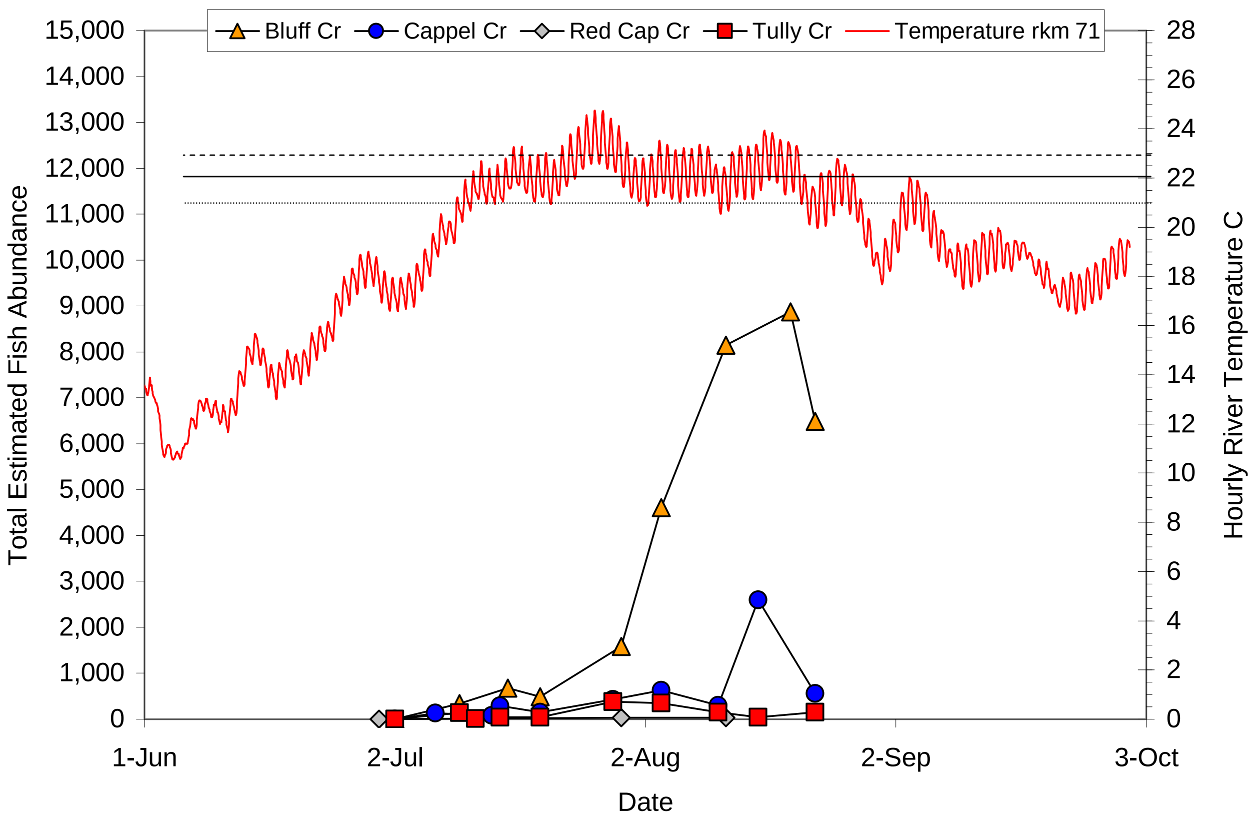

Figure 4. Estimated total fish abundance for all age classes and species of salmonids observed at the four index sites during the summer of 2010 as a function of date illustrating the seasonal progression of thermal refuge use as driven by water temperatures and the outmigration of juvenile salmonids. 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.

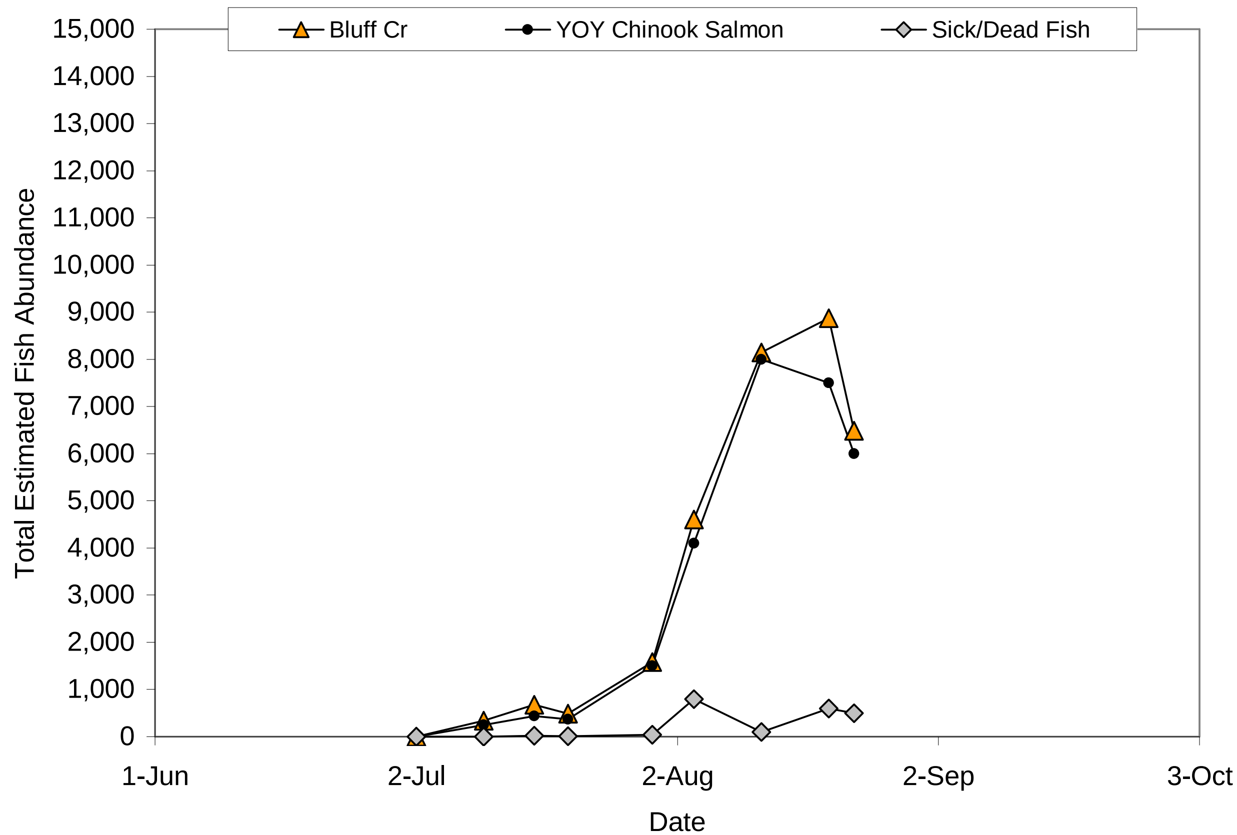

Figure 5. Total estimates salmonid abundance at the Bluff Creek thermal refuge in 2010 compared to total young-of-the-year (YOY) Chinook salmon abundance, illustrating the typical dominance of juvenile Chinook in thermal refuge in the lower Klamath River annually. The total number of sick and dead fish 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.

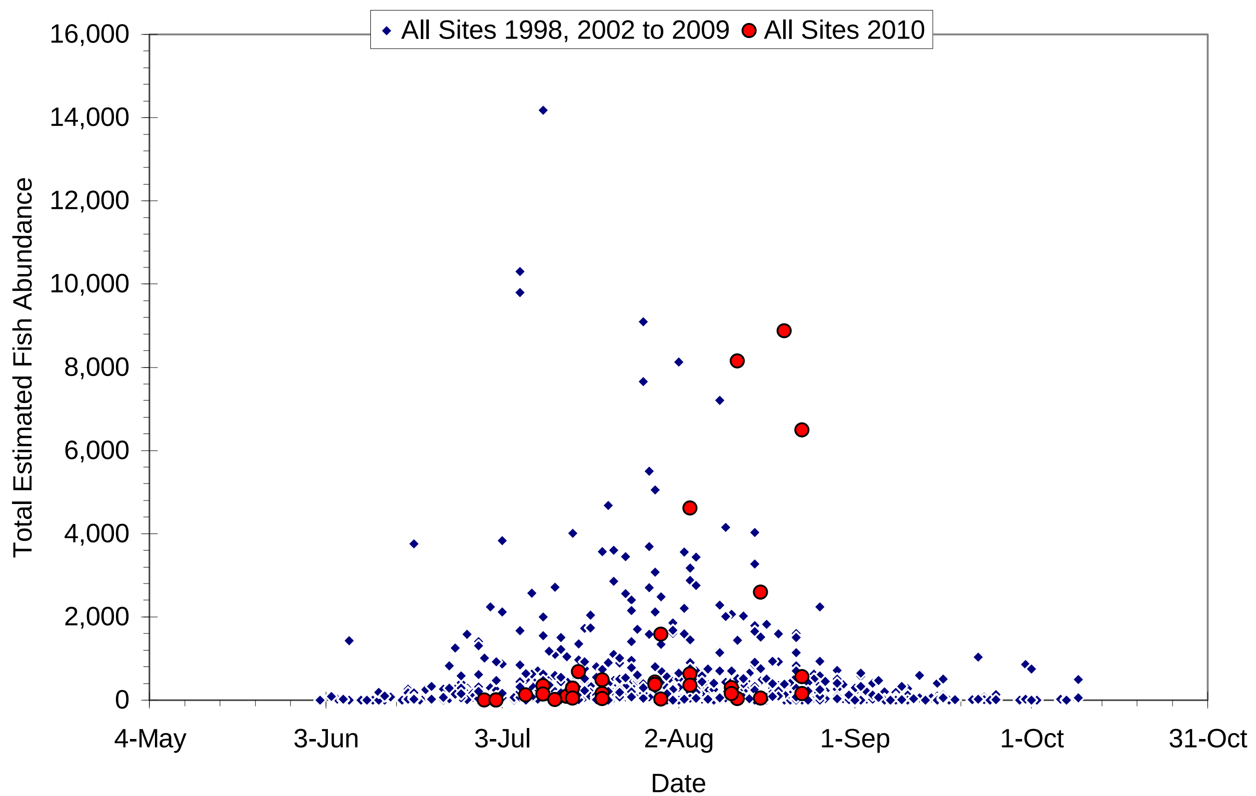

Figure 6. Estimated total fish abundance for all age classes and species of salmonids as a function of day of the year at all sites during previous study years (1998, 2002-2009) in comparison to the 2010 study year. This graph illustrates the consistent seasonal progression of salmonid use of thermal refuges in the Klamath River basin, which is generally a function of water temperature and out-migration progression that is auto-correlated with date.

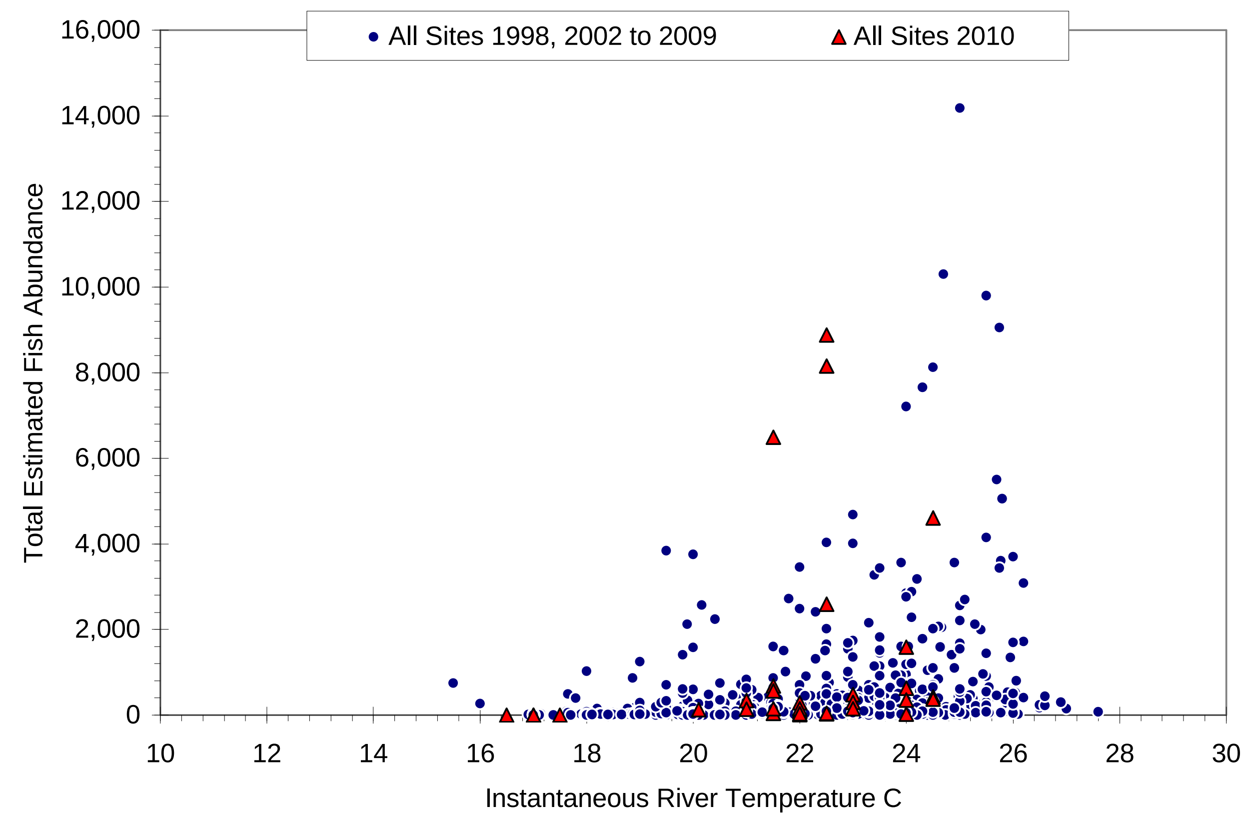

Figure 7. Estimated total fish abundance for all age classes and species of salmonids as a function of instantaneous river temperature at all sites during previous study years (1998, 2002-2009) in comparison to the 2010 study year. This graph illustrates strong positive relationship between water temperature and thermal refuge use by juvenile salmonids although other factors are influential as well.

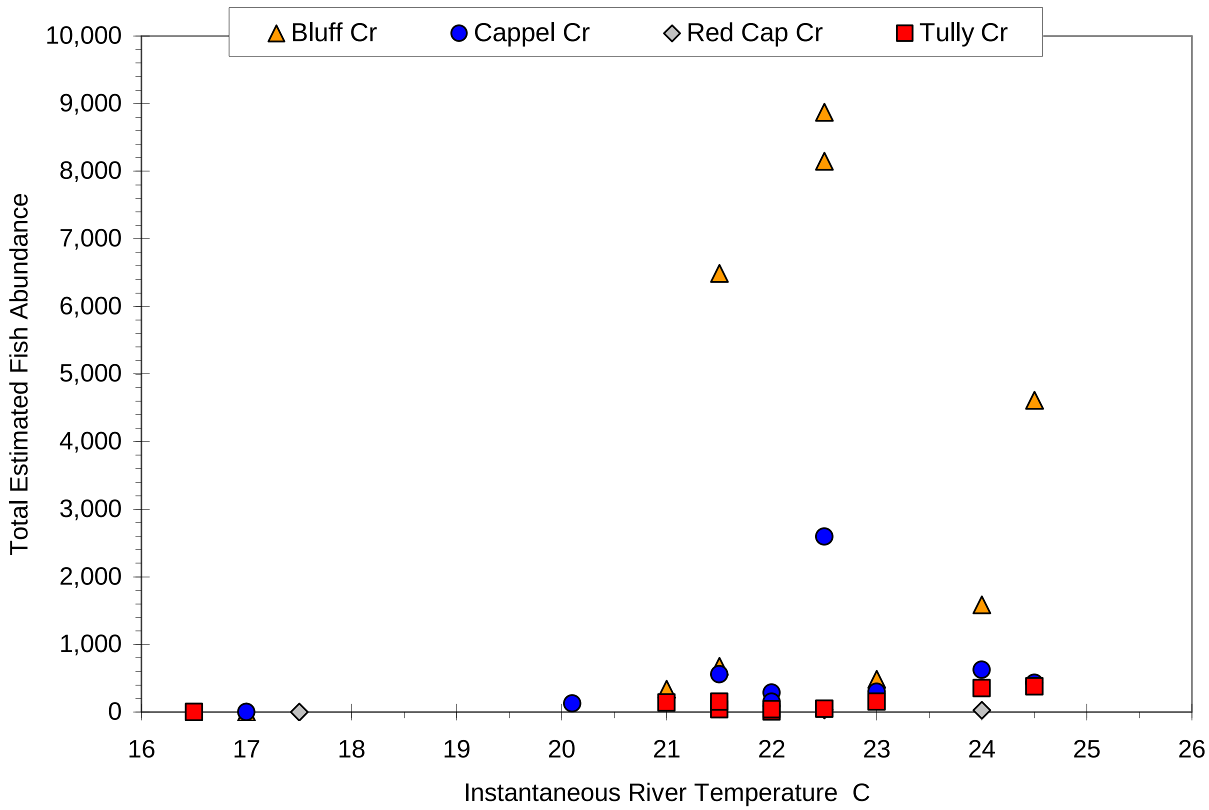

Figure 8. Estimated total fish abundance for all age classes and species of salmonids observed at the four index sites during the summer of 2010 as a function instantaneous water temperature of the adjacent mainstem Klamath River. The Red Cap Creek thermal refuge had negligible use by salmonid because the configuration of the mouth resulted in poor holding habitat (i.e. shallow and swift).

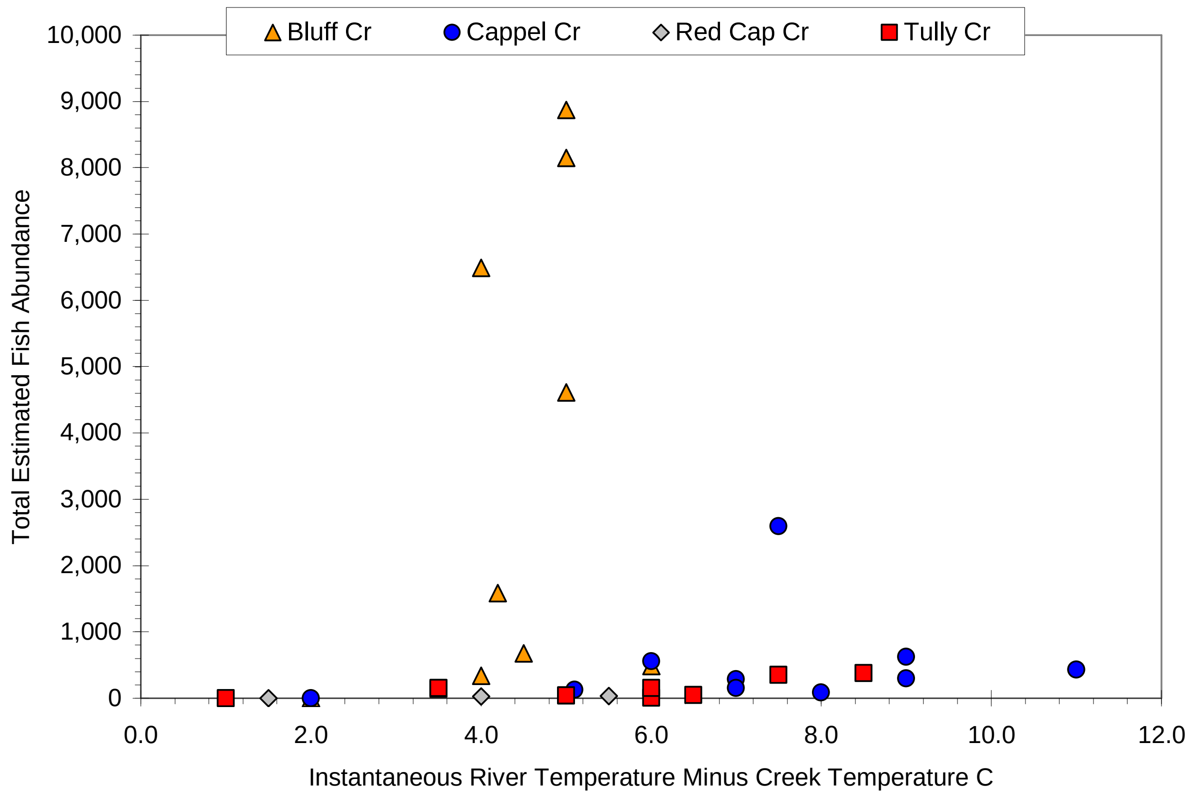

Figure 9. Estimated total fish abundance for all age classes and species of salmonids observed at the four index sites during the summer of 2010 as a function the difference in instantaneous water temperatures between the refuge forming creek and the adjacent mainstem Klamath River. This graph illustrates 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. In addition other factors influence thermal refuge use by juvenile salmonids such as fish cohort abundance, natal rearing, thermal refuge quality, human and predator disturbance, etc.

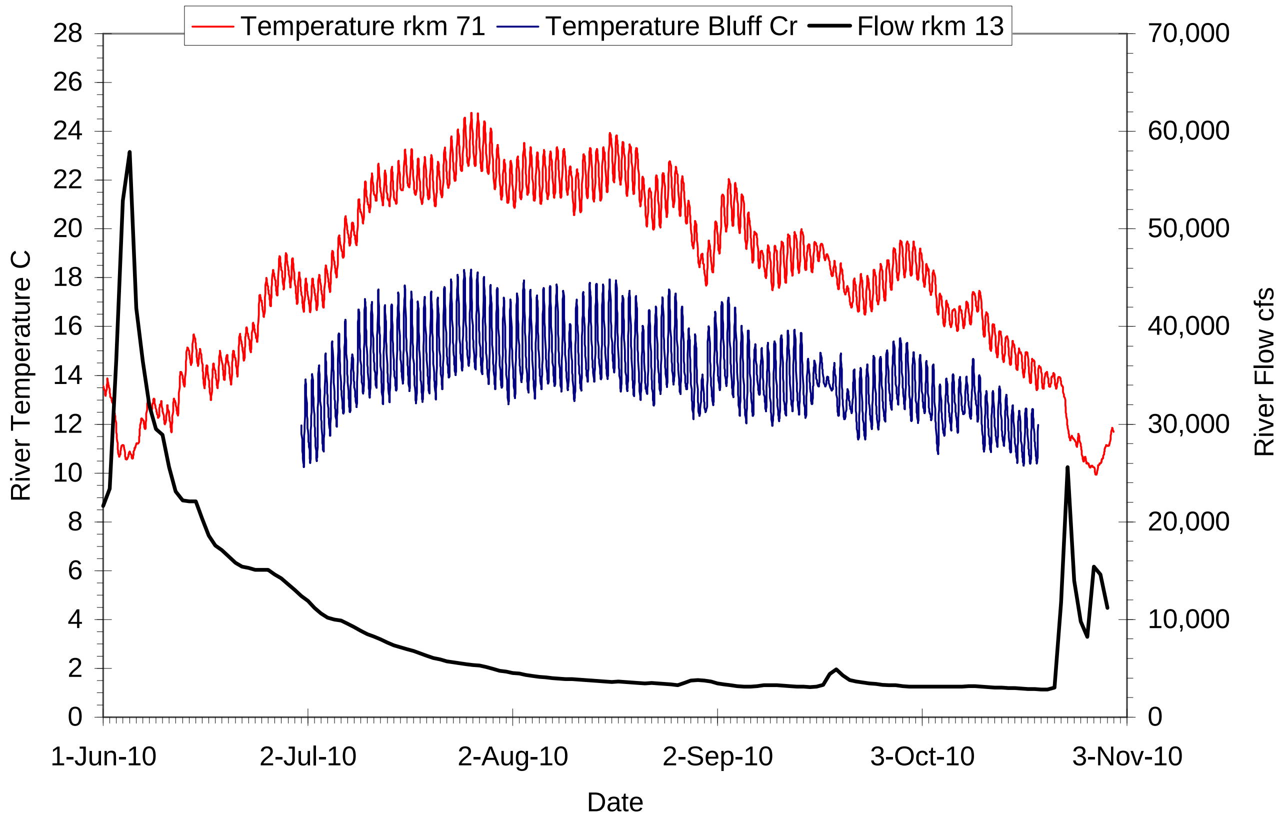

Figure 10. Water temperature and flow of the lower Klamath River during the summer of 2010 along with water temperature for Bluff Creek to provide context. Surveys were conducted during the months of July and August in 2010. Use of thermal refuges by fish was not observed until early July and continued through the termination of snorkel surveys at the end of August 2010. Due to an exceptionally late spring, flows remained high and water temperatures stayed cold extremely late into the season compared with other study years and use of thermal refuges by juvenile salmonids was delayed as a consequence.