Klamath Basin Pilot Project:
Coldwater Refugia Study and Videography

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Abstract: We found forward-looking infrared (FLIR) to be an effective, highly accurate, and cost effective method to map stream temperatures in the mainstem Klamath River. Results from the July 1998 flight matched patterns observed from instream monitors and modeled temperatures. Stream temperatures were mapped from just above Seiad (river km 217) to just above Cottonwood Creek (river km 297) and ranged from 23.8 to 26.8°C (mean = 25.4°C). These temperatures are just below or exceed the upper incipient level for salmonids. This suggests that temperature is a bottleneck for life stages of wild salmonids that rear or hold in this section of the Klamath River during July and August. Elevated stream temperatures should not affect hatchery reared chinook salmon as they are exposed to lower stream temperatures during their migratory phases. Potential thermal refugia were only found in association with tributary junctions, thermal refugia were not associated with individual channel units. We also radio-tagged nineteen adult fall chinook salmon with temperature sensitive tags in September 1996 and tracked them until late October 1996. There was no evidence that migrating adult fall chinook salmon were behaviorally thermoregulating during their upstream migration. Water temperatures were moderate for salmonids during the fall migration. Daily maximum temperatures did not exceed 20.0°C, but were typically above 15.0°C.

Introduction:

The purpose of this pilot program was to determine whether or not forward looking infrared (FLIR) videography could be used to develop thermal maps of the mainstem Klamath River to assess habitat limitations due to high stream temperatures for fall chinook salmon (*Oncorhynchus tshawytscha*). Mean daily stream temperatures exceed 7-day optimal temperatures (15°C) for chinook salmon for considerable periods from June through September in the Klamath River (Bartholow 1995). Further, maximum daily temperatures approach or exceed the upper incipient lethal temperature (25°C) regularly. The question is, how do the chinook salmon persist in the basin given that it is highly unlikely that they are better adapted to high temperatures than other stocks? Bartholow (1995) suggests that coldwater refugia may provide critical habitat for fall chinook salmon in the basin, citing Berman and Quinn’s (1991)
documentation of the use of coldwater refugia by spring chinook salmon in the Yakima River. The next question is where are these essential habitats?

We have been able to document the use of coldwater refugia as critical holding habitats for spring chinook salmon adults in the Middle Fork of the John Day River using a combination of radio-telemetry (temperature sensitive radio-tags) to track locations and movements of chinook salmon, FLIR videography to record thermal energy emitted from the stream, and continuous recording in-stream thermographs to track daily temperatures during the summer (McIntosh et al. 1995, Torgersen et al. 1995). This was a very effective procedure in a relatively small, fourth-order stream as our ground truthing revealed that the relationship between radiated energy (infrared) and kinetic energy (stream temperatures) were highly correlated ($r^2 = 0.93$) and that bottom temperatures were essentially the same as surface temperatures.

We suspected that these combined techniques would be a powerful way to assess the distribution of chinook salmon in relation to temperature patches in the Klamath Basin (e.g., examine the temperature plumes and temperature mixing zones of coldwater tributaries like the Scott River). Our primary concern was that we would not be able to detect deep, stratified thermal pools in the Klamath River. However, we thought that tracking salmon carrying thermally sensitive radio-tags would compensate for that problem. We proposed to tailor our approach to the larger Klamath system, to determine the feasibility of the approach for more extensive work.

The pilot study has proceeded in two stages. Stage I comprises objectives 1, 2, and that part of objectives 3 and 4 which requires ground truthing. This stage is field oriented and includes FLIR surveys and the radio telemetry work. Stage II entails objectives 3, 4, and 5 and involves the processing and analysis of aerial videography and linking this with the radio telemetry data in a GIS. The objectives for the project were:

1. Determine whether FLIR imagery will accurately characterize longitudinal thermal patterns of the Klamath River.
2. Determine if FLIR can detect thermal refugia in the Klamath River.

3. Determine whether true color videography can detect indicators of deep pools (e.g., color differences, detection of substrate).

4. Determine whether chinook salmon hold in habitats that are cooler than mainstem temperatures (using thermally sensitive radiotags).

5. Develop partnerships for future collaborative research and transfer information to all interested parties.

**Description of the Study Area:**

We conducted this study in the Klamath River Basin, California primarily on the mainstem of the Klamath River. For the radio-telemetry work, fish were tagged at Ishi Pishi Falls (river km 107) and tracked to their furthest upstream extent. The FLIR survey was conducted from just above Seiad (river km 117) to just above Cottonwood Creek (river km 297).

**Objective One:** Determine whether FLIR imagery will accurately characterize longitudinal thermal patterns of the Klamath River.

**Principle:** As FLIR imagery measures the thermal energy radiated from the water’s surface, vertical temperature stratification will prohibit the use of FLIR to characterize longitudinal thermal patterns of the Klamath River.

**Methods:** We conducted a field survey to determine whether vertical temperature stratification was a common characteristic of the mainstem Klamath River, particularly in pool habitats. Through consultation with biologists from the Coastal California Fish and Wildlife Office, the Yurok and Karuk tribes, and the USDA Forest Service we determined sampling sites where vertical stratification might be possible. With the aid of the USDA Forest Service Happy Camp
Ranger District, we rafted downstream from Humbug Point to the Sarah Totten Boat Access. We measured the surface and bottom temperatures of each pool and air temperature using an Atkins™ handheld digital thermometer. The Atkins thermometers are accurate to 0.1°C and have a response time of 0.5 seconds. Temperatures were taken between 09:00 and 17:00 hr from 10 Sept. 96 to 12 Sept. 96. We also measured the maximum depth of each pool with a line and weight. Weather factors that may influence temperature measurements such as wind and cloud cover were noted. Pools were geo-referenced using a Magellan™ GPS unit. Other descriptors of location were recorded so that pool locations could be placed on a GIS data layer. We also placed HOBO-temps at the bottom and just below the surface of two pools for the study period. Unfortunately only one set of monitors was recovered.

**Results:** We sampled forty-six pools in the study reach. Maximum depth ranged from 2 to 8.5+ meters. The temperature difference between the surface and the bottom of the pools ranged from -0.1°C (1 pool) to +0.1°C (7 pools) with no difference in temperature between the top and bottom of most pools (N = 38). Figure 1 shows the temperature values for the bottom and surface samples from upstream to downstream over the 3 days of sampling. The HOBO-temps placed at the surface and the bottom of the Coon Creek pool just below Happy Camp measured temperatures from 9/5/96 - 10-22-96. We found no difference in surface and bottom temperatures for the six-week sampling period (Figure 2). Our results indicate that streamflows in the study reach keep the water column well mixed vertically.

**Discussion:** We concluded that FLIR imagery could be used to characterize longitudinal thermal patterns of the Klamath River. Thermally stratified pools were not present in the study reach, therefore validating the use of FLIR for temperature mapping. Nielsen et al. (1994) found that large, backwater pools behind point bars were typically associated with thermally stratified waters. We found none of these pools in this reach of the river.
OBJECTIVE TWO: Determine if FLIR can detect thermal refugia in the Klamath River.

Principle: FLIR imagery will capture the longitudinal thermal characteristics and thermal patchiness of the Klamath River between Scott River and Shasta River. The availability of habitat of different temperatures, including thermal refugia, can be estimated within this reach of river.

Methods: FLIR imagery was collected on 19 September 1996, just prior to the radio tagging of adult fall chinook salmon at Ishi Pishi Falls. The aerial videography captured images from a stream reach of 64 km (40 miles). FLIR images were captured during the late afternoon using an AGEMA Thermovision™ 1000 FLIR from a helicopter platform flying 40 km hr⁻¹ at about 500m about the river’s surface at a vertical view. In 1998, the FLIR was collected in a similar manner, with an upgraded AGEMA Thermovision™ 1000 FLIR that recorded the imagery digitally at the rate of one frame per second directly to an onboard computer. Time of day, frame number, and pixel statistics were stored in header files associated with each digital image. Digital images were geo-referenced using a Trimble™ GPS receiver and the GPS data was related to UTC times in the header files for the images. Post-processing of imagery involves (1) temperature classification from pixel values in °C, (2) sub-sampling the imagery at regular intervals forming a near-continuous thermal map, (3) calculating median stream temperatures for the sub-sampled imagery, and (4) identifying thermal patches visually. Median temperatures are calculated to minimize the effect of extreme values providing a more representative statistic of stream temperatures. All data is linked to a GIS as a final product for this project.

Discussion: We completed processing the 1996 FLIR imagery in Fall 1996 and developed longitudinal profiles for the study reach. Due to our inability to retrieve the HOBO-temps we placed for ground-truthing the FLIR, we obtained data from Mike Deas at U.C. Davis for this purpose. Unfortunately, based on Mike’s data, we learned there had been a sensor malfunction on the 1996 flight and determined the study reach would have to be re-flown in 1997. We were finally able to attain our objectives in 1998 by using a different contractor after conducting two unsuccessful flights in 1996 and 1997 (with Pioneer Helicopters). In fact, we invested
considerable time with the second contractor as consultants to help them select the proper
equipment to get the job done properly. The flights in 1997 and 1998 were completed at no
additional cost to US Fish and Wildlife Service. The 1998 FLIR data collection was donated by
Snowy Butte Helicopters, Inc., Medford, OR as part of testing their current system.

Based on our results from Objective 3, we concluded that conducting a FLIR survey in the
summer would provide more useful information to Klamath River Fisheries Task Force than a
fall survey. Thermal stress to salmonids does not appear to be a problem for upstream migrating,
adult chinook salmon during the fall; however, summer conditions are clearly of concern for
stages of spring chinook and fall chinook salmon which are holding before spawning and/or
rearing in the system.

We conducted the FLIR survey on July 27, 1998 from 14:40 to 15:23. Timing of the
flight was intended to coincide with daily maximum temperatures, which typically occur
between 15:00 and 17:00. Data was collected from river km 217 (river mile 135, just above
Seiad) to river km 297 (river mile 184) a distance of 80 km (49 miles). To calibrate and validate
the accuracy of the FLIR imagery, we compared temperature values from two in-stream monitors
placed at the beginning and end of the survey reach to the corresponding FLIR images. Error
between the FLIR and in-stream monitors was ± 0.2°C. Flight time had a minimal effect on
temperatures as the net change in temperature for the sample reach due to flight time was 0.35°C.

We plotted median stream temperatures against river km to display the longitudinal
temperature profile for the study reach (Figure 3). In addition, temperatures for all visible
tributaries were measured and plotted in the longitudinal profile. At the time of the flight,
mainstem temperatures varied from 23.8°C to 26.8°C with a mean of 25.4°C. Data from the
instream temperature recorder at Iron Gate Dam (river km 306) indicates that the Klamath River
was 22.9°C at the time of the flight. From Iron Gate Dam downstream to just above Interstate 5
stream temperatures increased rapidly to the maximum for the study reach (26.8°C, river km
291.1). Stream temperatures then decreased downstream to their minimums (23.8°C, river km
258.8) just below Beaver Creek. Continuing downstream, temperatures increase until the
confluence with the Scott River (river km 230.6). The Scott River enters the Klamath River
2.0°C cooler (23.6°C) than the Klamath and moderates temperatures for several km downstream. Stream temperatures increase slowly downstream of the Scott River to river km 227.6 where they decrease slowly to the end of the survey. The FLIR survey did show that there were cooler and warmer reaches in the study area, a finding similar what Torgersen et al. (1999) found in the John Day River basin in eastern Oregon. Subsequent discussions with Mike Deas (U.C. Davis) confirm that our pattern fits his field data and modeling of stream temperatures in this reach. In addition, the decrease in stream temperatures from the Shasta River downstream to Beaver Creek are probably due to the effect of the constant temperature and flow releases from Iron Gate Dam (M. Deas, U.C. Davis, Pers. Comm.). The “node” of constant diurnal temperature as Mike Deas refers to it.

We were able to measure the temperature of 26 streams at their confluence with the Klamath River. Tributary temperatures ranged from 18.2°C (Jim Creek, river km 226.6) to 28.2°C (Shasta River, river km 284.8). All but four of the tributaries (Unnamed Tributary, Little Humbug Creek, Shasta River, Cottonwood Creek) were cooler then the Klamath River at the confluence at the time of the flight (Figure 3).

All FLIR imagery for the study reach was analyzed for areas of potential thermal refugia. Thermal refugia was defined as any part of the stream channel where the water temperature was \( \geq 1^\circ C \) cooler than the median temperature for the image. We were able to detect relatively few areas of thermal refugia for the study reach. All the areas we did detect were associated with cool water inputs from tributaries, such as the Scott River (Figure 4) and Horse Creek (Figure 5). Table 1 illustrates the temperature differences between mainstem temperatures and cool water plumes created by tributary inputs, with temperature differences ranging from 1.0 to 2.9°C. These areas closely corresponded with thermal refugia identified by Belchik (1997) in 1996. We did not find that pools were cooler than riffles. Moreover, thermal conditions within habitat units were uniform for the most part. Of particular interest, we detected a large warm plume at the confluence of the Klamath with the Shasta River which suggests to us that improving the Shasta catchment will pay big dividends (Figure 6). The Shasta River exceeded mainstem temperatures by 1.6°C.
Table 1. Examples of temperature differences detected using FLIR.

<table>
<thead>
<tr>
<th>Location</th>
<th>River km</th>
<th>Mainstem Temperature (°C)</th>
<th>Thermal Refugia Temperature (°C)</th>
<th>Difference (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kuntz Creek</td>
<td>225.3</td>
<td>25.3</td>
<td>24.0</td>
<td>-1.3</td>
</tr>
<tr>
<td>Mack Creek</td>
<td>228.0</td>
<td>25.6</td>
<td>22.8</td>
<td>-2.8</td>
</tr>
<tr>
<td>Tom Martin Creek</td>
<td>229.7</td>
<td>25.4</td>
<td>23.3</td>
<td>-2.1</td>
</tr>
<tr>
<td>Scott River</td>
<td>230.6</td>
<td>25.3</td>
<td>24.0</td>
<td>-1.3</td>
</tr>
<tr>
<td>Horse Creek</td>
<td>237.7</td>
<td>26.3</td>
<td>23.4</td>
<td>-2.9</td>
</tr>
<tr>
<td>Doggett Creek</td>
<td>249.6</td>
<td>25.0</td>
<td>24.0</td>
<td>-1.0</td>
</tr>
<tr>
<td>Beaver Creek</td>
<td>259.6</td>
<td>24.2</td>
<td>22.0</td>
<td>-2.2</td>
</tr>
</tbody>
</table>

**OBJECTIVE THREE:** Determine whether true color videography can detect indicators of deep pools (e.g., color differences, detection of substrate).

**Principle:** Differences in surface turbulence and reflectance are indicators of fast and slow water stream habitats. Using true color videography, we can classify stream habitats according to differences in visual characteristics. Large, deep pools should be much darker in color due to the attenuation of light with increasing depth. These characteristics will allow us to qualitatively classify stream habitats using remotely sensed data.

**Methods:** We compared pools surveyed in September 1996 for Objective 1 to the true color videography collected during July 1998 to determine if pools could be identified using remote sensing. Differences in surface turbulence and reflectance were used to distinguish fast water from slow water habitats. Increased surface turbulence and increased reflectance, causing them to appear white in the video characterized fast water habitats. To characterize pools of different depths, we examined the imagery for differences in appearance (color) and visibility of bottom substrate.

**Results:** We were able to distinguish fast and slow water habitats readily from true color videography (Figure 7). Slow water habitats were characterized dark colors and little or no
surface turbulence, while fast water habitats were characterized by lighter color and turbulent water surfaces. Unfortunately, we were unable to detect differences in pools of varying depths with true color videography. It should be noted that all pools in the study reach were \( \geq 2.0 \) meters in depth making them all deep pools to begin with. In addition, bottom substrates were rarely visible on the ground, let alone in the air, due to poor water clarity.

**OBJECTIVE FOUR:** Determine whether fall chinook salmon hold in habitats that are cooler than mainstem temperatures using thermally sensitive radiotags.

**Principle:** Patterns of habitat use related to stream temperatures can be determined by tracking radio-tagged fall chinook salmon implanted with temperature sensitive transmitters. Fish locations and corresponding data can be associated with FLIR imagery in a GIS. Habitat electivity can be determined from the combination of FLIR imagery and radio tracking data.

**Methods:** Adult fall chinook salmon were captured and radio-tagged at Ishi Pishi Falls from 17 September 96 to 20 September 96. Several Karuk tribal fishermen assisted in the tagging operation. Tribal fishermen dip-netted the fish and transported them to a tank containing the anesthesia MS222. Lotek™ radio tags, previously calibrated for accuracy, were inserted down the gullet of anesthetized fish. The fish were measured and the identification number of the radio tags were recorded. Radio tagged salmon were transported upstream to a recovery pool in PVC tubes filled with river water. Salmon were observed and if necessary given artificial respiration until they regained equilibrium.

Fish were tracked from 21 Sept. 96 to 22 Oct. 96 on twenty-three different days. Radio tracking was conducted from a pickup truck equipped with an antenna and a Lotek™ receiver. Fish were located using triangulation. A Magellan™ GPS unit was used where feasible to georeference fish locations; where signals could not be received because of the canyon walls, road mile markers were used. Surveys began at Ishi Pishi Falls or at the location of the lowest fish in the river and continued upstream until all fishes were located. For each tracking record, the
following data was collected: date, time, tag frequency, thalweg temperature, channel unit type (pool, riffle, glide), internal body temperature of tagged fish, and GPS coordinates. Thalweg temperatures were not collected at inaccessible sites and fish temperatures were not available where signals were weak.

**Results:** We tagged nineteen fish in four days with the help of the Karuk fishermen. Fifteen of the nineteen fish survived to the end of the study. Eight fish were recovered at the Iron Gate hatchery, a tribal fisherman caught one fish at Ishi Pishi Falls, one fish regurgitated a tag, and two fish were missing. Interestingly, seven salmon dropped back below the falls after being tagged. Five of those fish survived to the end of the study, three of which were recovered at the hatchery. It took a minimum of 15 days for the migrating salmon to reach the hatchery, but four fish were recovered in the last two days of the fieldwork.

Stream temperatures were relatively cool during the 1996 study period. The average of 67 thalweg temperature measurements was 15.7°C (standard deviation = 1.6, range = 11.1 to 18.1°C). Fifty-nine paired observations of adult spring chinook internal temperatures and thalweg temperatures were recorded. The average adult spring chinook internal temperature for the study period was 16.0°C (standard deviation = 1.6, range = 11.6 to 19.0°C). The average difference between body core and stream temperatures was −0.3°C (range = -1.4 to 1.8°C), with 93% (N=55) of body temperatures within ±1.0°C of the thalweg temperatures. These differences are well within that expected for the metabolism of migrating salmonids (Berman and Quinn 1991). There was only one observation where the body core temperature was >1.0°C (-1.4°C) less than the thalweg temperature.

**Discussion:** Based on the above results, it appears that none of the migrating fall chinook were stressed by high temperatures. We found virtually no evidence that adult spring chinook salmon were behaviorally thermoregulating during the study period. Only one fish appeared to be holding water that was more than 1.0°C cooler than ambient conditions. Interestingly, temperature is probably a critical problem for all juvenile life stages of wild spring and fall chinook stocks, but not for hatchery runs. Water temperatures for migratory smolts and adults should be physiologically tolerable during spring and fall. This explains the success of the
hatchery program in comparison to the dwindling number of wild stocks of salmonids: temperature regulation of hatcheries shield holding adults and juvenile life stages from temperature stress.

**Summary and Conclusions:**

We found that FLIR was an efficient, highly accurate, and cost-effective method to map stream temperatures in the mainstem Klamath River. Our initial concerns that vertical thermal stratification would limit our ability to accurately measure water temperatures proved unfounded. No vertical stratification was found in any of the pools in the study reach, even those exceeding 8.5 m in depth. Therefore, surface water temperatures as detected by FLIR were representative of the water column.

Water temperatures did not appear to be a significant stressor on adult fall chinook salmon during the September 17 – October 22, 1996 migration. Daily maximums never exceeded 20.0°C, although daily maximums commonly exceeded 15°C. We found little evidence that radio-tagged fish were behaviorally thermoregulating during the fall migration. These results are consistent with the relatively cool ambient conditions for salmon during this time of year.

We conducted a FLIR survey on July 27, 1998 to characterize summer thermal conditions in the mainstem Klamath River. A longitudinal temperature profile was developed for the study reach. The results of this survey were consistent with field data and modeling from U.C. Davis (Mike Deas, U.C. Davis, Pers. Comm.). We also surveyed the study reach for the areas of potential thermal refugia. All areas of potential thermal refugia were associated with tributary junctions, a similar finding to Belchik (1997). We found no evidence of thermal refugia at the channel unit scale. With the data from this project, researchers in the Klamath basin now have highly accurate temperature maps to more effectively delineate and survey these areas for there potential as thermal refugia. While tributaries did provide the only source of thermal refugia, it must be noted that they are a very small area relative to the mainstem Klamath. In addition, except for the Scott River, they provide very little flow and subsequent cooling to the Klamath
River. One potential area for future examination may be the influence of artificially elevated flow regimes on thermal conditions. Other researchers have noted local thermal refugia can be reduced or eliminated by elevated and warmer mainstem flows (Gordon Reeves, PNW Research Station, Pers. Comm.).

While water temperatures do not appear to be a significant problem during the fall, it is clear from our 1998 survey that summer conditions are at or near upper incipient lethal temperatures for salmonids for extended periods. Life stages that need to use the mainstem during this period face extreme conditions for survival. Tributary junctions and the tributaries themselves provided moderated conditions, the mainstem Klamath River appears to represent very poor habitat for salmonids. Improving habitat conditions in tributary systems will increase available habitat and contribute to improved mainstem conditions, but discharges from the Iron Gate Dam clearly limit mainstem temperatures. The temperature of discharges from Iron Gate Dam (July 27, 1998 = 22.8°C) set the lower limit for stream temperatures for the basin.

References:


Figure 1. Bottom and surface temperatures for pools surveyed between Humbug Point and Sarah Totten Boat Access.
Figure 2. Comparison of surface and bottom temperatures for Coon Creek Pool from HOBO monitors.
Figure 3. Median stream temperatures derived from FLIR imagery for the Klamath River, July 27, 1998.
Figure 4. FLIR and true color videography for the Klamath and Scott River confluence. Scott River averages 1.3°C cooler than Klamath River.
Figure 5. FLIR and true color imagery for Horse Creek/Klamath River confluence. Horse Creeks averages 2.9\degree C cooler than the Klamath River.
Figure 6. FLIR and true color imagery for Klamath/Shasta River confluence. Shasta River averages 1.6°C hotter than Klamath River at confluence.
Figure 7. True color image showing differences in surface features of slow and fast water habitats.