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THERMAL REFUGIA AND CHINOOK SALMON HABITAT IN OREGON: APPLICATIONS OF AIRBORNE THERMAL VIDEOGRAPHY

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ABSTRACT

We examined the use of thermal refugia by adult spring chinook salmon (*Oncorhynchus tshawytscha*) in the Middle Fork and North Fork of the John Day River in central Oregon by comparing fish distributions with remotely sensed image data and relating individual fish locations to thermal refugia and reach-scale isotherms. Distribution and holding behavior of chinook salmon were assessed using snorkel surveys of untagged fish and telemetry of salmon tagged with temperature-sensitive, internal radio-transmitters. We identified spatial associations between fish and coolwater inputs and thermal gradients by overlaying thermal imagery with fish locations recorded with a global positioning system and detailed hand-drawn maps. Chinook salmon frequently occupied positions 1 to 3˚ C cooler than available surrounding habitat. However, elements of instream cover such as depth, undercut banks, overhanging shore vegetation, large substrate, and large woody debris may also play a primary role in habitat selection by salmon. Airborne thermal remote sensing is a useful tool for detecting warm and cold water sources and mapping spatial heterogeneity of stream temperature across varied spatial scales. It provides a fast, efficient method for monitoring stream temperature over large areas.

INTRODUCTION

The John Day River basin has one of the healthiest runs of wild spring chinook salmon (*Oncorhynchus tshawytscha*) in Oregon. The river reaches utilized by spawning salmon today represent less than a third of the probable historical distribution in the John Day River system. Elevated stream temperatures resulting from land-use practices, such as logging, road building, grazing, and mining, throughout the basin are significant factors limiting the current distribution of spawning chinook to the uppermost headwater reaches of the Mainstem, Middle Fork, and North Fork of the John Day River (Wissmar et al. 1994).

Airborne videographic techniques have proved highly useful for addressing freshwater ecosystem management problems related to land use. Airborne video cameras and thermal radiometers that measure visible, reflected, and thermal infrared wavelengths are well-suited for vegetation and water-related applications (Luvall and Holbo 1991, Snider et al. 1994, Rango 1994). Hick and Carlton (1991) detected coldwater areas in an Australian river that were important refugia for rainbow trout. Aerial videography has been used in resource management to evaluate fish habitat in streams (Overton and Mussakowski 1983), monitor aquatic vegetation, spawning areas, and measure stream dimensions (Mussakowski 1984).

Spring chinook salmon return from the 2-3 year ocean phase of an anadromous life cycle to their natal streams in late spring. The adult salmon migrate upstream and then hold in cooler headwater reaches during the hot months of summer; the salmon spawn in the fall when stream temperatures become more tolerable. Adult salmon cease to feed upon entering fresh water and, therefore, function on a limited energy reserve until spawning. Because salmon are poikilothermic, i.e., their body temperature is the same as the water temperature, their metabolic rate increases directly with temperature. Thus, high water temperatures (>20˚ C) prior to spawning compromise energy necessary to insure reproductive success.

Salmon that are able to reside in coolwater refugia before spawning are energetically fit to spawn and produce viable offspring.

The objectives of this study were 1) to examine the distribution and habitat use of holding spring chinook in minimally disturbed versus human-altered river systems, 2) to assess thermal patterns and coolwater refugia at a variety of spatial scales, and 3) to compare habitat selection by spring chinook with respect to thermal patterns in disturbed versus altered environments. The goal was also to assess the utility of thermal remote sensing for detecting and quantifying coolwater habitats.

STUDY AREA

The John Day River basin is located in central Oregon and drains approximately 20,300 km^2. The study sites in the North Fork and the Middle Fork flow through predominantly coniferous forest with interspersed meadow lands at elevations up to 1800 m. Summer temperatures are relatively high (38° C maximum) with low humidity. The predominant land uses in the altered stream, the Middle Fork, are grazing and logging which has resulted in degradation and removal of riparian vegetation, sloughing of undercut stream banks, and upland soil compaction. The average density of adult spring chinook in the Middle Fork is 18 fish/km. The North Fork study site is located in designated wilderness in the Umatilla National Forest. Nearly all chinook holding and spawning occurs in the North Fork wilderness reach, which supports more than twice as many chinook per kilometer as the Middle Fork.

METHODOLOGY

The distribution of salmon and their utilization of stream habitat were assessed using two techniques: radio-tracking of tagged fish, and empirical observation of untagged fish. Radio telemetry of 12 individual fish with internal temperature-sensitive, radio-transmitter tags facilitated detailed tracking of hourly, daily, and seasonal behavior of salmon with respect to ambient stream temperature fluctuations. Snorkel surveys of the reaches occupied by holding salmon provided 1) estimates of adult densities, and 2) maps of reach-wide distribution of salmon. Selection by salmon of holding habitats, such as pools, riffles, and glides, as well as types of cover, i.e., large woody debris, large substrate, depth, shade, and undercut banks, were noted and sketched on detailed field maps to be later compared with thermal maps obtained through remote sensing.

Assessment of stream thermal patterns was conducted at point locations and with continuous thermal mapping from remote sensing. HoboTemp[R] digital data loggers were placed at the upper and lower boundaries of study reaches and provided information on water temperature fluctuations throughout the field season and served as temperature ground-truth points at a temporal resolution of 30 minutes. Thermal mapping with the use of low altitude forward-looking infrared (FLIR) videography was conducted during peak summer temperatures during the first week of August. We surveyed approximately 108 km of the Middle and North Forks of the John Day River in two days between 15:00 and 16:00 hours to capture peak water temperatures. Thermal imagery in the 8-12 µm wave band was collected with an AGEMA Thermovision[R] 800 FLIR from a helicopter platform flying 40 km/hour at 250-300 m above the river surface at an oblique angle 35-40 degrees from the nadir. With a 20 degree field of view and an image size of 140 x 140 pixels, we were able to collect imagery with ground resolutions ranging from 20-40 cm. Analog data were calibrated in degrees C, digitized, and stored during flight at a rate of 3 frames/second on the hard drive of a 486 personal computer. Time of day, frame number, and pixel statistics were stored in header files associated with each digital image. Position fixes for each image were obtained by relating GPS data acquisition times from a running GPS receiver to image acquisition times in the header files. Post-processing of imagery involved 1) temperature classification from pixel values in degrees C, and 2) subsequent compilation of mosaics forming continuous thermal maps of study reaches. Locations of spring chinook, obtained through radio-tracking and snorkel surveys, were subsequently overlaid on the thermal maps to detect associations between fish behavior and spatial patterns of water temperature.

Ground truthing measurements, comparing radiant temperatures recorded in the imagery to actual kinetic water temperatures, were collected in riffle and pool habitats at the surface and in the water column. Thermal stratification was insignificant or not present even in pools greater than 1.5 m deep; this suggests thorough mixing from convection and turbulence within the water column. The accuracy of apparent temperatures in the imagery was acceptable, with an average difference of ±0.4° C not accounting for confounding factors such as shade, overhanging vegetation, and depth. Linear regression demonstrates a good fit (p-value < 0.0001, r-squared $= 0.93$) between radiant and ground-truthed (kinetic) temperatures approximating a near 1:1 direct relationship (Figure 1).

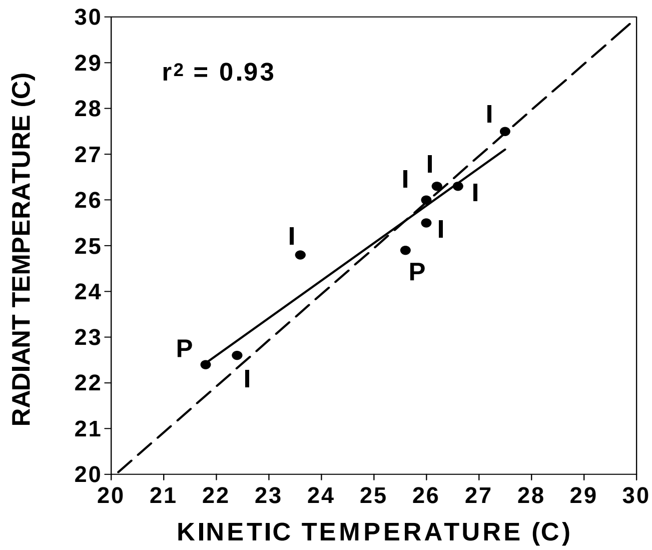

Figure 1. Field observations of kinetic water temperature (I = measurements in riffles, P = measurements in pools) compared to radiant temperatures of imagery show a highly significant (p-value < 0.0001, r-squared = 0.93) direct 1:1 relationship without accounting for confounding factors such as shade, depth, and overhanging vegetation. For reference, the dashed line represents a perfect 1:1 relationship, and the solid line is the fitted regression.

RESULTS AND DISCUSSION

Spring chinook salmon in the upper Middle Fork were consistently located in coolwater patches. These patches were 1-3° C cooler than surrounding habitat within a 10 m radius. Coolwater areas occurred most frequently in pool habitats where cold groundwater flow may be entering the channel laterally through the pool substratum (Figure 2). The actual presence and magnitude of such groundwater flow remains to be investigated. Many of these coolwater refugia in the grazed reaches of the Middle Fork could not be linked to obvious surface vegetation or channel morphology characteristics and, hence, were not identifiable without the use of FLIR imagery. Analysis of thermal imagery also facilitated detection and evaluation of warmwater point sources such as tributary junctions and flood irrigation canals. The thermal environment of the upper Middle Fork was characterized as spatially heterogeneous with disjunct patches of relatively cooler water (Figure 2).

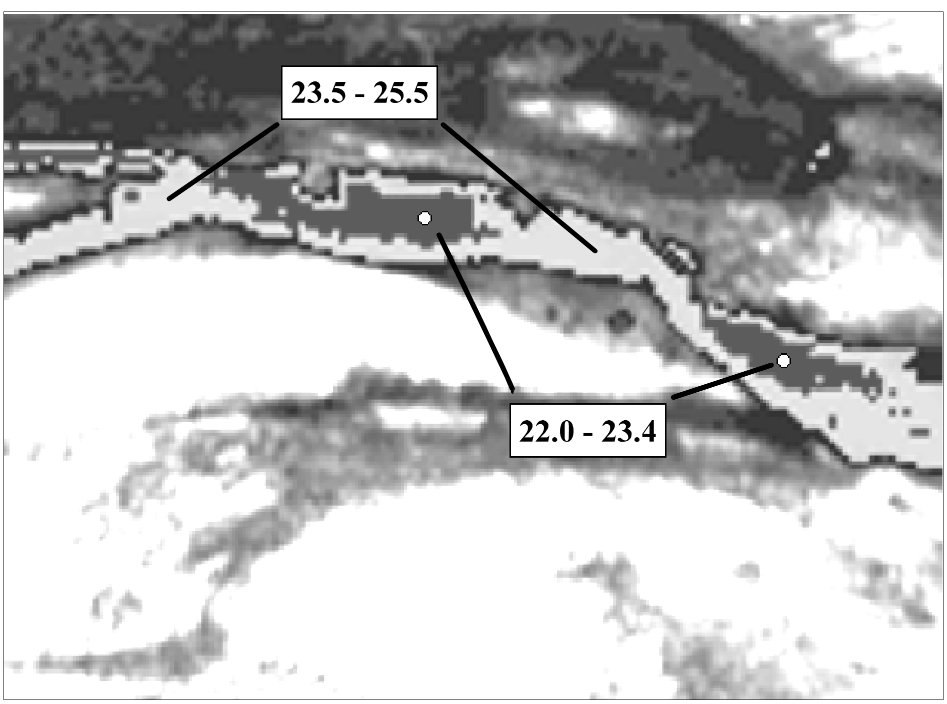

Figure 2. A thermal infrared image of spring chinook habitat in the Middle Fork John Day River. Darker tones indicate cooler radiant temperatures. The active river channel (center of image) has been classified in light gray (23.5 - 25.5˚ C) and darker gray (22.0 - 23.4˚ C) to show thermal refugia used by salmon (white circles). The image represents a ground area of approximately 63 x 45 m.

In contrast to the Middle Fork, the wilderness reaches of the North Fork were 5-7° C cooler and spatially uniform in temperature. Chinook salmon were not observed utilizing coolwater refugia in the North Fork. The wilderness reaches had steeper canyon walls, denser riparian vegetation, and were higher gradient than the Middle Fork reaches, so shading may be a significant factor leading to homogeneously cool water temperatures.

Prior to thermography, we attempted to determine chinook selection of coolwater habitats solely by using temperature-sensitive tags to compare average fish temperature to random thermometer measurements up- and downstream of the salmon. We were unable to detect the presence or utilization by salmon of coolwater refugia with this method. This was probably the result of our sampling design failing to allow analysis across nested spatial scales.

In summary, our preliminary results suggest that stream temperature affects habitat selection by chinook salmon especially in altered river systems like the Middle Fork John Day River. High resolution thermal remote sensing is an effective tool for assessing spatial heterogeneity of stream temperature because it facilitates fast, efficient detection and quantification of coolwater refugia at a variety of spatial scales. In addition, large areas can be surveyed quickly and cost-effectively. FLIR technology is a valuable, quantitative tool for freshwater fishery managers seeking to identify, restore, and protect habitat for coldwater fishes and aquatic organisms.

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REFERENCES

Hick, P.T. and M.D.W Carlton. 1991. Practical applications of airborne multispectral scanner data for forest, agriculture, and environmental monitoring, 24th International Symposium on Remote Sensing of the Environment, pp. 60-61, Environmental Research Inst. of Michigan, Ann Arbor.

Luvall, J.C., and H.R. Holbo. 1991. Thermal remote sensing methods in landscape ecology. M.G. Turner and R.H. Gardner, eds. Quantitative Methods in Landscape Ecology: The analysis and interpretation of landscape heterogeneity, Ecological Studies, Analysis and Synthesis, Vol. 82. Springer-Verlag, New York.

Mussakowski, R. 1984. The application of video remote sensing to resource surveys and environmental monitoring, Proceedings of the Canadian Symposium on Remote Sensing, Montreal, Quebec, Vol. 8, pp. 91-99.

Overton, J. and R.S. Mussakowski. 1983. Stream habitat evaluation using color video recording techniques from a helicopter, Prepared for Fisheries Branch, Ministry of Natural Resources, Ontario Centre for Remote Sensing, Ministry of Natural Resources, Toronto, Ontario, Canada.

Rango, A. 1994, Application of remote sensing methods to hydrology and water resources, Hydrological Sciences, Vol. 34, No. 4, pp. 309-320.

Snider, M.A., Hayse, J.W., Hlohowskyj, I., and LaGory, K. 1994, Multispectral airborne videography evaluates environmental impact, GIS World, June, pp. 50-52.

Wissmar, R.C., Smith, J.E., McIntosh, B.A., Li, H.W., Reeves, G.H., and Sedell, J.R. 1994. Ecological health of river basins in forested regions of eastern Washington and Oregon, Gen. Tech. Rep. PNW-GTR-326. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 65 p.