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Airborne Thermal Remote Sensing Of Salmonid Habitat For Restoration Planning In Pacific Northwestern Watersheds

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Many technologies that have roots in defense-related applications have been successfully transferred to civilian, commercial use in environmental analysis, planning, and many other applications. As part of the Environmental Technologies Initiative (ETI), we examined the utility of military-origin remote sensors for water quality monitoring applications. Overseen by EPA, this project was carried out in cooperation with research laboratories of the U.S. Forest Service and the U.S. Army Corps of Engineers. Our project focused on using forward-looking infrared (FLIR) imagery as a monitoring tool for assessing salmonid habitat in several rivers and streams in Oregon, Washington, and Idaho.

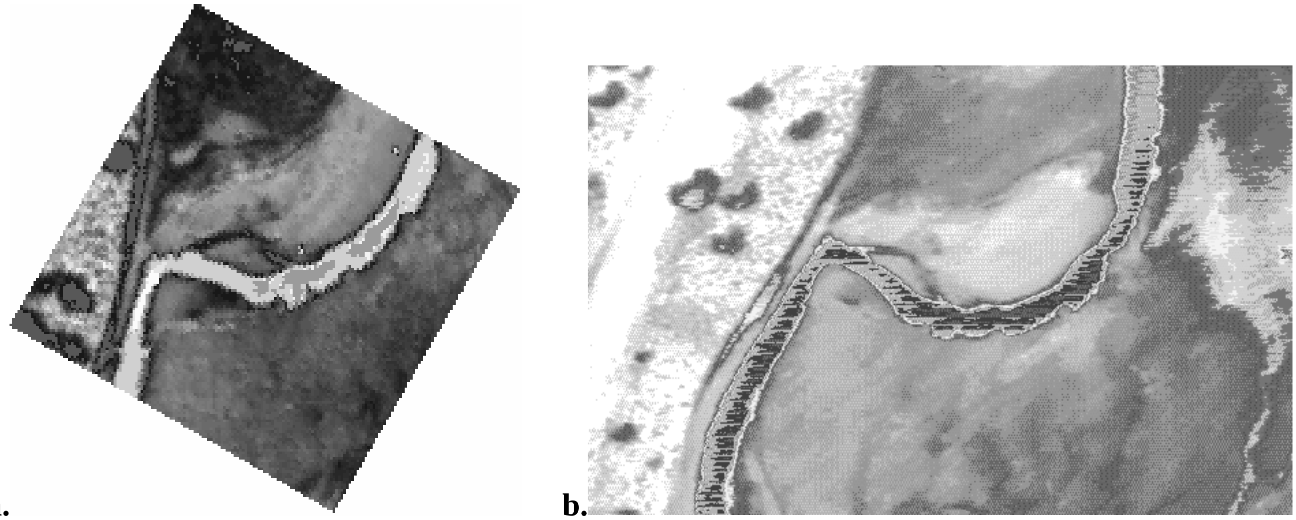
FLIR systems were originally designed for military night surveillance applications, however they are now utilized extensively in medical operations, law enforcement, fire reconnaissance, search and rescue, and environmental monitoring because are relatively portable and provide real-time thermal imagery that may be captured digitally or recorded on video tape. Because FLIRs are so portable, they may be easily operated from air (fixed-wing and helicopter) or ground-based platforms, making them ideal for terrestrial and aquatic resource assessment (Luvall and Holbo 1991). Our primary use of FLIR was to supplement water temperature information from in-stream data loggers with spatially continuous thermal image data composing entire river reaches. We were able to integrate temporally continuous, spatially limited temperature monitor data with spatially continuous, temporally constrained FLIR imagery.

Aerial videography and remote sensing techniques are increasingly being applied operationally in inland water resources and fisheries research to address issues of aquatic habitat assessment and restoration (Rango 1995, Crowther et al. 1995, Hardy and Shoemaker 1995). Multispectral aerial videography can provide high-resolution, spatially continuos information on stream channel morphology, the distribution of aquatic habitat components, such as riffles and pools, and riparian vegetation characteristics and areal extent. Thermal infrared mapping using FLIR imagery, coupled spatially with videography in the visible spectrum, records continuous water temperature patterns and facilitates identification of cool-water refugia important for coldwater fish species (Torgersen et al. 1995). Longitudinal stream profiles of thermal patterns can be obtained with airborne video thermography. The frequency, total area, and average surface area of cool-water areas, i.e. tributary confluences, ground water seeps, and subsurface stream outflow areas, can be identified in entire reaches known to be vital for spawning salmon.

Stream temperature is a critical issue particularly in the Columbia River basin in Oregon, Washington, and Idaho where historical and present land-use pressures, such as logging, road building, grazing, and mining, have limited the spawning distribution of salmon to only the uppermost river reaches where the water is cool and tolerable to salmon and trout (Beschta et al. 1987, Platts 1991, Wissmar et al. 1994). Some anadromous salmonids migrate from the ocean and enter natal streams in the spring, several months before spawning, when water temperatures are still within preferred tolerance zones for migration. The salmon must then remain in headwater streams throughout the summer, often exposed to high ambient stream temperatures and low flow conditions. Energy expenditure in coldwater fishes increases at elevated temperatures, so the reproductive performance of spawning salmon with finite energy reserves may be compromised when stream temperature rises above preferred tolerance zones. Ambient water temperatures in spawning and holding reaches for spring chinook (*Oncorhynchus tshawytscha*) in the Middle Fork and the Mainstem John Day River frequently exceed both the thermal optima cited for spring chinook) migration (16°C) and spawning (14°C) as well as the upper zone of thermal tolerance (22°C) (Armour 1991, Bjornn and Reiser 1991).

Approximately 1600 river kilometers of FLIR coverage were obtained for analysis during the heat of the summer, 1995, and these data, combined with limited FLIR imagery from 1994, formed the basis of this project. Thermally intact and impaired river reaches of ecological significance to anadromous salmon and trout were aerially surveyed in the following drainages in 1995: Asotin, Grande Ronde, Lolo, Tucannon, Umpqua, Yakima, as well as the Main, Middle, North, and South Forks of the John Day River. Thermal infrared data (5-55°C) were recorded in S-Video format on Hi-8 video tapes at 425 meters above the ground using an Agema 1000 FLIR vertically mounted on the underside of a helicopter. Digital images with ground resolutions of 25-30 cm were captured from the analog video tapes in the laboratory using a TARGA+ frame grabber and DiaQuest video animation controller. GPS coordinates and SMPTE time-code recorded in-flight permitted each image to be integrated with spatially-explicit data layers in Arc/Info geographic information and ERDAS Imagine image processing systems.

We developed diurnal water temperature curves from selected data logger locations to predict expected stream temperature on the hottest days of summer when coldwater fishes are likely to experience thermal stress. The diurnal curves were used to interpret whether the FLIR imagery, collected between 12:00 and 18:00, represented a probable daily maximum. The imagery proved useful for both classifying river reaches according to thermal characteristics and detecting cool-water refugia of critical importance to salmonids. With the aid of radio-telemetry in 1994, we were able to track the movements of tagged salmon and observe their use of cool-water areas identified in the thermal imagery (Torgersen et. al. 1995). The imagery also proved effective for locating and assessing the relative influence of warm-water inputs, such as irrigation inputs and tributaries. Specific reaches identified in 1994, a relatively hot summer, as important thermal refugia for salmon were re-examined using imagery from 1995, a comparably cooler summer (Figure 1). Preliminary analysis suggests that relatively cool reaches, possibly influenced by groundwater inputs, are predictable on a year-to-year basis. These predictably cool reaches also appear to be consistently utilized by salmon. This has important implications for stream habitat management and restoration because critical areas may be protected while reaches with habitat potential may be enhanced with riparian restoration efforts to increase shading.



a. b.

Figure 1. Sample thermal images from 1994 (a) and 1995 (b), Middle Fork John Day River. Lighter gray tones indicate warmer temperatures and darker gray tones indicate cooler temperatures. Direction of stream flow is from upper right to lower left. Image (b) represents an approximate ground area of 125 x 75 meters. In both years, adult chinook salmon were observed holding in the coolest (darkest) portions of the stream.

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