Mapping of critical summer thermal refuge habitats for chinook salmon, coho salmon, steelhead and bull trout in the Nicola River Watershed – 2016

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Introduction

Temperature has physiological effects on salmon, specific to each life stage and life history requisite. Research suggests that survival, growth and reproduction of our native salmonid species may be affected more by temperature than any other environmental parameter (McMullough et al. 2001). The Nicola River, and its tributaries, support important populations of anadromous and non-anadromous salmonids. These streams regularly experience high water temperatures, during summer months, which exceed critical thresholds for relevant salmonid life-history requisites (i.e. migration, spawning and rearing). Groundwater inputs and groundwater-surface water exchange (known as hyporheic exchange) are known to affect water quality conditions (both physical and chemical) in streams in many ways; however, the effects to temperature regimes are perhaps the most important (Baxter and Hauer 2000; Baxter and McPhail 1999).

The BC Government recently surveyed natural resource professionals in the Thompson-Okanagan Region regarding research and information needs in supporting sustainable watershed management. When asked about groundwater-surface water interactions, the majority of respondents noted that the priority need was to identify where they occur, how they vary seasonally and what the water quality conditions are (Sherer 2016). This project involved collecting aerial thermal images by using an infrared camera attached to an Unmanned Aerial Vehicle (UAV). Cool-water zones, associated with groundwater inputs, hyporheic exchange and tributaries were identified and mapped. This method of data collection, although novel, has been adapted from numerous remote sensing techniques that are already in use (Torgerson et al. 2001; Deitchman 2009; Sheng et al. 2010; Culbertson et al. 2014). The crew was able to collect continuous thermal infrared (TIR) imagery for approximately 23 km of the Nicola River, from the confluence of the Coldwater River to the confluence of Spius Creek, as well as an approximately 1 km segment, immediately downstream of the dam on Nicola Lake.

The 2016 funding for the project was provided by the Government of Canada's Habitat Stewardship Program (Prevention Stream). Although only one year of funding was received for the project, in-kind work will continue through the summer of 2017 (through Thompson Rivers University) in order to expand this thermal mapping data set. The project will also expand to include *in situ* monitoring of stream temperature and groundwater upwelling at identified thermal refugia.

Methods

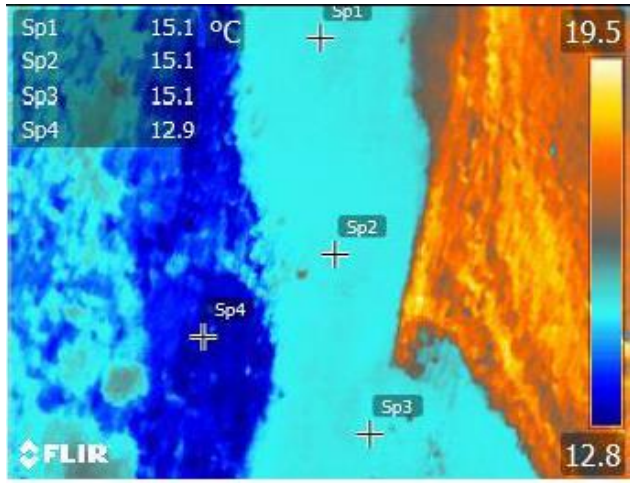
Planning and consultation for the project was conducted by the authors in collaboration with the Fraser Basin Council, Thompson Rivers University and the Nicola Research Collaborative Committee.

TIR images are collected using a camera/sensor that detects emittance of thermal (longwave) radiation from objects. Traditionally, TIR remote sensing has been conducted from manned aircraft (e.g. helicopters and planes). However, recent advances in technology have allowed for production of TIR sensors that are much smaller in size and cost less. TIR data collection for this project was achieved with a small, UAV-mounted sensor. The crew was able to float sections of the Nicola River in a drift boat with the UAV operator collecting data almost continuously.

TIR images for the project were collected in September, 2016. The planned timing for data collection was intended to coincide with summer low-flow conditions and high stream temperatures, as described by Torgersen et al. (2001). The rationale for this is to maximize the effects of cool groundwater input on stream temperatures and to produce the strongest temperature signature on the TIR imagery. Ideally, TIR data collection would have started in the middle of August, however, supply of the required TIR sensor was delayed until the first week of September, 2016.

The TIR sensor used for the project was a Zenmuse-XTR, radiometric, forward-looking infrared (FLIR) thermal camera (336 x 256 resolution, 9 mm lens and a 30Hz refresh rate) attached to a DJI-Inspire 1 professional UAV. Images were collected at a targeted altitude of 60 m with the camera in nadir position. The UAV was piloted manually using DJI's GO app, with images being collected every five seconds. The UAV was flown down the stream centreline when the field of view of the camera was able to capture both streambanks in a single image. When the river was too wide to capture in a single image, the UAV was piloted to capture the remaining segments of stream. The Zenmuse XTR camera can store images as simple JPEGs, radiometric JPEGs or TIFF files. All image storage formats include location data, however it is important to note that the accuracy of the GPS receiver on the UAV is considered 'recreation grade' (i.e. does not collect the required carrier data for differential correction).

Post-processing and analysis of collected images was completed using FLIR Tools (Version 5.11.16357.2007). An arctic color palette was applied to the images and they were assessed individually for areas that displayed the cool-water signatures, indicating the presence of groundwater. These images were further analyzed by determining the average, relative water temperature at three background points (top, middle and bottom of the image), followed by determination of the relative temperature of the identified groundwater input. In this way, the difference in temperature between the identified groundwater input and the average background stream temperature could be determined (Figure 1). Only FLIR images that had visible groundwater input were included for reporting. Locations of groundwater inputs, as seen in Appendix A, were added to a Geographic Information System (GIS) using ArcMap (Version 10.5) to produce a map (attached).



In addition to the individual FLIR images of potential groundwater inputs, a stitched thermal map layer of the stream sections that were flown was created using Pix4D Mapper Pro (Educational Version). The imagery was processed in small batches (typically 10 to 50 images) in order to optimize the image stitching procedure. Stitched images were exported in TIFF format and were added to the GIS map, noted previously (Figure 2).

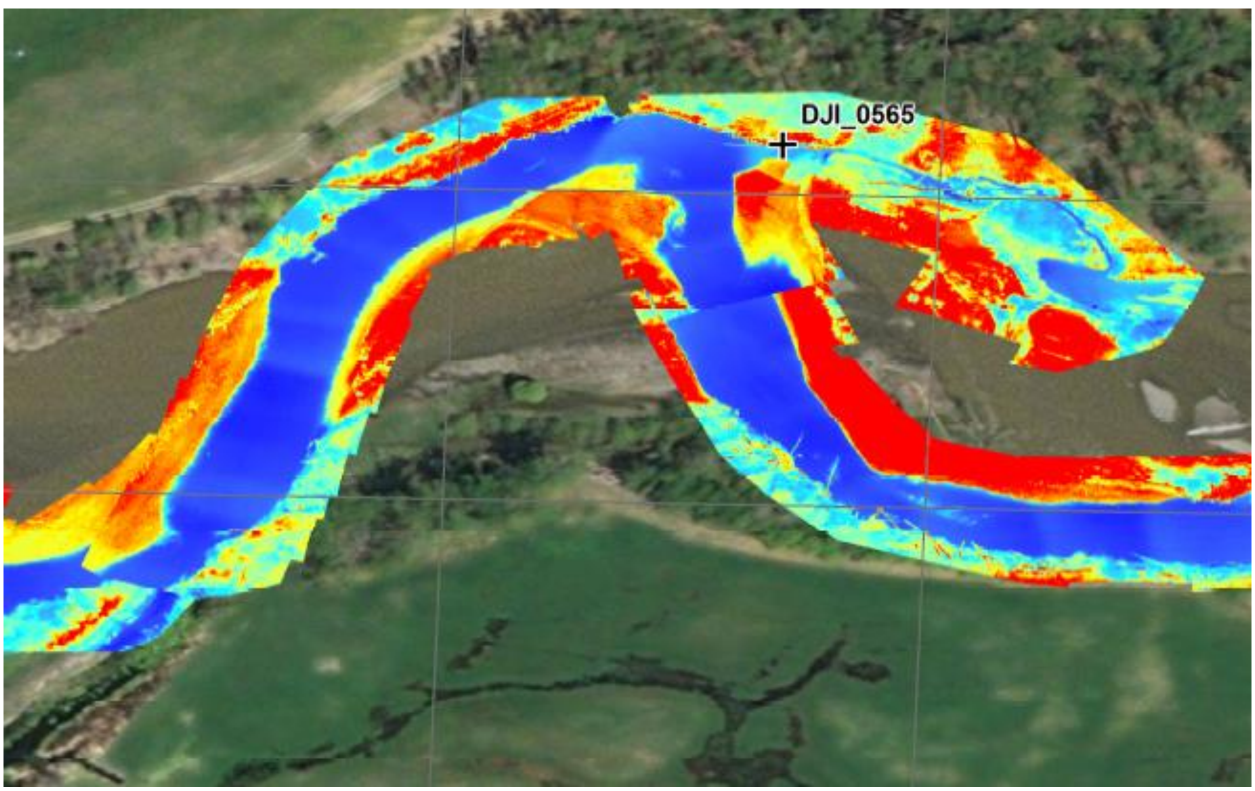


Figure 2: Example of stitched TIR images of the Nicola River in GIS.

Results

The combination of a DJI Inspire UAV and the Zenmuse-XTR radiometric FLIR thermal camera was a stable aerial platform for TIR mapping. In four days of flying, the crew was able to survey 24 km of the Nicola River, collecting approximately 4000 TIR images. Surveyed stream segments included 23 km of the Nicola River, from the confluence of the Coldwater River to the confluence of Spius Creek, as well as an approximately 1 km segment, immediately downstream of the dam on Nicola Lake. The UAV had a typical flight time of approximately 16 minutes per battery (depending on wind and air temperature conditions). With seven batteries and a generator that could charge two batteries at a time (approximately 45 min charge time), the crew was able to collect data for 8 to 10 hours with only a few 20 to 30 minute breaks to wait for batteries to complete charging. In the future, a third charger and a total of 10 batteries is recommended to prevent down-time.

Of the approximately 4000 TIR images that were collected, 111 displayed locations with cool-water signatures of groundwater input. These images are included in Appendix A, with location reference points (based on the centre of the image) included in the project map book (Attached). Also included in the map book is the stitched TIR image layer, described in the previous section. The stitching capability of the images varied greatly between sites. Stitching software and algorithms generally require ample image overlap with enough consistent and detectable features between images. This is challenging when working with moving water. That being noted, the image stitching ability was quite good for the first half of the data collection period (i.e. from the Nicola River confluence with the Coldwater River to approximately halfway to Spius Creek). After this point, the stitching ability of the images was substantially reduced. We suspect two primary reasons for this: one, that wind speed increased enough to cause significant roughness on the surface of the water, causing distortion between TIR images; and two, that channel widths in the further downstream sections of the Nicola River were wider, reducing prominent, detectable bank features between images. Regardless of the challenges associated with the stitched TIR images displayed in the map book, the radiometric TIR images included in Appendix A provide the most useful tool for evaluating the presence of groundwater. These images are high resolution (compared to other methods of TIR data collection) and do not show the effects of distortion that the stitched images do.

Groundwater input on the surveyed section of the Nicola River was first detected at a location approximately 1.7 km downstream of the confluence with the Coldwater River (approximately 400 m upstream of where it meets Lindley Creek Road). The first major upwelling area was located approximately 3.3 km downstream of the Coldwater River confluence, in the Stumbles Creek (Mameet Springs) area. This upwelling area is approximately 1 km long and accounted for 29 TIR images that displayed groundwater input. It is important to note that this area has an abundance of relic channels and sloughs which may improve its suitability as juvenile salmon rearing habitat as well. From this point, downstream to the confluence with Spius Creek, groundwater input was detected consistently, but in somewhat clumped distributions. The approximately 1 km of the Nicola River that was surveyed immediately downstream of the dam on Nicola Lake also indicated fairly extensive groundwater input, with cool-water signatures detected on 14 TIR images.

Discussion

The thermal mapping conducted as part of this project was effective in identifying some high potential thermal refugia for fish in the Nicola River; however, the study of refugia should not be limited to a temperature requirements for specific fish species and life-stage alone. In order to capture the emergent properties of the collective elements of these habitats, future studies are required that incorporate broader ecosystem interactions. In the same BC Government survey noted previously, natural resource professionals not only identified the need to know where groundwater-surface water interactions occurred; they identified a need for information on how to better manage these resources with respect to cumulative effects, climate change, water withdrawal, forestry effects to watersheds, and broader aquatic ecosystem management (Sherer 2016). Another questions to consider is, how adverse are the ecological effects of high temperature regimes? The adaptation of species and populations as driven by ecosystem disturbance may have benefits that arise through shorter-term adverse effects. In studying drought in aquatic ecosystems, Humphries and Baldwin (2003) recognized that drought is an integral part of population maintenance, among other effects, and little is known about its role.

Although only one year of funding was awarded for this project, work will continue in 2017 to expand the TIR dataset for the Nicola River watershed. Additional work on thermal refugia will also expand to include *in situ* monitoring of groundwater-surface water interactions, through deployment of arrays of temperature data loggers at sites indentified in 2016, as well as installation of streambed groundwater monitoring wells and stilling wells to measure vertical hydraulic gradient and groundwater velocities at these sites (methods will be based on Baxter et al. [2003]).

Aquatic ecosystems are extremely complex and are affected by a multi-dimensional array of anthropogenic and non-anthropogenic factors. Researchers are increasingly confirming that managing for single species lacks efficacy. In a recent publication, Drouineau et al. (2016) makes the case for a paradigm shift in fisheries research and management from a reductionist approach, to a protean, multifaceted scientific approach that is adaptable, complex, and recognizes uncertainty. The formation of the Nicola Research Collaborative Committee, facilitated by the Fraser Basin Council, has been a positive step towards effectively managing aquatic ecosystems in the Nicola Watershed.

Closure

We trust that this map book, photo plates appendix and accompanying report meet your present requirements. If you have any questions, please feel free to contact us directly.

Sincerely,

ORIGINAL SIGNED BY

Tom Willms, R.P.Bio., P.Ag.

ORIGINAL SIGNED BY

Dr. Garrett Whitworth, PhD

Attachments:

1 – TIR Map Book

2 – Appendix A: TIR Photo Plates

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