# Kenai Thermal Imagery

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# Executive Summary

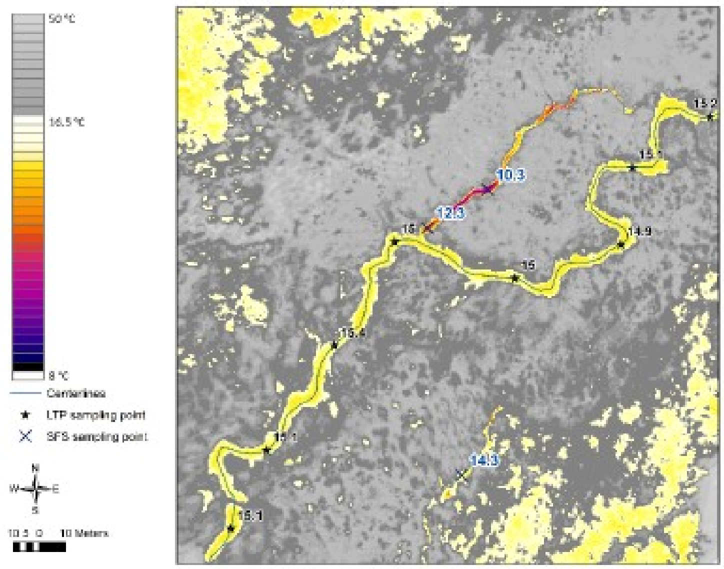



Figure 1: Example of airborne thermal infrared imagery showing temperature contrast in a stream. A cold water inflow (purple and blue colors) enters the main channel (yellow color). Figure from NV5 Geospatial consultants report.

## From Thermal Infrared Imagery to Conservation Actions

Cold Water Refugia, or areas within a stream that are persistently colder than surrounding areas, are critical features of wild salmon habitat throughout their range. Stream reaches with cold seeps and springs often result in much cooler water, which are increasingly important for wild salmon to keep cool as water temperatures in many streams have warmed. Some human activities can diminish or extinguish cold water refugia, such as groundwater withdrawl and construction of impervious surfaces. To conserve cold water refugia these sites must first be mapped and identified, and land owners and managers must understand best practices for their conservation.

Since 2020, three nonprofits - Cook Inletkeeper, Kachemak Heritage Land trust, and Kenai Watershed Forum - have worked together to identify where cold water refugia are found in the Kenai Peninsula lowlands, a region where productive wild salmon habitat intersects with a growing development footprint. We used cutting-edge methods to locate cold water refugia with thermal infrared imagery, a technology similar to night vision goggles that shows heat contrast. Our resulting "treasure map" of cold water refugia locations is a valuable tool for prioritizing conservation and outreach efforts.

In this project we focused our research on tributaries of the Kenai and Kasilof rivers; specifically in the lower sections of streams outside of the federally protected Kenai National Wildlife refuge as outlined in the Mountains to Sea planning document (Morton et al. 2015). Our goals with thsi project were

1. Identify land parcels that contain one or more cold water refugia features, and communicate information about these features and possible conservation strategies to land owners
2. Use a variety of techniques to communicate our results to over sixty landowners, agencies, and organizations

Conservation actions that will result from these efforts include parcel acquisition and conservation easements, voluntary compliance, stewardship and restoration projects, and voluntary land agreements or exchanges.

## The Future

Our efforts in applying thermal imagery data for conservation purposes, among others, highlights the value of recognizing cold water refugia as an asset for wild salmon habitat (Snyder et al. 2022). The work described here can continue to expand into additional territiories: there are twenty river corridors of conservation priority described in the Mountains to Sea plan, while we possess aerial thermal infrared imagery on just five (the Anchor river plus the four rivers described in this report) (Mauger, McCarty, et al. 2015).

Beyond gathering additional thermal infrared imagery data in order for the work of conserving cold water refugia to have a sustained and widespread impact beyond this project we recommend that future efforts develop Alaska-specific technical and legal definitions, and applying them towards management needs.

Two examples of potential applications follow:

### Example: Source Water Protection Areas

The U.S. Environmental Protection Agency (U.S. EPA) defines "Source Water Protection Areas" for groundwater sources used for drinking water, which delineate geographic areas that contribute to the drinking water supply[1]. Similar logic could apply towards defining the extent of riparian landscape that supplies cold water refugia. Researchers with Kachemak Bay National Estuarine Research Reserve (KBNERR) in Homer, Alaska recently demonstrated that the extent of land that recharges cold water refugia can be delineated by use of a GIS-based model(Gerlach et al. 2021).

As of winter 2022 the Kenai Peninsula Borough is currently in the process of reviewing its permitting process for material extraction sites (i.e. gravel pits). Initial discussions between the the Borough and KBNERR have included the possibility of permit reviewers being able to use their maps of subterranean aquifer flow paths to comment on proposed development plans. This cooperation could help ensure that future development minimizes impact on the aquifers that supply cold water refugia, in the same way that defining Source Water Protection Areas help protect drinking water sources.

### Example: Columbia River Cold Water Refugia

In an example from the Columbia River in the Pacific Northwest, the U.S. EPA has taken detailed steps to identify, define, and recommend conservation actions for cold water refugia. Here, cold water refugia were defined by quantitative flow volumes and their level of contrast with connected, warmer water bodies[2]. Such efforts could set an example for Alaska to follow in beginning to develop its own technical definitions of cold water refugia.

Existing efforts to technically define cold water refugia have focused on physiological needs of adult upstream migration. However, salmon at all life stages benefit from a mosaic of water temperature environments, such as when juvenile fry migrate between colder and warmer and areas to feed and digest (Armstrong et al. 2013). Thus it is recommended that future technical definitions also consider the needs of juvenile salmon.

## Next Steps

We will continue to use our existing dataset to prioritize land conservation efforts in the Kenai Peninsula lowlands area. Currently we have surveyed the lower sections of four tributaries, while the Mountains to Sea document highlights twenty priority river corridors as conservation targets.

Specific actions that will continue to support the goals of this project include:

[1]https://www.epa.gov/sourcewaterprotection/delineate-source-water-protection-area
[2]https://www.epa.gov/columbiariver/columbia-river-cold-water-refuges-plan

- Identifying where current, future, and retired material extraction sites (i.e. gravel pits) may influence conservation goals in the 20 Mountains to Stream corridors, and supporting efforts to include groundwater considerations in permit reviews
- Continue to communicate with the local U.S. Fish and Wildlife office, which in 2022 initiated an effort to gather aerial thermal infrared imagery in local river corridors used by migrating adult coho salmon[3]. A cost-effective collaboration could result if USFWS aerial thermal imagery can be used for the same conservation goals as detailed in this project
- Continue to communicate with the Alaska Department of Environmental Conservation and other agencies about moving towards formally defined standards for cold water refugia
- Develop and publish standards for collection and application of thermal imagery in aquatic habitat, similar to published standards for stream temperature monitoring (Mauger, Shaftel, et al. 2015a)
- Convert the thermal imagery map files acquired from this project to a format accessible from an online web browser or Google Earth

A two-page project summary titled, "Science Based Land Conservation: Cold Water Stepping Stones" is outlined below in Figure 2. Download a full size version of this information by clicking on the link below.

[3]https://www.peninsulaclarion.com/sports/refuge-notebook-flying-a-remote-sensing-mission-on-the-refuge/


Figure 2: Project Summary Sheet

# 1 Introduction

The following chapters contain data and analysis related to the Kenai River Thermal Imagery project conducted from 2020 - 2022. This work is a collaborative effort between three Kenai Peninsula Nonprofits: Cook Inletkeeper, Kachemak Bay Heritage Land Trust, and Kenai Watershed Forum. It is funded by the Alaska Sustainable Salmon Fund (project #53003).

This report is generated using Quarto, an open source publishing platform. It is best accessed online at the url https://kenaiwatershed.quarto.pub/kenai_thermal_imagery/. The contents of this report can also be downloaded as an Microsoft Word document here:

All code used to generate this report is available in the project's GitHub repository at https://github.com/Kenai-Watershed-Forum/kenai_thermal_imagery_v2.

# 2 Project Map

Our research focused on four streams in the Kenai Peninsula lowlands region in southcentral Alaska:

- Three tributaries of the lower Kenai River
  - Moose River
  - Beaver Creek
  - Funny River
- One tributary of the lower Kasilof River
  - Crooked Creek

The ArcGIS Online project map may be accessed below or at ArcGIS Online (Click Here: https://arcg.is/0vaueq).

The online map contains layers with the following data:

- Project Watershed Boundaries
- National Hydrography Database (rivers, lakes, streams, etc)
- Anadromous Waters Catalog
  - Streams
  - Lakes
- Kenai Peninsula Borough Parcel Boundaries
- Thermal Imagery Data from NV5 Geospatial consultants report
  - Significant Thermal Features (identified from thermal imagery)
  - Longitudinal Temperature Profiles (main channel temperatures of study streams)
  - Water Temperature Logger Sites

# 3 Thermal Imagery Data

To acquire and prepare thermal aerial infrared imagery, we worked with NV5 Geospatial[1] (formerly Watershed Sciences, Inc), a contractor who has led prior efforts in the region to gather thermal aerial infrared data for aquatic habitat research (Watershed Sciences 2010). On July 5, 2020, NV5 collected thermal infrared imagery from a helicopter-mounted camera for the four steams on the Kenai Peninsula lowlands that were the focus of this study (Beaver Creek, Funny River, Moose River, and Crooked Creek). All streams were flown during the afternoon hours in order to maximize the thermal contrast between the river's water and the banks.

The surveys extend for a total length of 59.1 km of the streams. Flight transects proceeded from the mouth of each stream in an upstream direction. The data were collected to aid the team in identifying the spatial variability in surface temperatures as well as thermal influence of point sources, tributaries, and surface springs.

Specific deliverables generated by NV5 Geospatial from the thermal imagery data include:

- Rasters (map image files; .tif and .jpg formats)
- Shapefiles (longitudinal temperature profiles, stream centerlines, others; .shp format)
- Other supplemental items (coordinates of significant thermal features, maps and figures, and others)

The full technical report from NV5 Geospatial describing detailed methods and interpretation can be downloaded at the following link:

The image raster files are of a large size (~3 GB) and may be acquired by contacting staff at Cook Inletkeeper (sue@inletkeeper.org), Kenai Watershed Forum (hydrology@kenaiwatershed.org), or Kachemak Heritage Land Trust (info@kachemaklandtrust.org).

## 3.1 Parcel data summary

We generated a table in GIS (ArcMap Pro 10.8.1) of parcels in the Kenai Peninsula Borough that intersect with cold-water inputs (e.g. seeps, springs) within the surveyed areas of Beaver

[1] https://www.nv5.com/geospatial/

Creek, Crooked Creek, Moose River, and Funny River. We identified a total of n = 31 unique parcels containing a total of n = 63 unique cold water refugia features.

Figure 3.1 summarizes the ownership type of these parcels by general category of owner type.

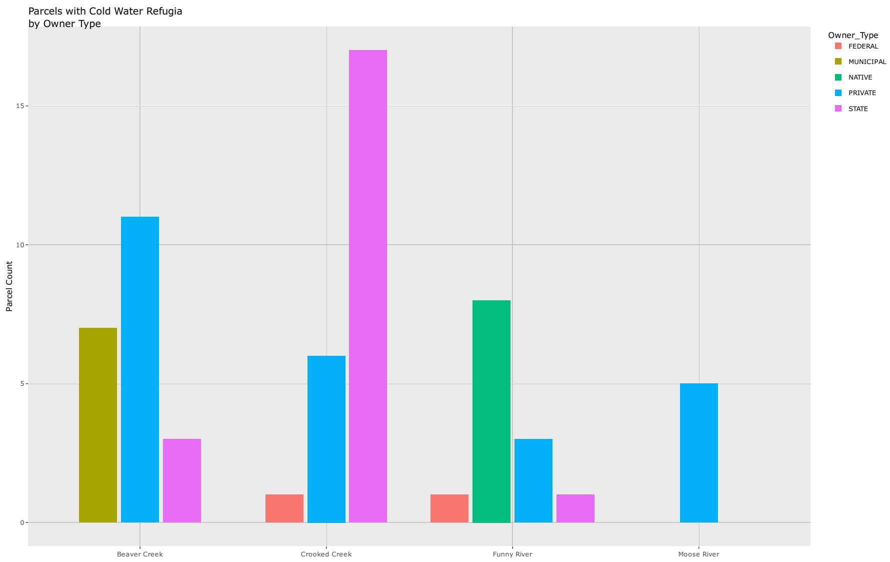



Figure 3.1: Parcel ownership by land owner type for lands containing cold water refugia in our study streams

## 3.2 Ground truth data

On July 7-8, 2021 we visited a subset of sites identified by the NV5 Geospatial Consultants report as cold water features. We visited 12 of 63 total sites. We recorded surface water temperatures of the identified features as well as the adjacent main stem using a using a Hach Sension 5 portable meter. The average time difference between main stem temperature observation and off-channel observation was 13.9 minutes. We created a graphic sketch of the layout of each feature, and recorded site photos.

Field forms, including site sketches, can be accessed at the following link:

In general we observed symmetry in the pattern of temperature contrast for both our ground-truthed data as well as temperatures observed from the thermal aerial infrared dataset. This indicates that the temperature contrasts identified from the aerial imagery are persistent and not ephemeral. Figure 3.2 through Figure 3.4 visualize water temperature data sourced from the significant features in aerial imagery on July 20, 2020 along with ground-truthed measurements from July 7-8, 2021.

Note that the temperature data reported from thermal infrared imagery observations consists of multiple statistics, whereas the ground-truth values consist of a single observation. Multiple statistics are reported for the aerial thermal infrared temperature values as a result of the sampling method used, wherein ten surface temperatures within a two-meter radius are evaluated. See the, “Interpretation and Sampling” section in the technical report from NV5 Geospatial Consultants, available for download above (NV5 Geospatial 2021).

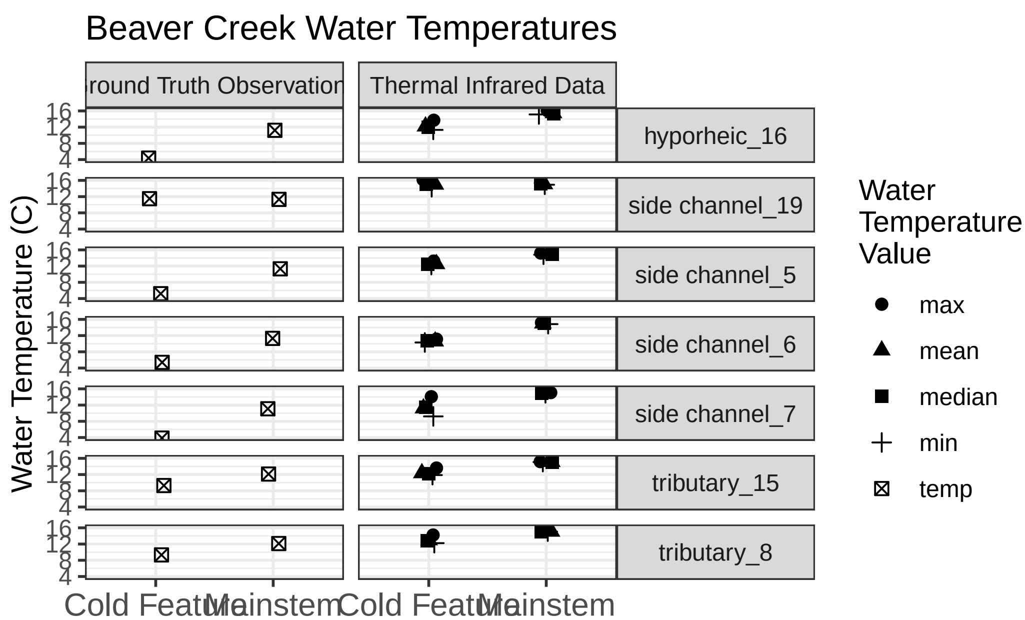



Figure 3.2: Beaver Creek water temperatures, ground truth and thermal infrared imagery observations.

## 3.3 Collaborative Assessment

Researchers with participating organizations assessed conservation strategies within each study watershed, and recorded their notes on a shared platform. These collective notes are being used internally to inform strategy for outreach approaches with local property owners.

Data sources used to assess parcel-specific conservation strategies include:

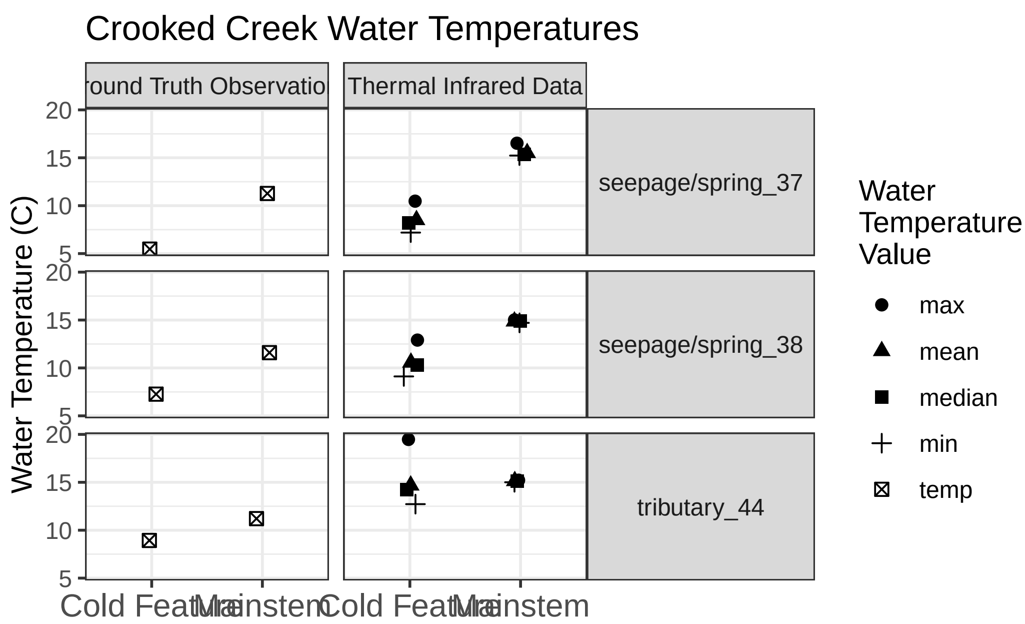



Figure 3.3: Crooked Creek water temperatures, ground truth and thermal infrared imagery observations.

- Custom maps for each significant thermal feature, including information about the parcel or parcels that it occupies
- Information about individual thermal features from the NV5 Geospatial Consultants Report, including mean value and contrast with the main stem
- The ArcGIS Online project map

**Project collaborators may access the Thermal Imagery Database Google Sheet using the link below:**

**Link: Thermal Imagery Collaborative Assessment**

An example map is shown in @fig-example-map.

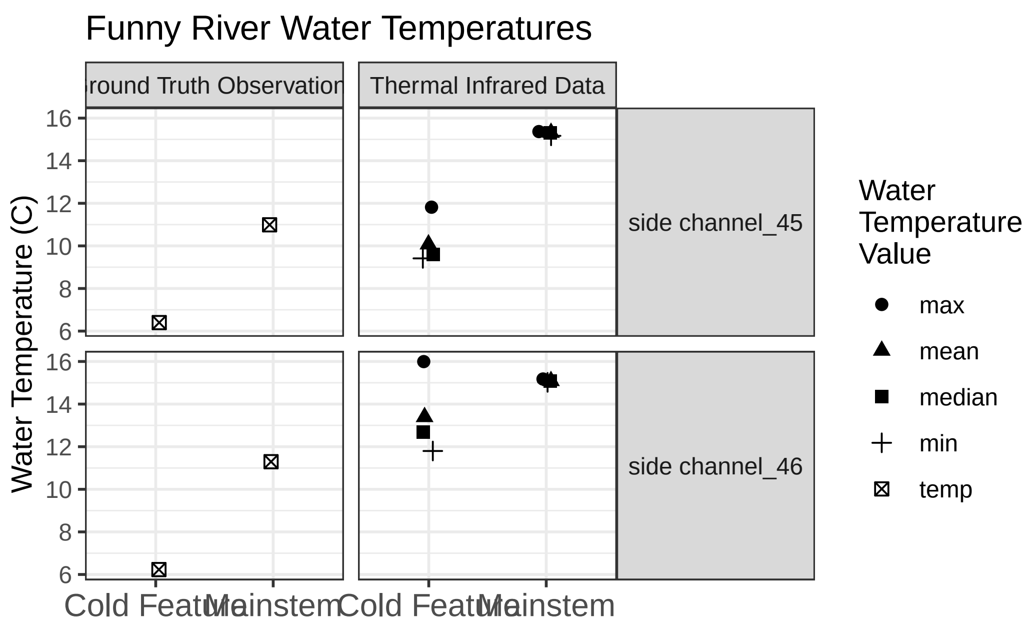



Figure 3.4: Funny River water temperatures, ground truth and thermal infrared imagery observations.

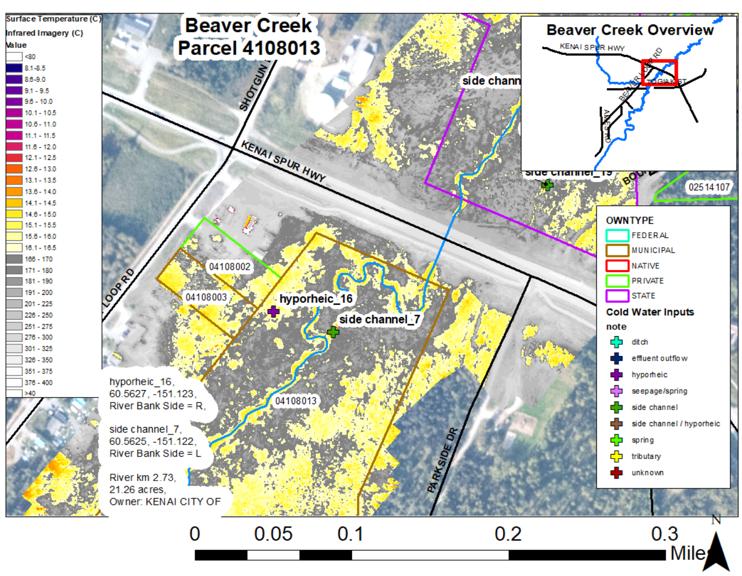



Figure 3.5: Example of airborne thermal infrared imagery map with parcel overlay.

# 4 Water Temperature Loggers

In order to supplement aerial thermal infrared imagery and cold-feature ground truthing data, we deployed water temperature loggers in the lower reach of each study stream to collect continuous time series of water temperature. We used Onset HOBO Temp Pro V2 loggers, deployed and maintained according to published regional standards (Mauger, Shaftel, et al. 2015b).

This section describes methods to visualize and perform basic quality checks on continuous temperature loggers deployed in the study streams. All data files (.csv) used in these analyses can be downloaded from this project's GitHub repository.

## 4.1 Locations

See the Project Map (Section 2) section of this report for locations of water temperature logger sites. The ArcGIS Online layer titled, "Water Temperature Logger Sites" displays these locations.

Locations will also be reflected in the Alaska Center for Conservation Science's AKOATS map (Alaska Online Aquatic Temperature Site)[1] in Spring 2023.

## 4.2 Logger Data QA/QC

Data retrieved from the field was subjected to a basic quality assurance process before being incorporated into the analysis dataset. We visually inspected each water temperature time series and excluded data indicative of pre/post deployment or exposure. Figure 4.1 and Figure 4.2 provide a visual example of water temperature time series prior to and post quality assurance processes.

### 4.2.1 Additional data preparation

The following sections describe additional details on data preparation specific to each water temperature logger site.

[1] https://accs.uaa.alaska.edu/aquatic-ecology/akoats/

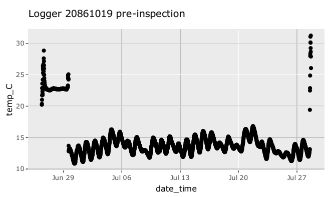



Figure 4.1: Example of water temperature time series prior to quality assurance process

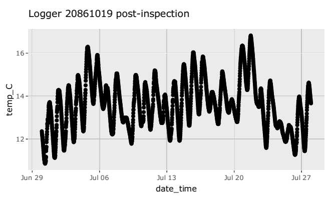



Figure 4.2: Example of water temperature time series after quality assurance inspection

#### 4.2.1.1 Beaver Creek

Loggers at the Beaver Creek logger site were deployed in early summer 2020. As part of a separate research project, Alaska Center for Conservation Science (University of Alaska Anchorage) established a logger site several hundred meters upstream also in Summer 2020.

We examined if data from the two sites are similar enough to use as a proxy for each other when data observations are missing. Time series from both sites are shown in figure Figure 4.3, and simultaneous values from both sites are presented in figure Figure 4.4.

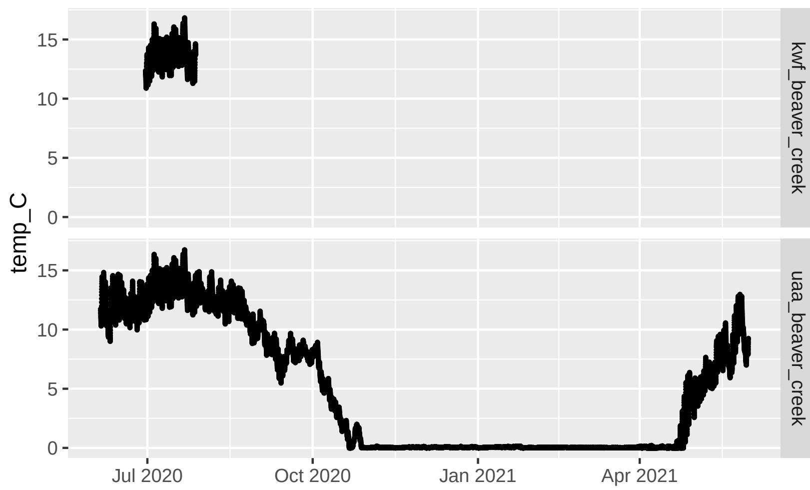



Figure 4.3: Water temperature time series from Lower Beaver Creek at two nearby sites.

The average absolute difference in temperature between the two logger sites in Beaver Creek is 0.06 ± 0.05 C (mean ± sd). For most applications, a substitution of data from either of these sites in Lower Beaver Creek will still accurately represent water temperature.

#### 4.2.1.2 Lower Crooked Creek

Lower Crooked Creek has two adjacent water temperature monitoring locations within 20 m of each other. Further details on these two sites are described below, and figure @fig-cc-map shows locations of the two sites.

##### 4.2.1.2.1 Lower Crooked Creek Real-time temperature monitoring site

Cook Inletkeeper maintains a site installed by Beaded Stream (Anchorage, AK) that records air and water temperature data in real-time and streams these data live at https://inletkeeper.org/our-work/healthy-habitat/real-time-temperature-sites/crooked-creek/. Water and

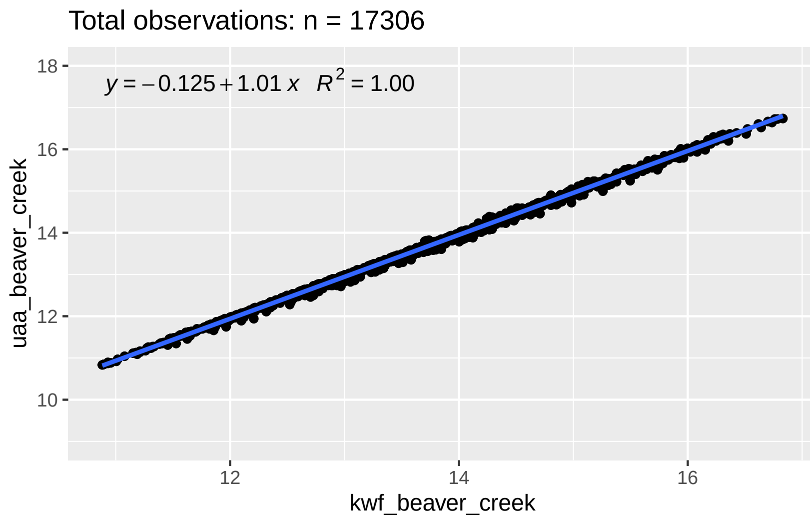



Figure 4.4: Regression of simultaneous water temperature observations from two nearby sites in Beaver Creek.


Figure 4.5: **?(caption)**

air temperature data has been recorded and streamed from this site at hourly intervals since summer 2017.

Temperature data from this location can be downloaded as a csv file directly from the above Inletkeeper web link. However, ***as of 2022-12-13 there is an error with the publicly available csv file***. The publicly available csv file has incorrect time stamps after 12/31/2019. Beaded Stream staff is aware of the error, and says the remedy will require an in-person visit to the field. In the mean time, contact Beaded Stream staff to request access to most current data.

The data with correct time stamps from 2017-08-15 though 2021-10-26, obtained directly from the internal Beaded Stream dashboard, is also available for download at this link from GitHub: **Download Lower Crooked Creek Realtime Temperature Data**.

##### 4.2.1.2.2 Lower Crooked Creek HOBO TempPro V2 logger site

A pair of HOBO Temp Pro V2 loggers are installed at a location 20 m upstream from the real-time temperature logger site. Water temperature is recorded at 15 minute intervals.

During a site visit on 7/28/2021, we discovered that this pair of loggers potentially resided within a small, previously unidentified cold water plume incoming from the river-left bank. (On the ArcGIS Online project map, this feature is identified as "tributary_44." It was unclear if the local cold water seep was influencing the loggers in way such that they would not represent main channel temperature.

In order to determine if HOBO logger data prior to 7/28/2021 is influenced by the cold seep, we performed the following steps:

1. *Relocated loggers.* On 7/28/2021, we modified logger deployment such that one logger was directly upstream of the cold water seep, and one remained in its original location within the seep.
2. *Compared temperature data upstream vs. downstream of the seep.* We observed consistently cooler temperatures in the downstream logger, with an average absolute difference of $1.47 \pm 0.30$ °C (mean ± sd). Figure @fig-cc-plots displays time series from both loggers as well as the difference values where simultaneous data from both locations exists.

From these data we observe that the small cold water tributary consistently affected main stem temperature where the loggers recorded temperature. Temperature contrast was much less apparent in cooler months, after approximately September 1st, 2021. Thus, the data from these HOBO loggers prior to 7/28/2021 in the location downstream of the small cold water tributary should not be considered representative of main channel Crook Creek temperatures.

We reviewed all paper field forms from the lower Crooked Creek site from 2015 - present (link here) to determine the time extent that HOBO loggers may have been influenced by the cold water tributary. These notes suggest that the period extended from from 5/31/2019 -

7/28/2021. Prior to 5/31/2019 there is not evidence on file that can confirm whether or not the loggers were deployed within the cold water plume.

One possible explanation for why technicians failed to observe the cold water seep when they installed the HOBO loggers in Summer 2019 is that high discharge level in the Crooked Creek main channel temporarily masked the localized effect of cold water input. These results highlight the value of regular site visits to re-verify that the site is well-mixed, or checking temperatures beyond the minimum of five observations across a transect.

Additionally, these results exemplify the role of cold water inputs in maintaining thermal refugia for salmonids in watersheds such as Crooked Creek. Note in figure Figure 4.6 that water temperature within the cold water plume in the main channel was often 1.5 °C cooler than the non-influenced location. Temperature differentials of this nature help allow salmonids to access a diverse portfolio of thermal environments important to functions throughout their life cycle such as migration, metabolism, and foraging.

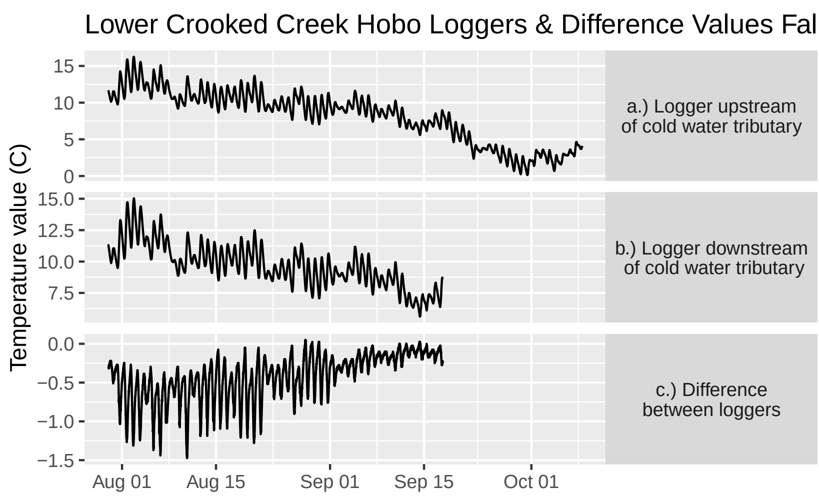
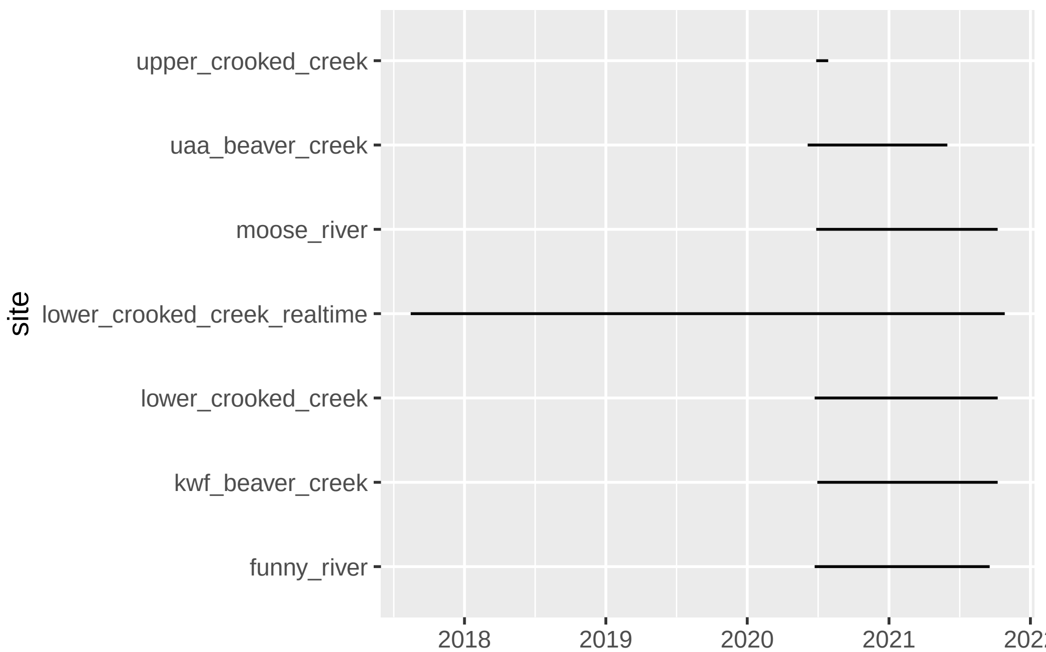



Figure 4.6: **?(caption)**

### 4.2.2 Extent of water temperature time series

Figure **?@fig-extent-fig** displays temporal extent of currently available water temperature at each site


upper_crooked_creek
uaa_beaver_creek
moose_river
lower_crooked_creek_realtime
lower_crooked_creek
kwf_beaver_creek
funny_river
site
2018
2019
2020
2021
2022

# 5 Applications

We applied our findings of where cold-water inputs were located towards education and outreach opportunities in the Central Kenai Peninsula region. We used a variety of methods including comments on public land management plans, direct mailers, cooperative planning with peer researchers, and communication with state and federal agency staff.

We used the thermal features map layer generated from this project as a tool to help generate comments on a local land management plan. We commented on the City of Kenai 2021 Land Management Plan, which highlighted a number of parcels in the Beaver Creek corridor, and recommended parcel-specific actions (e.g. retain, sell, re-zone).

We created a separate map showing parcels highlighted in the plan, with management status available in a point and click format. The parcels were superimposed on a several layers highlighting ecological values such as wetlands and anadromous streams, as well as the thermal features identified in this project. Methods are described in a separate stand-alone document at https://rpubs.com/kwf/867931.

Access the City of Kenai Land Management Plan Comments Map here: https://arcg.is/1Oq9Kq.

Access PDFs of submitted Public Comments below:

## 5.1 Landowner Outreach

### 5.1.1 Letter

We composed a letter addressed to landowners whose property contains cold water features that flow in to one of our study streams. This letter describes the nature of the project and the value of cold water features to salmon habitat. Landowners are invited to contact the researchers if they would like more information about their specific property.

A draft version of the letter to landowners may be accessed below:

### 5.1.2 Postcard

We designed and mailed a post card to landowners whose property contains cold water features that flow in to one of our study streams. The postcard notifies landowners that their specific parcels are of high conservation value, and encourages them contact project scientists to learn more about best practices.

A PDF proof version of the postcard may be accessed below:

### 5.1.3 Communication with local State and Federal Agency Staff

We met with state and federal agency staff to discuss the nature of our research and its applications.

- In conversations with staff from the Alaska Department of Environmental Conservation (ADEC), we learned more about the process by which new research such as ours may be applied in the future. Emerging research on how water quality issues may affect freshwater fish habitat is typically first evaluated by the Alaska Department of Fish and Game (ADF&G) before being evaluated in a regulatory context such as ADEC. With that in mind, our final reports will be made available to ADF&G staff.
- On June 1, 2022 we met with local U.S. Fish and Wildlife staff to discuss the nature of thermal infrared imagery gathered in summer 2022 for a separate USFWS project related to adult coho salmon movement. These data are currently being evaluated, and it is our hope that they may later also be applicable for the purposes of identify cold water refugia in the conservation priority corridors identified in the Mountains to Sea report(Morton et al. 2015)

### 5.1.4 General Recommendations by Stream Corridor

#### 5.1.4.1 Beaver CreeK

"very parcelized"

#### 5.1.4.2 Funny River

"Lots of state ownership, only 7 private parcels"

#### 5.1.4.3 Moose River

"Too parcelized for meaningful land acquisition?

#### 5.1.4.4 Crooked Creek

“very parcelized”

# 6 Summary

muhlfield 2021 https://www.nature.com/articles/s41558-021-01013-w

armstrong 2021 https://www.nature.com/articles/s41558-021-00994-y

lessons from kenai decision support tool

link to google doc for future collab

https://gis.audubon.org/kenai/

https://gis.audubon.org/kenai/documentation/KenaiDecisionSupportTool_UsersManual_9Jan2014.pdf

VII. Objectives • Identify areas of cold water refugia within four streams on the Kenai Peninsula using TIR imagery • Initiate discussion with landowners about potential land conservation efforts

spreadsheet of thermal features available to project managers only at the moment to presver landowner privacy

example of initiating conversaion: sgc

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Watershed Sciences. 2010. "Airborne Thermal Infrared Remote Sensing: Anchor River Basin, Alaska." Homer, Alaska. https://inletkeeper.org/wp-content/uploads/2017/10/Airborne-Thermal-Infrared-Remote-Sensing-Anchor-River-Basin-Alaska.pdf.