**Appendices**

Appendix A – Stream and Air Temperature Monitoring Methods

*General*

We collected water and air temperature data at a minimum of three sites per tributary along a longitudinal gradient from lower to upper reaches. We recorded data at 15-minute intervals from May to August 2015 and May to September 2016 using water temperature data loggers (HOBO® Temp Pro v2, Onset Corp, Bourne, MA) or Hydrolab sondes (Hydrolab MS-5 Sonde, OTT, Loveland CO) (Fig. B1). For the main stem Kenai River, we acquired data from U.S. Geological Survey (USGS) gauge station sites or airport meteorology records from the National Weather Service (NWS). Coordinates and period of deployment for all sensors are summarized in Table A1. Temperature field data were summarized to weekly and daily means.

We checked all loggers for accuracy using methods outlined in (Mauger et al. 2015) prior to and post field deployment. We downloaded data at regular intervals (24 - 36 days for the HOBO logger and 10 days for the Hydrolabs), inspected them for anomalies that would suggest malfunction or exposure to air and removed them if so, and replaced loggers as needed. Hydrolab probes were maintained and calibrated in a laboratory on a 10-day scheduled interval according to a manufacturer recommended quality assurance plan on file with the Kenai Watershed Forum (Soldotna, AK).

*Water Temperature Logger Deployment*

To ensure that water temperature logger sites were not influenced by local thermal anomalies, we selected sites in accordance with standards published in Mauger et al. (2015). At potential monitoring sites we performed channel transects of at least five points to verify that surface (0.1 m depth) and benthic temperatures did not vary greater than 0.25 °C upon logger deployment, retrieval, and opportunistic site visits. At one site where current was too swift to safely perform a channel transect (Middle Ptarmigan Creek) we performed a circular transect in a three meter radius around the logger. We used a Cooper-Atkins AquaTuff Instant Read® Bare Wire thermocouple or YSI® 556 instrument for instantaneous water temperature measurements.

*Air temperature Logger Deployment*

To understand relationships between air temperature and water temperature, at most sites we installed one logger (HOBO® Water Temp Pro v2) to record air temperature at 15-minute intervals onshore. Loggers were housed in Onset® M-RSA solar radiation shields to block direct solar radiation and maximize airflow. We secured the shields approximately 2 m above the ground to a sturdy tree, out of direct sunlight and in areas of adequate air mixing. We located air temperature monitoring sites well upslope of the stream where possible to minimize air temperature anomalies often associated with riparian zones. We calculated straight-line distance between water temperature logger sites and the nearest air temperature logger site using QGIS 3.4.11 (QGIS Development Team 2019). Distances (n = 19) ranged from 3.1 to 14330.0 m, averaging 2486.4 ± 4058.6 (mean ± SD).

*Merging Data from Multiple Sites*

Some water temperature datasets had missing intervals due to exposed or malfunctioning loggers. To achieve datasets of greater continuous length, nearby sites were evaluated as potential sources of replacement data. To fill in data gaps we used data from the nearest available logger if datasets were sufficiently similar: we calculated absolute difference values for all concurrent observations between the two sites and considered them sufficiently similar if overall mean absolute difference was < 0.2 °C, which is the same level of precision as the HOBO® TempPro v2 loggers

Extent of logger deployment and composition of final datasets is summarized in Fig. A1.

A screenshot of a cell phone

Description automatically generatedA screenshot of a cell phone

Description automatically generated

***b***

***a***

**Figure A1.** Deployment lengths for all temperature loggers. Water temperature data (a) was acquired from sites maintained by University of Alaska Fairbanks (UAF), Kenai Watershed Forum (KWF), and United States Geological Service (USGS). Air temperature data (b) was acquired from sites maintained by UAF and the National Weather Service (NWS).

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Table A1.** Locations and coordinates for temperature sensors from 2015 and  2016. | | | | | | | | | |
| Stream Name | Stream Reach | Data Type | Sensor Model | No. of Sensors | Coordinates | | Years Deployed | | Agency |
|  |  |  |  |  | N | W | 2015 | 2016 |  |
| Beaver Creek (Lowland) | Lower | Air | HOv2 | 1 | 60.560472 | -151.125556 | X | X | UAF |
| Water | HOv2 | 1 | 60.560500 | -151.125556 | X | X | UAF |
| Water | HY | 2 | 60.560300 | -151.125767 | X | X | KWF |
| Middle | Air | HOv2 | 1 | 60.574528 | -151.094944 | X | X | UAF |
| Water | HOv2 | 1 | 60.575639 | -151.095750 | X | X | UAF |
| Upper | Air | HOv2 | 1 | 60.614917 | -151.086528 | X | X | UAF |
| Water | HOv2 | 1 | 60.615083 | -151.085972 | X | X | UAF |
| Russian River (Montane) | Lower | Air | HOv2 | 1 | 60.485139 | -149.996500 | X | X | UAF |
| Water | HOv2 | 1 | 60.485222 | -149.996500 | X | X | UAF |
| Water | HY | 2 | 60.453000 | -149.986767 | X | X | KWF |
| Middle | Air | HOv2 | 1 | 60.450389 | -149.989139 | X | X | UAF |
| Water | HOv2 | 1 | 60.450250 | -149.987917 | X | X | UAF |
| Upper | Air | HOv2 | 1 | 60.359556 | -149.898222 | X | X | UAF |
| Water | HOv2 | 1 | 60.359500 | -149.898722 | X | X | UAF |
| Ptarmigan Creek (Glacial) | Lower | Air | HOv2 | 1 | 60.404167 | -149.369333 | X | X | UAF |
| Water | HOv2 | 1 | 60.403722 | -149.369611 | X | X | UAF |
| Water | HY | 2 | 60.404833 | -149.307611 | X | X | KWF |
| Middle | Air | HOv2 | 1 | 60.414000 | -149.347194 | X | X | UAF |
| Water | HOv2 | 1 | 60.414056 | -149.346639 | X | X | UAF |
| Upper | Air | HOv2 | 1 | 60.412417 | -149.306167 | X | X | UAF |
| Water | HOv2 | 1 | 60.412000 | -149.307611 | X | X | UAF |
| Kenai River (Main Stem) | Lower | Air | - | 1 | 60.579700 | -149.239100 | X | X | NWS |
| Water | GS | 1 | 60.477500 | -149.079444 | X | X | USGS |
| Middle | Air | HOv2 | 1 | 60.485139 | -149.996500 | X | X | UAF |
| Water | GS | 1 | 60.497778 | -149.807778 | X | X | USGS |
| *Sensor Model*: HOv2 = HOBO TempPro v2; HY = Hach Hydrolab, GS = USGS Gauge  Station.  *Agency:* UAF = University of Alaska Fairbanks, KWF = Kenai Watershed Forum,  USGS = U.S. Geological Survey, NWS = National Weather Service. | | | | | | | | | |

Appendix B – Summary of Fish Sampling Periods

A screenshot of a cell phone

Description automatically generated

**Figure B1.** Temporal extent of sampling periods, defined as the period of days between fish sampling events (31 ± 5 days, mean ± standard error) days). The transition point between seasons denotes a fish sampling event. Three sampling events per site occurred in summer 2015 and four at most sites in summer 2016.

Appendix C – Age Assignment and Assumptions

*Scales Collection and Processing*

We collected five to ten scales from the mesoderm above the lateral line and below the dorsal fin (Minard and Dye 1988) of all fish that were sampled for stomach contents, using forceps to gently scrape against the grain. We examined scales selected for analysis under 6.0x magnification with a stereomicroscope and photographed them pressed beneath a glass slipcover. To reduce interpretation bias, two readers estimated the age of juvenile salmon independently without access to information on fish size or time of year of collection. A scale annulus was defined using the criteria of circuli crowding and “cutting over” described by (Beamish and McFarlane 1983). Scales to which readers did not assign a consensus age were eliminated from further analysis. Individual ages for salmon from which scales were not collected were assigned through visual inspection of fork length frequency histograms. We generated plots of fork length frequency distribution for fish segregated by year, watershed, species, and sampling event. We used fork length data from fish with manually aged scales to verify the fork length/age threshold values by plotting manually aged scales below the frequency distribution on the horizontal axis.

*Age Assignment from Scales*

We assigned ages to individuals from which scales were not collected by visual inspection of fork length frequency histograms. We created separate plots for each iteration of species, watershed, year, and season (see Fig. C1 for example). We plotted aged scales below the x-axis to visualize how the age threshold lined up with their distribution. We manually identified the threshold and assigned ages above and below accordingly.

A picture containing text

Description automatically generated

**Figure C1.** Example density histogram of fork lengths from Coho Salmon captured from Beaver Creek (Lowland watershed) in Fall 2016 (n = 320). Threshold between age 0 and age 1 is indicated by the red dashed line. Manually aged scales are plotted below the x-axis.

*Growth rate estimates from chronological fork length distribution modes*

The progression of fork length modes through time may be used to estimate growth within fish populations (Isely and Grabowski 2007). Use of this method requires several assumptions:

*Assumption 1-* *Each mode represents a distinct age class*. Fork length data partitioned into distinct modes, each of which we assumed was composed primarily a single age class (ages 0, 1, and 2 for Coho Salmon, and ages 0 and 1 for Chinook Salmon). In order to verify the age composition of each mode we aged scales from individuals within each mode as available and verified the age assignment.

*Assumption 2-* *Growth rates across age classes is similar through time.* Somatic growth rates for each year (partitioned by age, year, species, and site) was drawn from a sample size sufficiently large so as to minimize the likelihood of uneven growth rates among age classes.

*Assumption 3-* *The sample is drawn at random with respect to size.* We used minnow traps as the exclusive gear type used in this study, and mesh size and trap entrance diameter were consistent across all sampling events. A fixed trap entrance diameter may bias against capture of larger fish, while mesh size may bias against retention of smaller fish. For the particular species and age classes of interest in this study it is anticipated that these biases were minimal.

Appendix D – *Linear mixed model assessment of temporal/spatial scales of growth*

We used a linear mixed modeling approach to assess how spatial and temporal predictors relate to growth rate metrics. We fit three models, each with a different response, to sets of predictor variables. We used year, species, and age as fixed variables and site as a random variable (Table D1).

|  |  |  |  |
| --- | --- | --- | --- |
| **Table D1.** Variables and levels for linear mixed model to determine spatial and temporal scales of growth simulations. | | | |
| Species  (Fixed) | Age  (Fixed) | Year  (Fixed) | Site  (Random) |
| Chinook | 0 | 2015 | Lower Beaver Creek |
| Coho | 1 | 2016 | Lower Russian River |
|  |  |  | Lower Ptarmigan Creek |
|  |  |  | Lower Kenai River |
|  |  |  | Middle Beaver Creek |
|  |  |  | Middle Russian River |
|  |  |  | Middle Ptarmigan Creek |
|  |  |  | Middle Kenai River |
|  |  |  | Upper Beaver Creek |
|  |  |  | Upper Russian River |

The three models considered are as follows:

1. Individual Weight ~ (1 | Site) + Julian Day + Species + Age + Year
   * (n = 4275 total fish weights)
2. Mass-Specific Growth Rate ~ (1 | Site) + Season + Species + Age + Year
   * (n = 55 seasonal mass-specific growth rate values (g·g-1·d-1). A season is defined as the interval of days between two sampling events at a site, approximately monthly intervals. Specific growth rate (SGR) values were calculated using the equation

where Wt2 is the mean weight of a fish population from a sampling event on Julian day t2, and Wt1 is the mean weight of fish from the site’s prior sample event.

1. Final Weight (Weight on Aug. 6th) ~ (1 | Site) + Species + Age + Year
   * (n = 45 available values for fish weight on the Julian day of earliest final site visit across all sites and years).

For all approaches, we used fish weights calculated from age-segregated back-transformations of length and weight data as described in (Ogle 2016). We used back-transformed weight rather than raw values as a response variable because stomach content mass can introduce error especially for small fish like those of our study population. A log transformation was applied to the back-transformed weight values to improve linearity of the relationship with time. Residual plots were visually inspected to verify random distribution. For the third approach, we used interpolated weight values acquired from a linear trend between mean weight values of last two sequential site visits of each field season. August 6th (Julian Day 218) was the earliest day for a final site visit among both years and all sites, and we calculated interpolated weight values for this date.

Model results from the three relationships are arranged in Table D2. After controlling for site-level variation, all predictors were significant covariates (p < 0.05) in Approach A (individual fish weight vs. Julian day). Only season was a significant covariate in Approach B (mean daily growth rate vs. season). Year and age were significant covariates in Approach C (growth potential; or size at end of summer). We retained all variables as factors by which to segregate fish size and growth data as inputs in bioenergetics models that used observed field data. Approach C offered the best correlation between predictors and response (R2 = 0.86) and was selected as the response for which to compare in future scenarios.

|  |  |  |  |
| --- | --- | --- | --- |
| **Table D2.** Three linear mixed model results used to identify effect sizes of spatial and temporal predictor variables on growth and size responses. | | | |
|  | Massa | Seasonal Growth Rateb | Final Sizec |
| Julian day | 0.0071 \*\*\* |  |  |
|  | (0.0002) |  |  |
| Year (2016) | 0.2085 \*\*\* | 0.0015 | 0.8599 \* |
|  | (0.0126) | (0.0015) | (0.338) |
| Species (Coho) | -0.3551 \*\*\* | 0.0003 | -0.6249 |
|  | (0.0193) | (0.0019) | (0.4136) |
| Age (Age 1) | 1.3027 | -0.0017 | 5.8631 \*\*\* |
|  | (0.0190) | (-0.0017) | (0.3772) |
| Season |  | -0.0037 \*\*\* |  |
|  |  | (0.0010) |  |
| N | 4226 | 55 | 45 |
| N (Site) | 10 | 10 | 10 |
| AIC | 3517.8110 | -362.3963 | 146.0357 |
| BIC | 3562.2541 | -348.3450 | 156.8757 |
| R2 (fixed) | 0.6356 | 0.1984 | 0.8604 |
| R2 (total) | 0.7097 | 0.2076 | 0.8645 |
| \*\*\* p < 0.001; \*\* p < 0.01; \* p < 0.05  a.) Individual fish mass; b.) Slope of the line between mean fish sizes between two site visits; c.) Fish mass on August 6th. | | | |
|  |  |  |  |

**References**

Beamish, R. J., and G. A. McFarlane. 1983. The Forgotten Requirement for Age Validation in Fisheries Biology. Transactions of the American Fisheries Society 112(6):735–743. Taylor & Francis.

Isely, J. J., and T. B. Grabowski. 2007. Age and Growth. Pages 187–228 *in* C. S. Guy and M. L. Brown, editors. Analysis and Interpretation of Freshwater Fisheries Data. American Fisheries Socity, Bethesda, Maryland.

Mauger, S., R. Shaftel, E. J. Trammell, M. Geist, and D. Bogan. 2015. Stream temperature data collection standards for Alaska: Minimum standards to generate data useful for regional-scale analyses. Journal of Hydrology: Regional Studies 4, Part B:431–438.

Minard, E. R., and J. E. Dye. 1988. Rainbow Trout Sampling and Aging Protocol. Anchorage, Alaska.

Ogle, D. 2016. Introductory Fisheries Analysis with R, 1st edition. CRC Press, Boca Raton, Florida.

QGIS Development Team. 2019. QGIS Geographic Information System.