Extensive Riparian Status and Trends Monitoring Program – Stream Temperature

Phase I: Westside Type F/S and Type Np Monitoring Project

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EXTENSIVE RIPARIAN STATUS AND TRENDS MONITORING PROGRAM - STREAM TEMPERATURE

Phase I:

Westside Type F/S and Type Np Monitoring Project

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Prepared for:

The Riparian Science Advisory Group of the

Cooperative Monitoring, Evaluation, and Research (CMER) Committee

Adaptive Management Program

Washington Department of Natural Resources

Olympia, WA

Washington State Department of Ecology

Forest Practices Adaptive Management Program

The Washington Forest Practices Board (FPB) adopted an adaptive management program in concurrence with the Forests & Fish Report (USFWS 1999) and subsequent legislation. The purpose of this program is to:

> Provide science-based recommendations and technical information to assist the board in determining if and when it is necessary or advisable to adjust rules and guidance for aquatic resources to achieve resource goals and objectives (Forest Practices Rules, WAC 222-12-045).

To provide the science needed to support adaptive management, the FPB made the Cooperative Monitoring, Evaluation and Research Committee (CMER) a participant in the program. The FPB empowered CMER to conduct research, effectiveness monitoring, and validation monitoring in accordance with guidelines recommended in the FFR.

Disclaimer

The opinions, findings, conclusions, or recommendations expressed in this report are those of the authors. They do not necessarily reflect the views of any participant in, or committee of, the Timber/Fish/Wildlife Agreement, the Forests and Fish Agreement, the Washington Forest Practices Board, or the Washington Department of Natural Resources; nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

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Executive Summary

This study was initiated to provide data needed to evaluate landscape-scale effects of implementing the forest practices riparian prescriptions and to evaluate progress toward meeting Clean Water Act (1977) requirements and riparian resource objectives.

We used a probability-based sampling design to sample stream temperature and canopy closure on Type F/S (fish-bearing) and Type Np (non-fish-bearing perennial) streams on land regulated under the Forest Practices Rules in western Washington. We monitored stream temperature and canopy closure over the summer of 2008 and 2009. Because only about half of the sites were monitored in 2008 due to delays in acquiring permission to access the sites, the statistics presented below are based on the 2009 sample year (July-August).

A Generalized Random Tessellation Stratified survey design for a linear resource was used to establish a statewide probability master sample of Type F/S streams and Type Np streams. A total of 61 sites on Type F/S streams were sampled of the 120 sites that were evaluated. Fifty-four sites on Type Np streams were sampled of the 228 sites evaluated.

For each stream type, cumulative distribution function (CDF) plots are presented, along with the estimated 25%-tile, median, and 75%-tile CDF values, for maximum summer stream temperature, the seven-day average maximum stream temperature (7DADM), and canopy closure (shown in the table below).

Stream Type	Metric	25%-tile	Median	75%-tile
F/S	Canopy closure	39%	78%	96%
	Maximum temperature	16.0 °C	18.7 °C	20.4 °C
	7DADM	15.4 °C	18.1 °C	19.5 °C
Np	Canopy closure	73%	93%	98%
	Maximum temperature	14.0 °C	16.2 °C	17.3 °C
	7DADM	13.2 °C	15.2 °C	16.5 °C

Three difficulties were encountered during implementation:

1. For both Type F/S and Type Np waters, small forest landowners were less likely to participate than industrial forest land owners. As a result, a substantial proportion of the land base was not sampled. However, it is unclear whether this introduced substantive bias into the study.

2. There were errors in the sampling frame that resulted in misclassification of some sampling sites (i.e., wrong water type or incorrect land use). These errors were relatively minor and expected when applying a regulatory definition to GIS-derived stream layers.

3. Some Type Np streams had too little water in the summer to submerge data loggers.

In spite of these difficulties, the estimated scope of inference was 70% and 68% of the original sample frame for Type F/S and Type Np streams, respectively.

Introduction

Washington State regulates forest management activities within riparian buffers to limit the loss of riparian shade and mitigate the effects of forest harvest on stream temperature. The rules differ for fish-bearing streams (Type F/S) and non-fish-bearing perennial streams (Type Np). On westside Type Np streams, 50-foot width buffers must be left along at least 50% of the perennial stream length, including buffers at tributary junctions, the upper most point of perennial flow, and several types of sensitive sites. The riparian management zone for westside Type F/S streams varies in width based upon soil site class and stream width, but all streams include a core zone comprised of a minimum 50-foot width no-cut buffer adjacent to each side of the stream. Outside the core zone are the inner zone and outer zone where some harvest is permitted. Several studies are currently underway to evaluate the effectiveness of riparian buffer requirements in maintaining adequate shade and preventing increased stream temperature in western Washington, non-fish-bearing streams (Hayes *et al.* 2005; Ehinger *et al.* 2011; McCracken *et al.*, in prep) and in eastern Washington fish-bearing streams (Light *et al*. 2003; Ehinger 2013; Cupp and Lofgren 2014).

The goals of this study are to collect an unbiased dataset (for later comparison against applicable water quality standards) and provide unbiased status estimates of two key riparian indicators at the landscape level—summer stream temperature and riparian canopy closure—for Type F/S and Type Np streams on forest lands in western Washington regulated under the Forest Practices Rules (FPR). These data will complement other effectiveness monitoring projects by allowing the estimation of the proportion of streams within specific water quality thresholds on a random sample of streams and providing context for other study results. We use a probability sampling design to provide robust statistical inference at the landscape scale. Probability sampling also offers a consistent approach to sampling statewide resources (e.g., Overton *et al.* 1990; Diaz-Ramos *et al.* 1996). To date, sampling of stream temperature and canopy cover condition in Washington state has been insufficient to characterize streams on the millions of acres of private and public forest lands because most data come from sites selected using criteria specific to that study (e.g., Hayes *et al.* 2005; Ehinger *et al.* 2011).

Context for Extensive Monitoring

The Extensive Riparian Status and Trends (ERST) monitoring program is organized into four separate projects (**Appendix A**) and two phases. The projects stratify Washington state by geographic region (eastside/westside) and by stream type (Type F/S—fish-bearing, Type Np—non-fish-bearing perennial). The phases refer to the status (Phase I) and trends (Phase II) components of the monitoring design.

The Phase I report for the Eastside Type F/S streams was completed in 2013 (Ehinger 2013).

This report summarizes results of Phase I for both Westside Type F/S and Type Np streams. The objectives include:

- Describe the frequency distribution of stream temperature (maximum summer stream temperature and seven-day average maximum stream temperature) and canopy closure in

Type F/S and Type Np streams on forest lands managed under the FPR in western Washington.

- Estimate frequency distributions of several descriptive non-temperature variables.

Methods

Study Design

In 2006, a Generalized Random Tessellation Stratified (GRTS) survey design for a linear resource was used to establish a statewide probability master sample[1] (**Table 1**; **Appendix B**)[2]. To optimize flexibility, no multi-density categories, oversample, panels, or stratifications were imposed. Only reverse hierarchical ordering was retained, applied simultaneously statewide so that any consecutive subset of sites is spatially balanced[3]. For the master sample, both inclusion probability and survey design weight were approximately equal to 1.0 (i.e., expected sample size = one site per km of stream length in the sample frame[4]). Each sample site consists of a latitude-longitude coordinate pair along a Type F/S or Type Np stream.

In 2007, the master sample was partitioned to meet the selection criteria for an FPR lands domain[5] in western Washington, hereafter referred to as the target lands domain. This target lands domain was defined by four criteria:

- Forested land cover, from USGS Landsat-based ‘Forest Land’ classification.
- Not federal ownership.
- Not part of a separate Habitat Conservation Plan.
- Not included in an Urban Growth Area.

Forested land not explicitly excluded by one of the last three criteria was considered part of the target lands domain and all Type F/S or Type Np streams within the target lands domain were candidates to be sampled[6].

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[1] The master sample consists of approximately 380,000 points, drawn by EPA from compiled coverages at the WRIA scale. For a summary of probability sample features, see **Appendix B**.

[2] See **Appendix C** for archived data types and locations.

[3] Provided any differential sampling is accounted for.

[4] A sample frame consists of a list, map, or other description of the units of the population to be sampled. (http://stats.oecd.org/glossary/about.asp).

[5] The target domain is used to describe the spatial extent of the target population, or ‘the set of elements about which information is wanted and estimates are required’ (http://stats.oecd.org/glossary/about.asp).

[6] Imperfections in stream classification in the hydrologic GIS layers resulted in a list of candidate sites consisting of a mixture of both target and non-target sites.

Hydrographic length was then calculated, taking into account partitioning to the target lands domain. For Type F/S surface waters, the result was 25,669 potential sampling sites (i.e., a sample frame length of 25,669 km and actual hydrographic segment length, as calculated by ArcMap, = 25,714 km) (**Table 1**). For Type Np surface waters, the result was 49,317 potential sampling sites (i.e., a sample frame length of 49,317 km and actual hydrographic segment length, as calculated by ArcMap, = 49,089 km). Greater than 80% of Type F/S hydrographic length and associated sampling sites corresponded to modeled water sub-type F1 (**Table 2**). Approximately 54% of Type Np hydrographic length corresponded to modeled water sub-type N1 (**Table 3**).

Because stream temperature is an issue in all streams, regardless of size, no stratification by stream size or Strahler order (Horton 1945; Strahler 1957) was imposed. Probability of a stream reach of any specific order being selected was thus in proportion to the stream order proportions of the hydrographic layer.

For each water type, the goal was a base sample of 50[7] sites. To achieve this, 120 Type F/S sites and 228 Type Np sites were evaluated (**Figure 1**) for use in the study. Sites were drawn sequentially to maintain spatial balance, and screened with high-resolution orthophotos to establish candidate sites. Parcel ownership was determined from county tax records. Landowner contact (i.e., permission to visit candidate sites) was made in person, where feasible, or by phone or letter. Where public access was available, some sites were first inspected to determine if the stream met the land use and stream type criteria prior to contacting the landowner. Sites determined to be non-target (e.g., not the appropriate water type, not forestry land use, not regulated under the FPR) were replaced by adhering to the GRTS sequence order and site-replacement process.

For Type F/S streams, the three main reasons for rejecting sites were: 1) no response from the landowner, 2) land was not used for forestry, and 3) incorrect water type (**Table 4**). We categorized each site into landowner categories (public lands—PUB, industrial landowners—IND, and small forest landowners—SFLO) to show rejection rates (**Table 5**). Of the 42 sites rejected for the reasons above, 36 were located on small forest landowner properties. Overall, the rejection rate on SFLO properties was 80%, compared to a 25% rejection rate on IND properties. Although SFLO sites comprised 42% of the sites evaluated, they comprised only 16% of the sites sampled.

For Type Np streams, the three main reasons for rejecting a site were: 1) incorrect water type, 2) land was not used for forestry, and 3) landowner declined to participate (**Table 6**). Of the 69 sites rejected for the reasons above, only 20 were on SFLO properties (**Table 7**). The rejection rate for both SFLO and IND properties was higher than for Type F/S streams, mainly due to the large number of incorrect water type designations on the hydrolayer.

All evaluated sites were plotted to show location and landowner category in **Figure 2**. If permission to access was granted, a hand-held GPS device was used to navigate to the site

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[7] To balance level of precision and sampling effort, GRTS designs often are variations on sampling 50 sites. This equates to +/- 10% precision and 90% confidence. Sample size is to some degree design dependent and can either be established prior to the sample draw and is used to fix design factors, or open-ended and determined by adequate representation of sub-populations or strata (see http://www.epa.gov/nheerl/arm/surdesignfaqs.htm#manysamples).

coordinates, the location monumented with a semi-permanent marker driven into the soil near the stream, the marker flagged, and relationship of the marker to the stream sample point described. Later, a second crew installed temperature data loggers and recorded non-temperature variables (see below).

Assumptions and Constraints

A number of assumptions were made regarding the target population, how it was identified, and the indicators measured. Some apply to GRTS, in general, and others, specifically to this study.

<u>Assumptions</u>

GRTS

- Landowner class does not influence response.
- Spatial balancing variable (hydrography) is correlated with response.
- Excluded sites have the same statistical properties as monitored sites (i.e., missing completely at random).
- Indicators integrate the processes being assessed.

ERST

- Errors in hydrography and water typing are recognized and corrected to the extent possible.
- Sample describes landscape-scale variability.
- Variability can be adequately quantified by GRTS probability approach.

<u>Known Constraints</u>

- Hydrography layer varies in stream density. National Map Accuracy Standard is ± 12.19 m (40 ft). Source scale is 1:24,000.
- The sample frame changes over time. Hydrography is continuously updated thru the Timber, Fish, and Wildlife Agreement water type modification process. In any given year, the modifications represent a very small proportion of the entire stream network, but over several decades, the change could be substantial.
- The fish-bearing/non-fish-bearing junctions were derived from a mix of model predictions, fish presence/absence surveys, and previous water type classification.

Variables Measured

This study measured a subset of stressor variables with special emphasis on stream temperature and riparian canopy closure. Water temperature is one of the most commonly violated water quality standards in Washington State and riparian shade, via riparian buffer requirements, is the regulatory means of meeting targets for stream temperature. Other non-temperature variables were also measured or derived to provide context for the stream temperature results and are described below.

Non-Temperature Variables

GIS-derived variables

Four study variables—elevation, catchment area, distance-to-divide, and catchment slope—were GIS-derived from readily available statewide public data. These provide a description of the sites included for temperature monitoring. Definitions for these variables and their source GIS layers are listed in **Table 8**.

Measured variables

A limited survey was undertaken to quantify several easily measured descriptors of study reaches (**Table 8**). Reach length was 30 times the average bankfull width (BFW), based on five BFW measurements. We set a minimum reach length of 150 m and maximum of 500 m. At one Type Np site, reach length was only 130 m because that was the length of the entire upstream perennial stream channel. Study reaches were evaluated by establishing six equally spaced transects perpendicular to stream flow running upstream from the sample point. Methods were adapted from Peck and colleagues (2006) and Schuett-Hames and colleagues (1999a, 1999b).

Thirteen site-level variables were quantified. Nine were quantified at the transects: 1) bankfull width, 2) wetted width, 3) mean depth, 4) channel gradient, 5) riparian canopy closure, 6) thalweg depth, 7) embeddedness, 8) bed particle size, and 9) channel aspect; and four were quantified over the intervals between transects: 10) LWD_{downed}, 11) $LWD_{suspended}$, 12) LWD_{jam}, and 13) riparian overstory type. Variables one through nine were included to assess reach-scale correlation with temperature. Variables ten through twelve were measured because LWD recruitment is a resource objective. Overstory type provides context for other results. These variables are referred to hereafter as habitat variables. Site-level and catchment-level characteristics are summarized in **Appendix D**. The measurement methods were chosen to conform to those identified in the FPR (e.g., canopy closure) or established Timber, Fish, Wildlife protocols (Schuett-Hames *et al.* 1999a, 1999b).

Temperature Variables

Stream temperature monitoring began in 2008. The intent was to monitor at least 50 sites in each stream type and to install all temperature loggers by 30 June 2008 to record each stream's annual thermal peak. However, by mid-July 2008 only one half that number of sites were installed due to delays in locating and obtaining permission to access private property. We continued in spring 2009 and by 1 July 2009 had installed loggers at 53 of 61 Type F/S sites and at 53 of 54 Type Np sites. The remaining sites were installed by 9 July 2009.

Temperature was recorded at 30-minute intervals at the upper and lower end of each study reach with *in situ* TidbiT data loggers (Onset Computer Corporation 2004) using the methods described in Schuett-Hames and colleagues (1999a). Data loggers were attached using zip ties to iron rebar driven into the stream bed. The Tidbits were suspended in the water column, and shielded from direct sun using perforated white PVC tubing. An air temperature data logger was deployed adjacent to the lower monitoring station approximately 30 cm above the water surface and shielded from direct sun (Schuett-Hames *et al.* 1999a). Height and distance from the stream varied where necessary to protect the data logger from direct sun.

Data loggers remained in place at least through August in each year. Peak summer maximum temperatures occurred over a one-week period at nearly all sites in each year, centered on 17 August in 2008 and 30 July in 2009, so it is unlikely that we missed the thermal peak. Temperature metrics were calculated for those sample sites with at least 30 days of data over the period 1 July through 31 August 2009 (**Appendix E**). Metrics for water temperature were:

- Maximum summer stream temperature (Tmax, upstream and downstream).
- Seven-day average of daily maximum summer stream temperature (7Tmax, upstream and downstream).
- Change in maximum summer stream temperature along reach (downstream minus upstream) for Tmax (D_Tmax).
- Change in seven-day average of daily maximum summer stream temperature along reach (downstream minus upstream) for 7Tmax (D_7Tmax).

Metrics for air were:

- Maximum summer air temperature (air_Tmax).
- Seven-day average of daily maximum summer air temperature (air_7Tmax).

We show the cumulative distribution plots only for Tmax, D_Tmax, and air_Tmax because they are very similar to those for seven-day averages. However, **Table 9** and **Table 10** include both maximum temperature and seven-day average maximum temperature.

Quality Assurance

Prior to deployment, temperature data loggers were compared to a National Institute of Science and Technology (NIST) thermometer by submerging them in an ambient room temperature (~20°C) water bath and in an ice-water bath at 0°C. Data loggers outside the manufacturer's stated accuracy (0.2°C for water temperature range data loggers, 0.4°C for air temperature range data loggers) in either water bath temperature were not deployed.

During the study, data loggers at several monitoring stations were exposed to air as stream water levels dropped. These data were identified and excluded from analysis. First, field notes were used to flag sites and general time periods when data loggers may have been exposed. Second, both stream and air temperature data for each site were examined to determine the date and time when a data logger may have been exposed. As a data logger becomes exposed to the air, the stream temperature record, especially daytime temperatures, more closely track air temperature. Because of the typically large difference between afternoon air and water temperature, it was usually apparent when a data logger became exposed. Full data filtering procedures are documented in the quality assurance plan (Ehinger *et al.* 2010).

In addition, as specified in the study plan for the ERST program (Ehinger *et al*. 2007), repeatability of data collection methods for non-temperature variables was evaluated at approximately 10% of the study sites. This subset of sites was randomly selected and methods were performed by different field crews during the repeat visit. In general, the mean coefficient of variation was less than 10% for wetted width and depth, bankfull width, gradient, and canopy closure; less than 20% for bankfull height and embeddedness; but sometimes exceeded 20% for particle size. Results are summarized in **Appendix F**.

Analysis

Effects of Site Rejection

Three observed categories of site rejection occurred frequently enough to affect the sampling:

1. No response from landowner (NR). This occurred more frequently with small forest landowners than the industrial landowners for both Type F/S (34% of SLFO sites attempted) (**Table 5**) and Type Np (9% of SFLO sites attempted) (**Table 7**). This unintended stratification changed the study design from equi-probability to variable-probability (see below). As this was not determined until after sampling, an alternative form of the Horvitz-Thompson π-weighted estimator (Horvitz and Thompson 1952; Thompson 2002) was incorporated during analysis to adjust initial weight for stratification by ownership. The rationale to account for potential biases introduced by differential loss of sites during evaluation, that is, loss other than completely at random, is described by Stevens and Jensen (2007).

2. Non-target (other) waters (OW). Approximately 8% of Type F/S sites evaluated (**Table 4**) and 22% of Type Np sites evaluated (**Table 6**) were misclassified (i.e., not the expected water type). This was seen across both main ownership classes but was higher for SFLO, affecting 14% of Type F/S sites in this ownership (**Table 5**) and 41% of Type Np sites (**Table 7**).

3. Target not sampled (TN). These sites were excluded typically due to insufficient water in the channel to submerge dataloggers, permission to access the site was obtained too late to be included, or additional sites were not needed. These exclusions comprise 8% of Type F/S sites evaluated (**Table 4**) and 40% of Type Np sites evaluated (**Table 6**).

Cumulative Distribution Functions

Data for the analysis were summarized for the period from 1 July through 31 August 2009. Results were calculated using the GRTS spatial survey design and analysis package (*spsurvey* v. 2.2; Kincaid and Olson 2011) and the accessory package *sp* (Pebesma and Bivand 2011). These packages provide overview, survey design, and data analysis for areal, finite, and linear resources, and automate plotting and confidence band estimation using cumulative distribution functions (CDF). Currently, these flexible, non-standard functions only exist for R, an open-source implementation of the S statistical language developed at Bell Laboratories. See Ihaka and Gentleman (1996) for the original published description of the R Project, and Becker and colleagues (1988) for development of S. The R code is included in **Appendix G**.

Initial per site weights for the sample domain and target population were 213.908 for Type F/S and 216.303 for Type Np. The site weight represents the hydrologic length in kilometers that each site represents. Final weights per site, adjusted using the *adjwgt* function to take into account post-sampling stratification by ownership and the number of sites of indeterminate status as target or non-target, were:

- Industrial landowners (IND) = 266.810 (Type F/S), 587.410 (Type Np).
- Municipal landowners (MUN) = 648.908 (Type Np only).
- Small forest landowners (SFLO) = 434.501 (Type F/S), 1378.929 (Type Np) (personal communication (J.E.J.), D.P. Larson and T. Olson, E.P.A.).

Latitude and longitude were transformed to Albers projection, spheroid Clarke 1866 (Snyder 1987), using the *albersgeod* function, consistent with the original sample draw.

Results are reported as:

- CDFs and mean catchment-scale characteristics of base sample.
- CDFs and mean reach-scale characteristics of base sample.
- CDFs of canopy closure and maximum temperature.

The analysis pathway defines vectors for sites, sub-populations, design, and variables of interest, and then calls functions to write results as percentiles and overall means and plots CDFs. Confidence bands are shown in figures at the 95% level. Although mean values are more intuitive to resource managers, they may be biased. The percentile estimates are not biased. Both are reported for the reader.

The R package *spsurvey* contains a function to examine year-to-year cumulative distribution function inference for probability survey data. However, installation of data loggers, which began in 2008, tended to follow site availability rather than GRTS order, which disturbed the study's spatial balance for the year of initial installation. This was resolved in 2009. Only the 2009 data were analyzed.

To evaluate the relationship of temperature results to regional climatic influences, the historical mean of daily maximum air temperature for July was calculated for seven sites in western Washington: Buckley (Pierce County), Centralia (Lewis County), Elma (Grays Harbor County), Forks (Clallam County), Longview (Cowlitz County), Peterson's Ranch (Skamania County), and Sedro-Woolley (Skagit County). These sites were selected because of proximity to forest lands distributed throughout western Washington, and because of their long data record. The time period of these data was 1958-2008.

Correlation analyses

We used a Spearman rank correlation to assess the strength of the relationship between downstream water temperature and upstream water temperature, air temperature, canopy closure, and eleven of the GIS-derived and habitat variables, including: mean depth, thalweg depth, wetted and bankfull width, width:depth ration stream gradient, total LWD, elevation, catchment area, distance to divide, and catchment slope.

We ran the analysis using all Type F/S and Np sites together and for each stream type alone to distinguish between relationships that actually differ between stream types or only because the streams represent opposite extremes of the distribution. Only sites for which both downstream water temperature and air temperature data were available were used for the correlations.

Results

Type F/S streams

Stream aspect was relatively uniformly distributed except that very few sites with a northeast aspect were sampled (**Figure 3**). Median canopy closure was similar for coniferous and mixed riparian vegetation types, 87% and 88%, respectively (**Figure 4**). Median canopy closure for the deciduous vegetation type was lower, 67%, and more variable with minimum and maximum values near 0% and 100%. Overall median canopy closure was 78% (mean 68%) and the 25th percentile of the estimated canopy closure distribution was 39% (i.e., 75% of the population is estimated to exceed 39% canopy closure) (**Figure 5**).

The GIS-derived catchment variables and several habitat variables varied widely across sites with a few very high values skewing the distribution (**Appendix D**; **Table D-1)**. For example, median catchment area was 193 ha and the mean was 5970 ha. Median distance to divide was 2622 m and mean was 11,493 m. Median station elevation was 94 m and the mean was 150 m. Median and mean catchment slope were 6.9% and 9.3%, respectively. Likewise bankfull width and wetted width were skewed with median values of 4.9 m and 3.0 m, respectively and mean values of 10.5 m and 7.5 m, respectively; median particle size was 6.4 mm and mean was 22.3 mm. Median thalweg depth and mean depth were 0.3 m and 0.1 m, respectively and mean values were 0.4 m and 0.2 m, respectively. Median total LWD pieces was 21.6 pieces per 100 m and mean was 27.4. CDFs and summary statistics are compiled in **Appendix D**.

The median Tmax and 7Tmax at the downstream locations were 18.7°C and 18.1°C, respectively (**Table 9**; **Figure 6**). The median D_Tmax and D_7Tmax (i.e., upstream-downstream differences in Tmax) was 0.1°C for both metrics, indicating little temperature change across the sampling reach. Median air TMax was 28.3°C (**Table 9**; **Figure 7**).

The 2009 season was much warmer than 2008. Maximum daily air temperature in July, during the period of maximum stream temperature, exceeded the 75th percentile of the historical record (1958-2008) at several locations around the study area (Buckley, Centralia, Elma, Longview, Peterson's Ranch, and Sedro) (**Figure 8**). As a result, stream temperatures in 2009 were warmer than in 2008. The mean Tmax and 7Tmax were 2.6°C and 2.7°C higher, respectively, and the mean air Tmax and 7Tmax were 3.3°C and 2.9°C higher, respectively, in 2009 than in 2008 at sites monitored in both years (**Figure 9**). In addition, maximum stream temperatures occurred three weeks earlier in 2009 than in 2008 (**Figure 10**).

Type Np streams

Stream aspect was patchily distributed with few sites having northeast or east aspects (**Figure 11**). Greater median canopy closure (median 95%) was observed at sites with mixed riparian canopy vegetation than at sites characterized as either coniferous (median 74%) or deciduous (median 70%) (**Figure 12**). Overall median percent canopy closure was 93% (mean 82%) and the 25th percentile was 73% (**Figure 13**).

Type Np catchment area ranged from 1.3 to 83.1 ha with a median and mean of 10.9 and 20.0 ha, respectively (**Appendix D**; **Table D-2**). Catchment slope was much steeper than the Type F/S streams, with a median and mean catchment slope of 22.4% and 21.9%, respectively, and at nearly twice the elevation, with a median and mean elevation of 258 m and 335 m, respectively. Distance to divide ranged from 156 m to 1976 m with a median value of 614 m.

Median and mean bankfull widths were 1.6 m and 1.9 m, respectively, and median and mean wetted widths were 0.9 m and 1.1 m, respectively. Thalweg depth and mean depth never exceeded 0.25 m and 0.19 m, respectively, with median values of 0.07 m and 0.03 m, respectively. Median and mean total LWD pieces were 32.7 and 38.6 pieces per 100 m. CDFs and summary statistics are compiled in **Appendix D**.

The median Tmax and 7Tmax at the downstream locations was 16.2°C and 15.2°C, respectively (**Table 10**; **Figure 14**). The median D_Tmax and D_7Tmax was 0.8°C for both metrics, a greater temperature change across the sampled reach than in the Type F/S sites. Median air 7Tmax was 23.9°C, compared to 25.1°C at the Type F/S sites (**Figure 15**).

The mean Tmax and 7Tmax were 1.1°C and 1.2°C higher, respectively, and mean air Tmax and 7Tmax were both 3.5°C higher, respectively, in 2009 than in 2008 at sites monitored in both years. Similar to the Type F/S sites, peak stream temperatures occurred three weeks earlier in 2009 than in 2008 (**Figure 10**).

Correlation analyses

For Type F/S, Type Np, and all sites combined, the strongest correlations were with upstream water temperature and air temperature (**Table 11**; **Figure 16**). For the habitat variables, there were significant positive correlations with width (wetted and bankfull), thalweg depth, catchment area, and distance to divide in the Type F/S and pooled sites, but no correlation in the Type Np sites. Similarly, there were significant negative correlations with canopy closure, stream gradient, total LWD, and catchment slope in Type F/S and pooled sites, but no correlation in the Type Np sites. For mean depth, there was a significant positive correlation in the Type F/S and pooled sites, but a significant negative correlation in the Type Np sites. There was a positive correlation in the ratio of width to depth in the Type Np sites, but no correlation in the Type F/S or pooled sites. Elevation was not correlated with stream temperature.

Discussion

Stream temperature and canopy closure

Canopy closure on Type F/S streams averaged 68% but was heavily impacted by eight locations with less than 20% canopy closure and bankfull widths ranging from 22 to 61 m, suggesting that the low shading was due to the width of the stream rather than the lack of riparian vegetation. Mean canopy closure on Type Np streams was influenced by six sites with some portion of the sampled reach unbuffered. Current forest practices rules require a buffer along at least 50% of Type Np streams, so this was not unexpected. Canopy closure ranged from 1% to 35% at these sites. However, overall Type Np sites averaged 82%, only slightly less than that observed by Schuett-Hames and colleagues (2011), Janisch and colleagues (2012), and McIntyre and colleagues (2018) in unharvested Type Np streams in western Washington. Other factors likely influencing canopy closure are stand type (**Figure 4** and **Figure 12**) and forest management history (which was not recorded).

In this study, maximum summer water temperatures in the Type Np streams were warmer, on average, and more variable among sites (spanned a wider range) than similar-sized streams in other recent studies from western Washington and Oregon (Dent *et al*. 2008; Groom *et al*. 2011; Kibler *et al*. 2013; Bladon *et al*. 2018; McIntyre *et al.* 2018). This is likely a sampling artifact of comparing this random sample with streams chosen because of specific physical (e.g., unharvested mature forest) or biotic (e.g., presence of cool water species) characteristics. The situation is similar when comparing our Type F/S sites with other studies because the range in size of Type F/S streams is even greater than in Type Np.

Air temperature in 2009 was much warmer than 2008 and this is reflected in the stream temperatures. The 1.2°C difference in mean 7Tmax between years observed here is similar to the 1.3°C difference observed by McIntyre and colleagues (2018) in unharvested western Washington Type Np streams between the same years. The between-year difference in 7Tmax in the Type F/S streams was even greater at 2.7°C. Between-year (2007 vs. 2008) differences in maximum stream temperature of 1.0°C were seen in eastern Washington Type F/S streams (Ehinger 2013), and were associated with air temperatures that were, on average, 1.7°C higher in 2007 than 2008. Between-year differences of this magnitude in the absence of forest management activities will make long-term effects of forest harvest on stream temperature difficult to distinguish from natural variability or climate change.

Correlation of water temperature with other variables

The significant correlations between stream temperature and the habitat variables seen in the Type F/S streams alone and in the pooled data set were predictable. The strong correlation with upstream water temperature was noted by Groom and colleagues (2011) and is likely even stronger in our streams because of the shorter reach lengths. Similarly, the correlation with air temperature and some habitat variables has been observed in western Washington Type Np streams (Ecology, unpublished data). A negative correlation of stream temperature with canopy closure has been observed elsewhere and is likely related to increased solar insolation due to less riparian shade, which may partially be a function of wider bankfull widths in larger catchments.

Many of the habitat variables are themselves correlated. For example, catchment area and distance to divide are measures of area above the sampling site, larger catchments tend to have wider streams, and wider forested streams tend to be less shaded. Nearly all of the correlations with stream temperature followed expected patterns of higher stream temperature in less-shaded streams, which tended to be wider and have larger catchments. One exception was mean water depth, which was positively correlated with stream temperature for the Type F/S and pooled data, but negatively correlated for the Type Np sites. This suggests that the positive correlation is an effect of catchment size, while the negative correlation for Type Np streams may reflect water volume.

Stream temperature was not correlated with most habitat variables for the Type Np sites. This is likely because the Type Np sites spanned a very narrow range of habitat values (e.g., wetted width, bankfull width, catchment area, distance to divide) (**Figure 16**) or in some cases did not include the very low values where the change in temperature was greatest (e.g., stream gradient or catchment slope). This is well illustrated in **Figure 17**, where Type F/S shade values are relatively uniformly distributed across the entire graph while Type Np shade values are bunched at 80%.

Comparison of Type F/S with Type Np streams

Three observations were made comparing Type F/S and Type Np streams.

1. Tmax was, on average, 3.0°C warmer in Type F/S streams than in Type Np streams. Mean Tmax at the downstream stations was 19.0°C (95% CI: 18.2-19.8°C) in Type F/S streams (**Table 9**) compared to 16.0°C (95% CI: 15.3-16.7°C) for Type Np streams (**Table 10**).

2. Mean D_Tmax at Type Np sites (1.2°C) was nearly four times that observed at Type F/S sites (0.3°C).

3. Stream temperature was correlated with many of the site level habitat variables in Type F/S streams, but not in the Type Np streams (**Table 11**).

These differences were not surprising. Type Np streams were, in general, located at higher elevations and were narrower than the Type F/S streams. As such, they experienced cooler air temperatures and were more shaded than the wider Type F/S streams, resulting in cooler stream temperatures. The greater temperature change from upstream to downstream in the Type Np streams is likely the result of lower water volumes (i.e., less thermal inertia) in the Type Np than in the Type F/S streams.

Implementation

The rate of site rejection was higher for Type Np sites than for Type F/S sites, but not atypical compared to other studies (Merritt *et al.* 1999; Herger and Hayslip 2000; Hayslip *et al.* 2004). GRTS designs allow site rejection rates to vary and, when this occurs prior to sampling, this may simply amount to refining the sampling frame. High rates of rejection not due to lack of access are a sign that a sampling frame was poorly defined. It is critical, however, that randomization and the matching between spatial balance of the target population and the sample is maintained.

As our results show, GRTS offers robust methods permitting inference in the presence of errors to the sampling frame (**Table 12** and **Table 13**). However, both study design and the scope of inference were weakened by unintended errors in implementation, the former by disturbance of the design-based spatial balance of the target population and the latter from bias introduced against sampling SFLO lands (**Figure 2**). Much of the inferential power to the western flank of the Cascades and Puget Sound regions was lost because few sites were sampled there (**Figure 1** and **Figure 2**). In this particular application of GRTS, some SFLO declined to participate (**Table 4** through **Table 7**; **Figure 2**), but other reasons for loss of sites were more significant, most notably:

- No response from the landowner.
- Lands converted to other purposes.
- Insufficient water in the stream.

Without re-sampling, complete correction is not possible. The remedy for future efforts is to replace excluded sites on an ownership-by-ownership basis until the target sample size is reached. Sufficient over-sample exists to accomplish this. It is also necessary to consider whether SFLO lands within the FPR lands domain meet the FPR land definition because many parcels are of mixed land use. However, this was beyond the scope of this project to evaluate.

Several other sources of uncertainty affect inference to the target population, but differ in their impact (**Table 12** and **Table 13**). Misclassification of ownership, for example, can occur if parcels mix land uses (e.g., agricultural and forest lands), if parcels are undergoing transfer of ownership, or if gaps exist in the ownership data derived from tax records. With careful review, this error can be minimized. The impact on inference to a non-stratified target population would be slight. Misclassification of Type F/S waters as Type Np or Type Np waters as Type F/S also occurred. This error, which can be introduced both before and during sampling, can alter the scope of inference. However, its impact is also expected to be slight given on-site stream type evaluations. Potentially of greatest significance to the scope of inference is inclusion of non-target waters and non-target lands in the sample frame (**Table 4** and **Table 6**). This is likely to affect the length of stream within the sample frame rather than the areal extent of the sample frame. Conversely, it is unknown how many waters were excluded by the target population definition. No design can evaluate resource fractions excluded from sample frames.

Several analysis options for this study were possible, depending on the underlying assumptions. For example, is the SFLO class sufficiently different in its management to affect the range of conditions of the stream and channel variables studied? If not, then the differential loss of sites related to ownership, rather than missing completely at random, can be overcome. In effect, ownership would be an irrelevant stratification imposed on an underlying uniform resource. Of significance to this study, however, was that the differential loss of sites disturbed the underlying design-based spatial dispersion of the sample relative to the target population. Taken together, all ownerships combined (**Figure 2**) seem to approximate the distribution of the target population.

Also of significance is how to account for sites of indeterminate target status because they could not be visited. Without further assumptions, loss of these sites reduces the inference domain from 25669 km to 20535 km of Type F/S stream and from 49317 km to 45207 km of Type Np stream.

We calculated the scope of inference using four different sets of assumptions (**Table 12** and **Table 13**) for both stream types. Ratios derived from the sites that were visited were used to approximate the proportion of indeterminate sites that were actually part of the target population. Using the hydrologic definition developed from available linework for a sampling frame consisting of Type F/S streams on western Washington FPR lands (**Table 1**), the sample frame length was 25669 km (**Table 12**: Case 1). This assumed that all sites were target. Accounting for misclassified sites (which were actually non-target) reduced the scope of inference to 23530 km (Case 2). This holds only if no other cases of non-target sites existed in the sample. However, there were 24 indeterminate (with respect to target vs. non-target) sites in the Type F/S sampling and 19 indeterminate sites in the Type Np sampling. Case 3 factors in the indeterminate sites by using the ratio of target to non-target sites, derived from the known sample sites, to estimate the proportion of the full sample which is actually in the target population. This reduced the scope of inference for Case 3 to 18984 km. Case 4 uses analogous calculations but goes one step further by estimating the proportion of non-target sites by ownership stratum. The scope of inference for Case 4 is reduced to 17952 km, or approximately 70% of the original sample frame. The percent of the estimated target population on which the inference is based is approximately 86%. The final scope of inference for Type Np sites was 33581 km, or 68% of the original sample frame of 49317 km (**Table 13**). The percent of the estimated target population on which the inference is based is approximately 37%. For both Type F/S and Type Np analyses, Case 4 can be viewed as a conservative estimate.

Although misclassification of stream reaches and the lack of access to some properties affected the study, even the most conservative estimates of the scope of inference (Case 4) are near 70%. More importantly, this is the only available unbiased estimate of current status of stream temperature and canopy cover in western Washington and so will prove valuable both in assessing compliance with the threshold (i.e., not to exceed) water temperature standards and in providing context for the experimental studies underway in western Washington (Hayes *et al.* 2005; Ehinger *et al.* 2011). The question as to whether there will be further work to assess trends over time is largely a policy issue that must include the cost of this study and other competing research needs.

Conclusions

In spite of the difficulties with landowner access, this study met its Phase I goal of providing a status estimate of stream temperature and canopy cover.

1. Mean canopy closure in the Type Np sites was 82%, very similar to unharvested Type Np sites in several western Washington Type Np studies. Likewise, mean canopy cover in the Type F/S streams was 68%, in spite of eight sites with bankfull widths exceeding 20 m and canopy closure less than 20%.

2. Median Tmax and 7Tmax was 18.7°C and 18.1°C, respectively, in the Type F/S streams, and 16.2°C and 15.2°C, respectively, in the Type Np streams in 2009.

3. Average change in stream temperature across the sample site was 1.2°C in the Type Np streams compared to 0.3°C in the Type F/S, in spite of the much shorter reach lengths in the Type Np (150 m) than the Type F/S (272 m) sites.

4. The strong correlation between stream and air temperature along with the differences between 2008 and 2009 stream and air temperatures suggest that it will be difficult to differentiate long-term changes in stream temperature due to forest harvest from natural variability and climate change.

The scope of inference for westside applications of ERST was reduced by the lack of access to small forest landowner sites and misclassifications of streams on the hydrolayer. For Type F/S waters, the target population inference was reduced to 70% of the original sample frame (from 25669 km to 17952 km) (**Table 12**). Likewise, for Type Np waters the scope of inference was 68% of the original sampling frame (from 49317 km to 33581 km) (**Table 13**). Though the distinction between areal extent of the target population (westside FPR lands) vs. length of target population (km of stream by water type) should be noted, the scope of inference is a function of the underlying assumptions.

If the Phase II of this study is implemented, we recommend:

1. Sites should be plotted during site selection to evaluate whether the underlying spatial balance of the sample is being maintained.

2. Land ownership should be evaluated during implementation to determine if unintended differential sampling is occurring.

3. Ongoing consultations with an expert knowledgeable in GRTS surveys during planning, implementation, and analysis of any future implementation of probability sampling to fully realize the potential of GRTS designs.

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Table 1. Hydrographic length and number of sites in the initial sample are shown below. Of these, 120 Type F/S sites were evaluated and 61 were sampled. Two hundred twenty-eight Type Np sites were evaluated and 55 were sampled.

	Type F/S	Type Np
Hydrographic length (km)	25,714	49,089
Number of initial sites	25,669	49,317
Number of sites evaluated	120	228
Initial weighting	213.908	216.303
Number of sites sampled	61	55

Table 2. Percent of total Type F/S stream length within the target domain vs. percent of initial sample points, by waters' sub-type. This shows that, after sampling, proportions of the Type F sub-types were largely preserved.

Sub-type	Definition	% of target domain	% of sample
F1	fish habitat	85.3	81.3
F2	unmodeled; no DEM-to-stream match; field survey/former water type indicates fish use/habitat	4.3	7.7
F3	interior arc of Type F impoundment	1.7	2.2
F4	mapping anomaly such as irrigation canal; former water type indicated fish use/habitat	0.2	1.1
F5	diversion waters or former Type 2 waters	5.6	3.3
F7	model override; data indicate fish use/habitat upstream of modeled end-of-fish habitat	2.7	4.4

Source: Metadata, Washington State Water Course Hydrography and FPARS Water Type Data Dictionary

Table 3. Percent of total Type Np stream length within the target domain vs. percent of initial sample points, by waters' sub-type. This shows that, after sampling, proportions of the Type Np sub-types were largely preserved.

Sub-type	Definition	% of target domain	% of sample
N1	non-fish habitat; upstream of modeled fish habitat	54.4	53.9
N2	unmodeled; no DEM-to-stream match; field survey/former water type indicates non-fish use/habitat	18.2	19.3
N4	mapping anomaly such as irrigation canal; former water type indicated no fish use/habitat	0.1	0.4
N6	previously untyped water upstream of a modeled end point	26.4	25.4
N7	model override; data indicate end of fish use/habitat downstream of modeled end-of-fish habitat	0.8	0.9

Source: Metadata, Washington State Water Course Hydrography, and FPARS Water Type data Dictionary

Table 4. Counts and percentages of the evaluated Type F/S sites (*n* = 120) and the reasons for rejection or inclusion as GRTS-derived, randomly-selected temperature monitoring stations.

Reason code	No. of sites	% evaluated sample	Definition
NR	17	14.2	no response from landowner
OL	15	12.5	other lands (non-FPR, non-forest)
OW	10	8.3	other waters (non-Type F)
TN	10	8.3	target not sampled
TS	61	50.8	target sampled
UK	7	5.8	reason for rejection unknown
Total	120		

Table 5. Summary of reasons for rejection or inclusion of Type F/S sites (*n* = 120) by land ownership class. PUB = public lands; IND = industrial landowners; SFLO = small forest landowners. See **Table 4** for definition of reason codes.

Reason code	PUB	IND	SFLO
NR	0	0	17
OL	2	1	12
OW	0	3	7
TN	0	7	3
TS	0	51	10
UK	0	6	1
Sum	2	68	50
% of total sample	1.7	56.7	41.7
Success rate	0%	75%	20%

Table 6. Counts and percentages of the evaluated Type Np sites (*n* = 228) and the reasons for rejection or inclusion as GRTS-derived, randomly-selected temperature monitoring stations.

Reason code	No. of sites	% evaluated sample	Definition
LD	5	2.2	landowner declined
NR	3	1.3	no response from landowner
OL	13	5.7	other lands (non-FPR, non-forest)
OW	51	22.4	other waters (non-Type Np or no channel)
TN	91	39.9	target not sampled
TS	54	23.7	target sampled
UK	11	4.8	reason for rejection unknown
Total	228		

Table 7. Summary of reasons for rejection or inclusion of Type Np sites (*n* = 228) by land ownership class. PUB = public lands; IND = industrial landowners; SFLO = small forest landowners; MUN = municipal landowners. See **Table 6** for definition of reason codes.

Reason code	PUB	IND	SFLO	MUN	Note
LD	0	0	5	0	
NR	0	0	3	0	affects SFLO class
OL	8	4	1	0	
OW	4	31	14	2	affects all ownership classes
TN	1	82	7	1	
TS	0	51	2	1	
UK	0	7	2	2	
Sum	13	175	34	6	
% of total sample	5.7	76.8	14.9	2.6	
Success rate	0%	29%	6%	17%	

Table 8. Definitions of catchment-scale and reach-scale non-temperature variables used by the Extensive Riparian Status and Trends study.

Variable	Definition	Source	Metric
Catchment area	Modeled runoff area (ha) above downstream sampling point; Model: Hydrologic Modeling Extension, Spatial Analyst, ArcView 3.2	30 m DEM hydrography	as defined
Catchment slope	Modeled cell slope (%) of catchment surface above downstream sampling point; Model: Surface tool, Spatial Analyst, ArcView 3.2; extent is catchment area	30 m DEM hydrography	average
Elevation	Value of grid cell (m) at downstream sample point	30 m DEM	as defined
Distance to divide	Estimated horizontal distance (m) between sampled reach and drainage divide associated with the main channel head	30 m DEM	as defined
Bankfull width[5]	Horizontal distance (m) either between upper scour lines on opposite banks or tops of banks, perpendicular to flow	on site	mean[1]
Wetted width[5]	Horizontal distance (m) between points on opposite banks, perpendicular to flow, at which substrate particles are no longer surrounded by free water	on site	mean[1]
Mean depth[5]	Vertical distance (m) between substrate and stream surface, perpendicular to substrate	on site	mean[2]
Thalweg depth	Maximum wetted depth (m)	on site	mean[1]
Gradient	Gradient (%) measured between successive transects using a clinometer and flagged height pole	on site	mean[3]
Aspect	Direction (degrees) perpendicular to valley floor slope as determined by compass at downstream sample point	on site	as defined
Embeddedness, mid-channel	Degree of fine sediments (%) surrounding coarse sediments at the surface of a streambed	on site	mean[6]
Particle size	Quantification of the distribution of particle size (geometric mean (mm)) at the surface of a streambed	on site	mean[6]
Canopy closure	Number of quarter concave densiometer cells >50% center-shaded, as read at center of bankfull channel	on site	mean[4]
Riparian vegetation	Category of dominant riparian vegetation: CONIF= coniferous; DECID=deciduous; SHRUB=shrub; GRASS=grass; BURNED=recent fire	on site	category
Large woody debris[5]	Number of dead, non-self-supporting pieces of wood >10 cm diameter and >2 m length, intersecting the bankfull zone; DOWN=modifying flow at bankfull; SUSPENDED=above flow at bankfull; JAM=10+ grouped, touching, pieces of qualifying wood	on site	count/100 m

[1] 6 transects, 1 measurement each
[2] 6 transects, 5 equally spaced measurements per transect: left bank, left center, center, right center, right bank
[3] 5 sub-reaches, 1 measurement each
[4] 6 transects, 4 readings per transect: left bank, right bank, upstream, downstream; corrected to percent
[5] adapted from Schuett-Hames *et al.* 1999a, 1999b
[6] 6 transects, 11 equally spaced estimates per transect, left bank to right bank

Table 9. Estimated mean, 25%-tile, median, and 75%-tile cumulative distribution function (CDF) values for Type F/S temperature metrics as calculated using the R package *spsurvey*.

Year	Matrix	Metric	n	Mean	Minimum	25%-tile (CDF)	Median (CDF)	75%-tile (CDF)	Maximum
2009	Air	Air Tmax	60	28.4	18.5	23.7	28.3	32.5	40.8
		Air 7Tmax	60	25.3	16.6	21.1	25.1	29.0	35.1
	Water	Upstream Tmax	60	18.6	12.4	15.7	18.5	20.0	28.1
		Upstream 7Tmax	60	17.7	11.8	15.0	17.7	19.1	26.9
		Downstream Tmax	55	19.0	12.6	16.0	18.7	20.4	27.6
		Downtream 7Tmax	55	18.0	12.1	15.4	18.1	19.5	26.4
		D_Tmax	54	0.3	-4.6	-0.2	0.1	0.5	7.4
		D_7Tmax	54	0.2	-4.3	-0.2	0.1	0.4	6.6

Table 10. Estimated mean, 25%-tile, median, and 75%-tile cumulative distribution function (CDF) values for Type Np temperature metrics as calculated using the R package *spsurvey*.

Year	Matrix	Metric	n	Mean	Minimum	25%-tile (CDF)	Median (CDF)	75%-tile (CDF)	Maximum
2009	Air	Air Tmax	51	26.5	15.2	22.8	26.2	28.6	41.2
		Air 7Tmax	51	24.2	14.8	20.3	23.9	27.0	35.3
	Water	Upstream Tmax	49	14.9	7.8	12.6	14.8	16.4	24.4
		Upstream 7Tmax	49	14.1	7.2	12.1	14.1	15.6	23.4
		Downstream Tmax	50	16.0	9.7	14.0	16.2	17.3	25.0
		Downstream 7Tmax	50	15.2	8.6	13.2	15.2	16.5	23.7
		D_Tmax	47	1.2	-4.3	-0.6	0.8	2.5	7.0
		D_7Tmax	47	1.1	-4.9	-0.2	0.8	2.3	5.8

Table 11. Summary of Pearson correlations (r), uncorrected p-values, and number of observations (n) between temperature metrics and habitat variables in Type F/S and Type Np streams. Correlations in **bold** print indicate P ≤0.05.

		All sites		Type F/S		Type Np	
		Tmax	7Tmax	Tmax	7Tmax	Tmax	7Tmax
Upstream Tmax	r	**0.889**	**0.884**	**0.949**	**0.934**	**0.757**	**0.728**
	p-value	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**
	n	**109**	**109**	**60**	**60**	**49**	**49**
Air Tmax 2009	r	**0.572**	**0.598**	**0.704**	**0.739**	**0.359**	**0.394**
	p-value	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	**0.010**	**0.004**
	n	**111**	**111**	**60**	**60**	**51**	**51**
Canopy closure	r	**-0.418**	**-0.433**	**-0.522**	**-0.545**	-0.194	-0.210
	p-value	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	0.168	0.135
	n	**113**	**113**	**61**	**61**	52	52
Mean depth	r	**0.404**	**0.425**	**0.645**	**0.649**	**-0.320**	**-0.293**
	p-value	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	**0.021**	**0.035**
	n	**112**	**112**	**60**	**60**	**52**	**52**
Thalweg depth	r	**0.420**	**0.442**	**0.649**	**0.657**	-0.249	-0.218
	p-value	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	0.075	0.121
	n	**112**	**112**	**60**	**60**	52	52
Wetted width	r	**0.510**	**0.534**	**0.672**	**0.686**	0.047	0.089
	p-value	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	0.739	0.532
	n	**112**	**112**	**60**	**60**	52	52
Bankfull width	r	**0.535**	**0.552**	**0.667**	**0.685**	0.132	0.156
	p-value	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	0.352	0.270
	n	**112**	**112**	**60**	**60**	52	52
Width:depth	r	0.172	0.169	0.147	0.169	**0.323**	**0.319**
	p-value	0.070	0.075	0.261	0.198	**0.020**	**0.021**
	n	112	112	60	60	**52**	**52**
Gradient	r	**-0.371**	**-0.372**	**-0.432**	**-0.418**	0.200	0.190
	p-value	**<0.0001**	**<0.0001**	**0.001**	**0.001**	0.154	0.178
	n	**113**	**113**	**61**	**61**	52	52
Total LWD	r	**-0.440**	**-0.454**	**-0.471**	**-0.497**	-0.218	-0.248
	p-value	**<0.0001**	**<0.0001**	**0.000**	**<0.0001**	0.120	0.076
	n	**113**	**113**	**61**	**61**	52	52
Elevation	r	-0.083	-0.037	-0.061	0.003	0.090	0.149
	p-value	0.385	0.698	0.638	0.982	0.527	0.293
	n	113	113	61	61	52	52
Catchment area	r	**0.541**	**0.570**	**0.668**	**0.690**	0.088	0.158
	p-value	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	0.535	0.262
	n	**113**	**113**	**61**	**61**	52	52
Distance to divide	r	**0.579**	**0.603**	**0.713**	**0.726**	0.162	0.216
	p-value	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	0.250	0.124
	n	**113**	**113**	**61**	**61**	52	52
Catchment slope	r	**-0.339**	**-0.329**	**-0.431**	**-0.398**	0.054	0.081
	p-value	**0.000**	**0.000**	**0.001**	**0.002**	0.702	0.568
	n	**113**	**113**	**61**	**61**	52	52

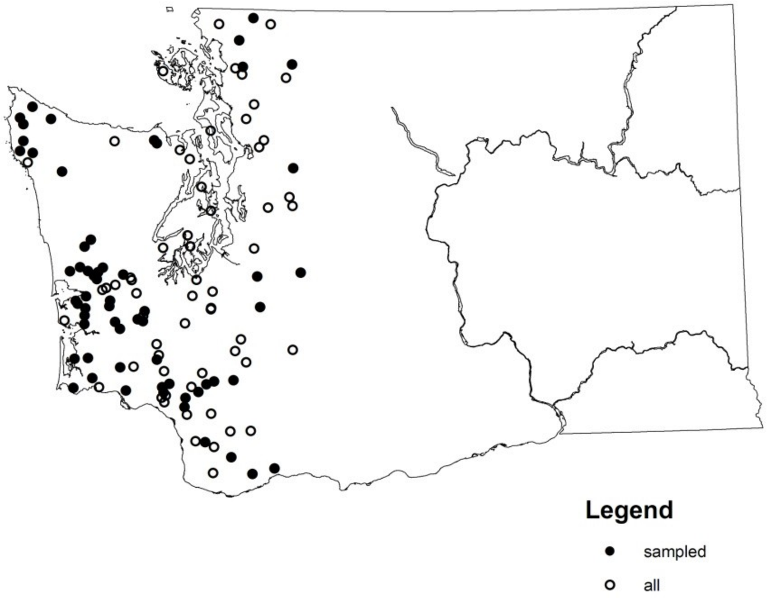
Table 12. Case-wise consideration of how assumptions can influence scope of inference (km of stream) using data from Type F/S streams. IND = industrial landowners; SFLO = small forest landowners.

Properties	Case 1	Case 2	Case 3	Case 4
Sample frame	25669 km	25669 km	25669 km	25669 km
Conditions	all sites are target	mix of target and non-target	mix of target and non-target	mix of target and non-target
	no loss of sites	loss of sites completely at random	loss of sites completely at random	differential loss of sites
	no ownership strata	no ownership strata	no ownership strata	strata by ownership
		if non-target = 10 sites in sample, then reduction in sample frame:	if target = 71 sites in sample, then estimated target of indeterminate sites: 71/96*24 = 17.8 estimated target: 71 + 17.8 = 88.8	estimated target using similar calculation IND + SFLO: 83.9
Inference scope		10/120 * 25669	88.75/120 * 25669	83.9/120 * 25669
	25669 km	23529.9 km	18984.4 km	17952.3 km
	100% of original sample frame	91.7% of original sample frame	73% of original sample frame	69.9% of original sample frame
Percent of estimated target population on which inference is based, if sample = 61 sites:			61/71*18984.4 = 16310.5 km, or ~86%	

Table 13. Case-wise consideration of how assumptions can influence scope of inference (km of stream) using data from Type Np streams. IND = industrial landowners; SFLO = small forest landowners.

Properties	Case 1	Case 2	Case 3	Case 4
Sample frame	49317 km	49317 km	49317 km	49317 km
Conditions	all sites are target	mix of target and non-target	mix of target and non-target	mix of target and non-target
	no loss of sites	loss of sites completely at random	loss of sites completely at random	differential loss of sites
	no ownership strata	no ownership strata	no ownership strata	strata by ownership
		if non-target = 51 sites in sample, then reduction in sample frame:	if target = 145 sites in sample, then estimated target of indeterminate sites: 145/209*19 = 13.1 estimated target: 145 + 13.1 = 158.2	estimated target using similar calculation for IND + SFLO: 155.3
Inference scope		51/228 * 49317	158.2/228 * 49317	155.3/228 * 49317
	49317 km	38285.6 km	34215.1 km	33581 km
	100% of original sample frame	77.6% of original sample frame	69.4% of original sample frame	68.1% of original sample frame
Percent of estimated target population on which inference is based, if sample = 54 sites:			54/145*34215.1 = 12742.2 km, or ~37%	

a) Type F/S



b) Type Np

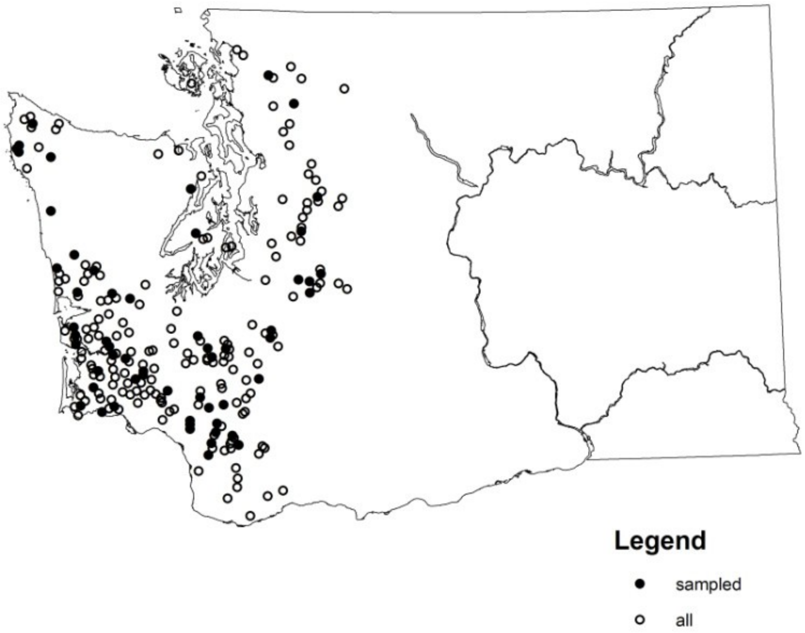


Figure 1. Map of a) Type F/S sites and b) Type Np sites that were sampled (shaded) or rejected (unshaded). Of the Type F/S sites, 61 sites were sampled and 59 rejected. Of the Type Np sites, 54 sites were sampled and 174 rejected.

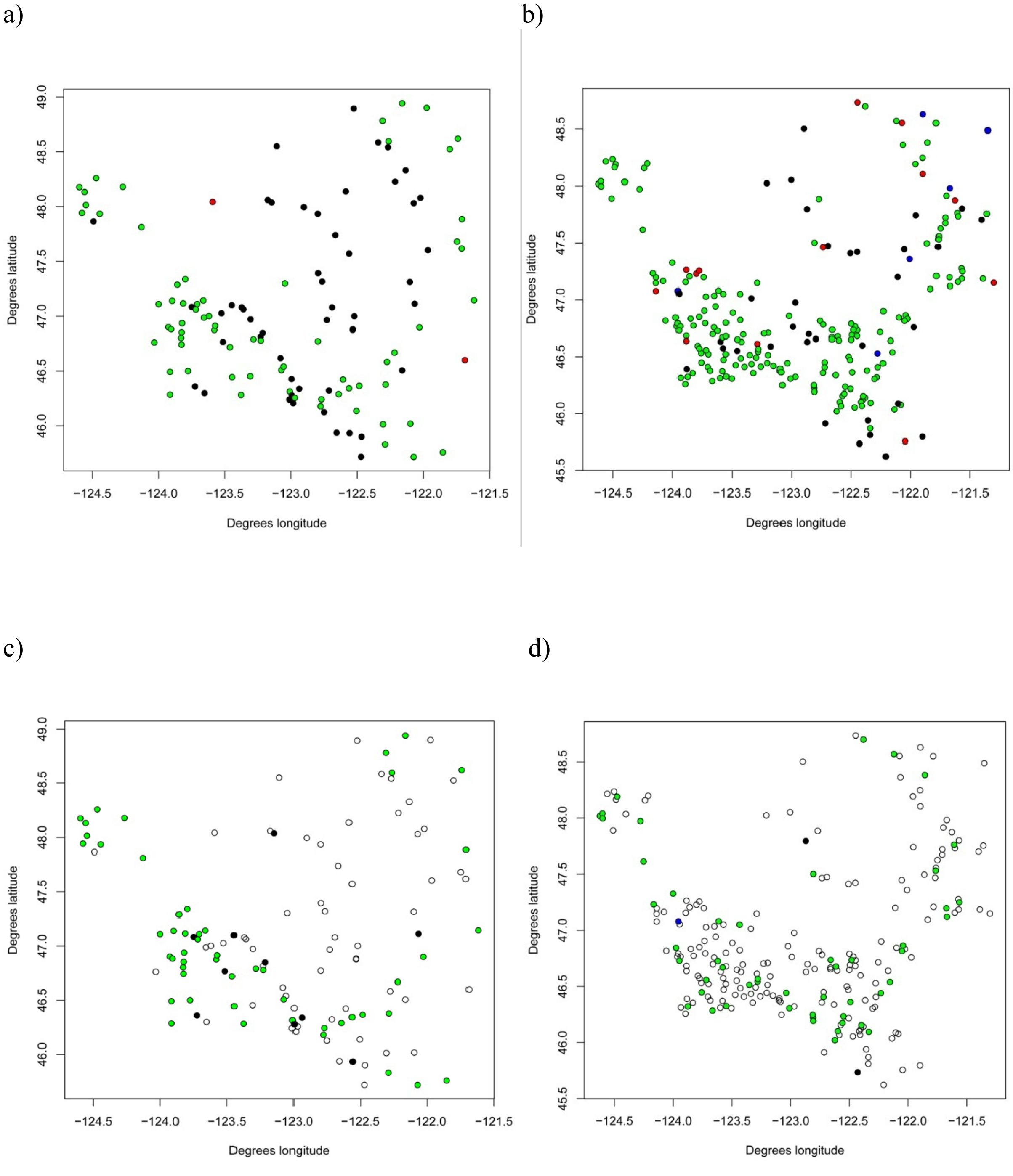


Figure 2. The upper two plots show the sites evaluated for a) Type F/S and b) Type Np by landowner class (green = industrial landowners, black = small forest landowners, red = public lands, and blue = municipal landowners). Plots c) and d) mirror plots a) and b), except that shaded circles are sites that were sampled and unshaded circles are sites that were not sampled.

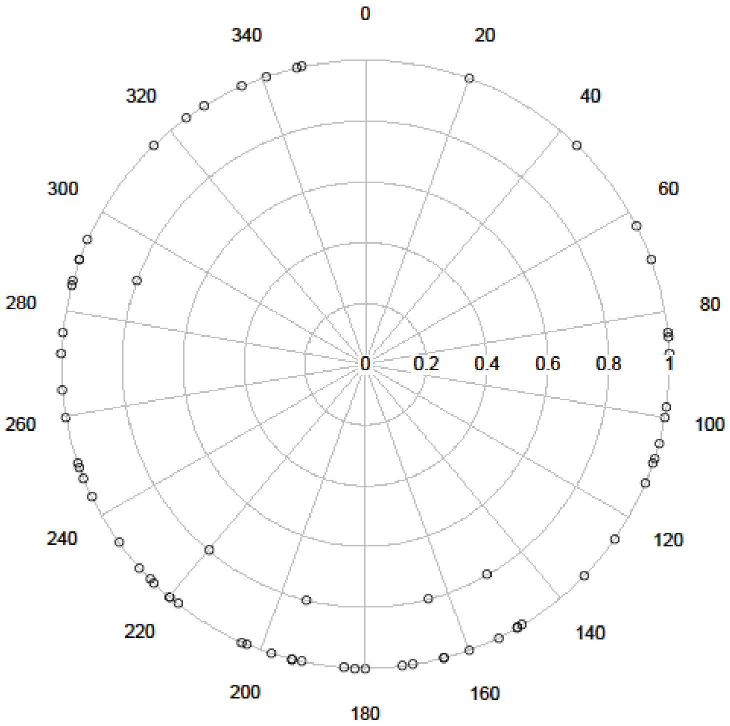


Figure 3. Reach aspect (in degrees) at Type F/S temperature monitoring stations. Each unique aspect value is represented by a point plotted at radial distance = 1. Cases in which a given aspect was common to more than one study reach are represented by points plotted at radial distance = 0.8.

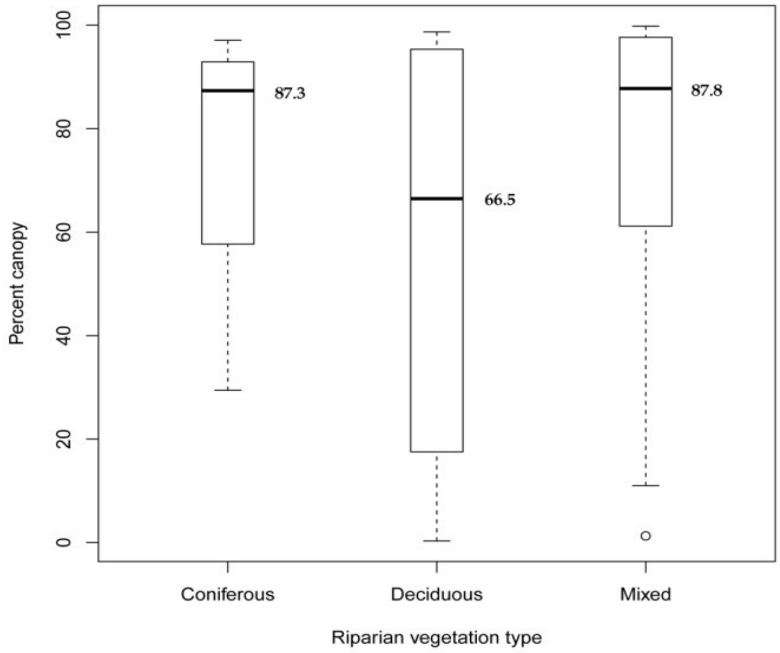


Figure 4. Percent riparian canopy closure by category of riparian vegetation encountered along Type F/S study reaches at temperature monitoring stations. Box plots show medians, quartiles, extremes, and outliers. Samples sizes were 4, 22, and 35 for coniferous, deciduous, and mixed vegetation types, respectively.

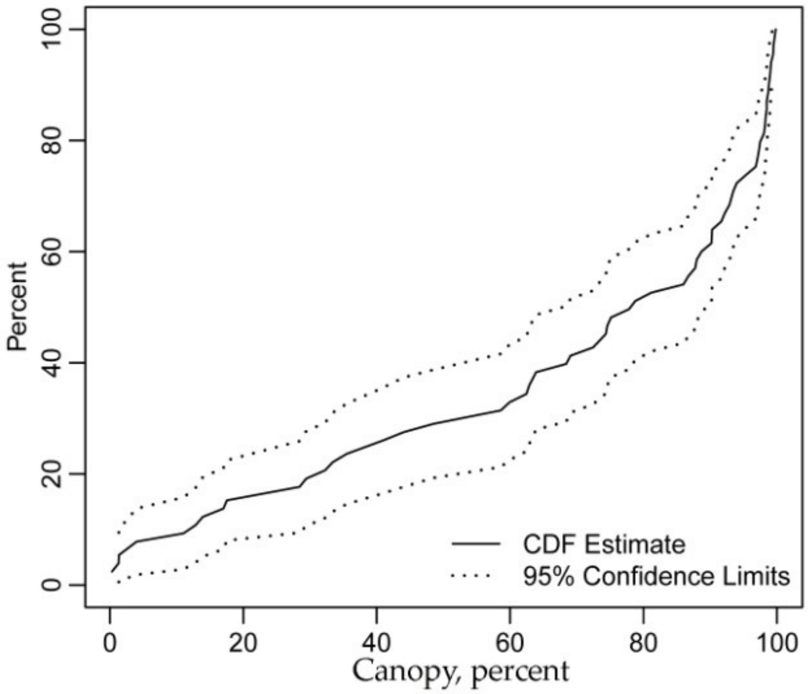


Figure 5. Cumulative distribution function (CDF) and 95% confidence limits for riparian canopy closure measured along Type F/S study reaches at temperature monitoring stations.

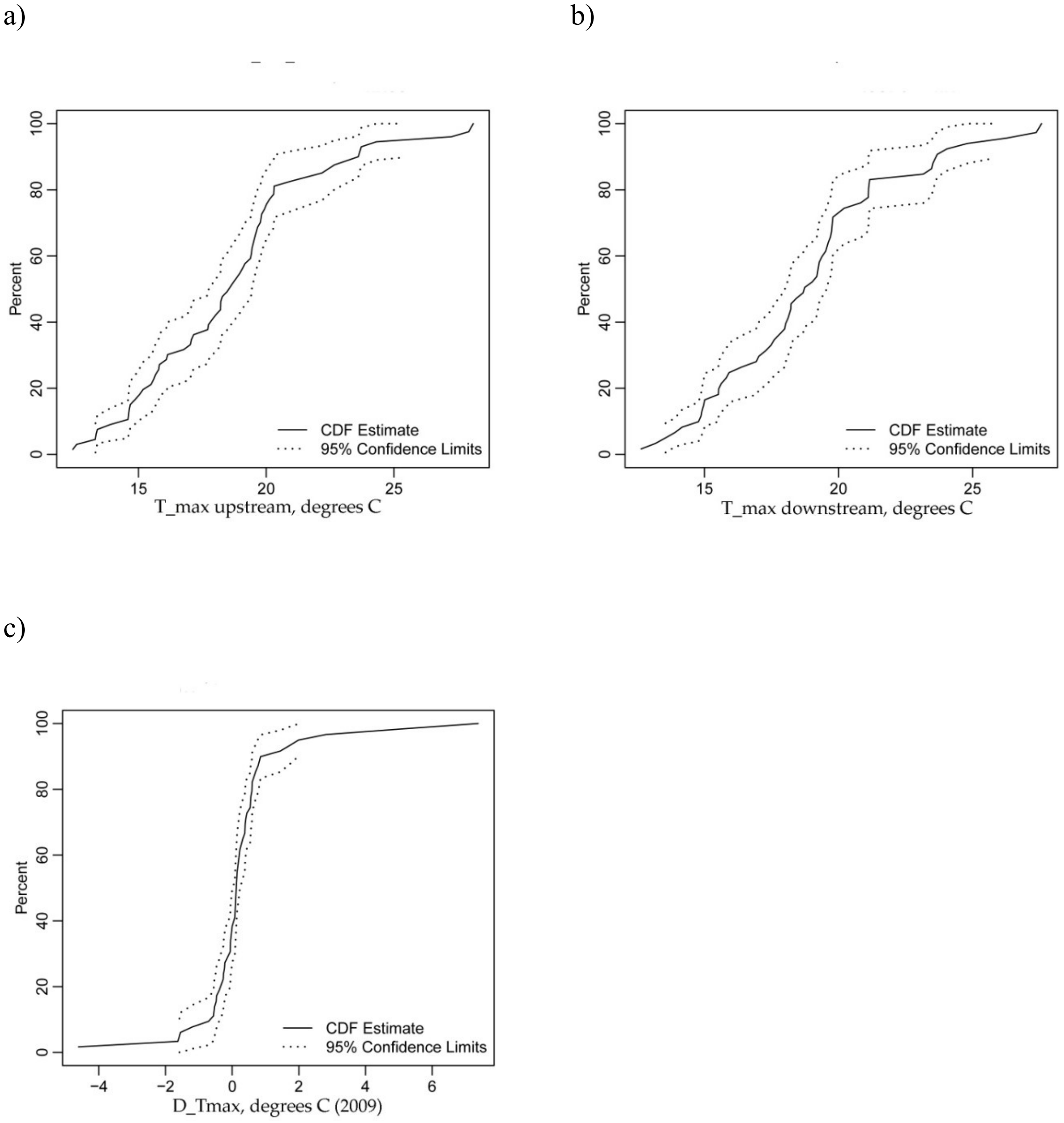


Figure 6. Cumulative distribution function (CDF) and 95% confidence limits for stream temperature metrics from the Type F/S temperature monitoring stations. Panel a) shows maximum summer temperature at the upstream end of the study reaches, panel b) shows maximum summer temperature at the downstream end of the study reaches, and panel c) shows differences (by site) between upstream and downstream maximum summer temperatures.

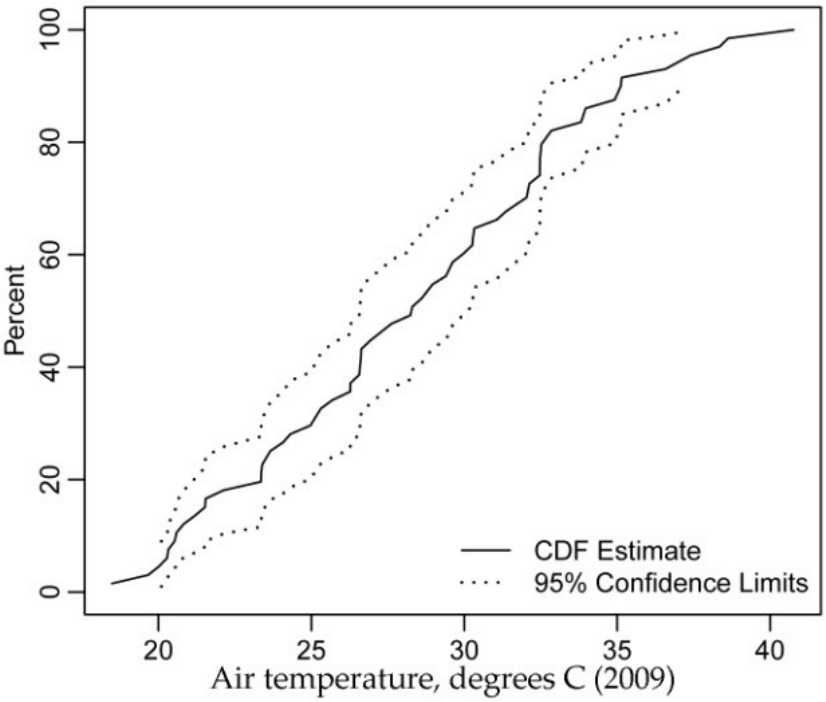


Figure 7. Cumulative distribution function (CDF) and 95% confidence limits for 2009 maximum summer air temperatures from the Type F/S sites (*n* = 60).

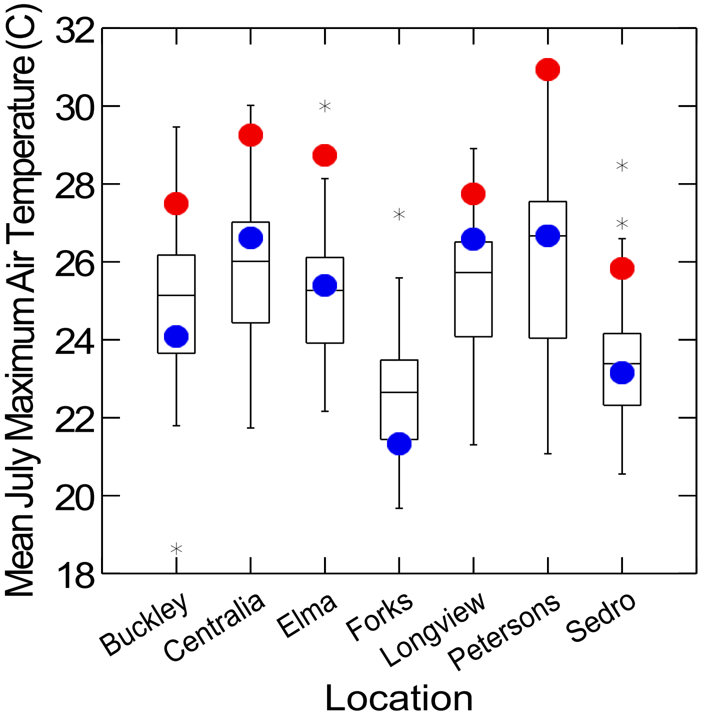


Figure 8. Distribution of mean daily maximum July air temperature values from 1958-2009 for seven locations in western Washington. Dots indicate mean daily maximum air temperatures for July 2008 (blue) and July 2009 (red) for these locations. July 2009 was warmer than July 2008, exceeding the seventy-fifth percentile of the historic record for the six stations with available 2009 data.

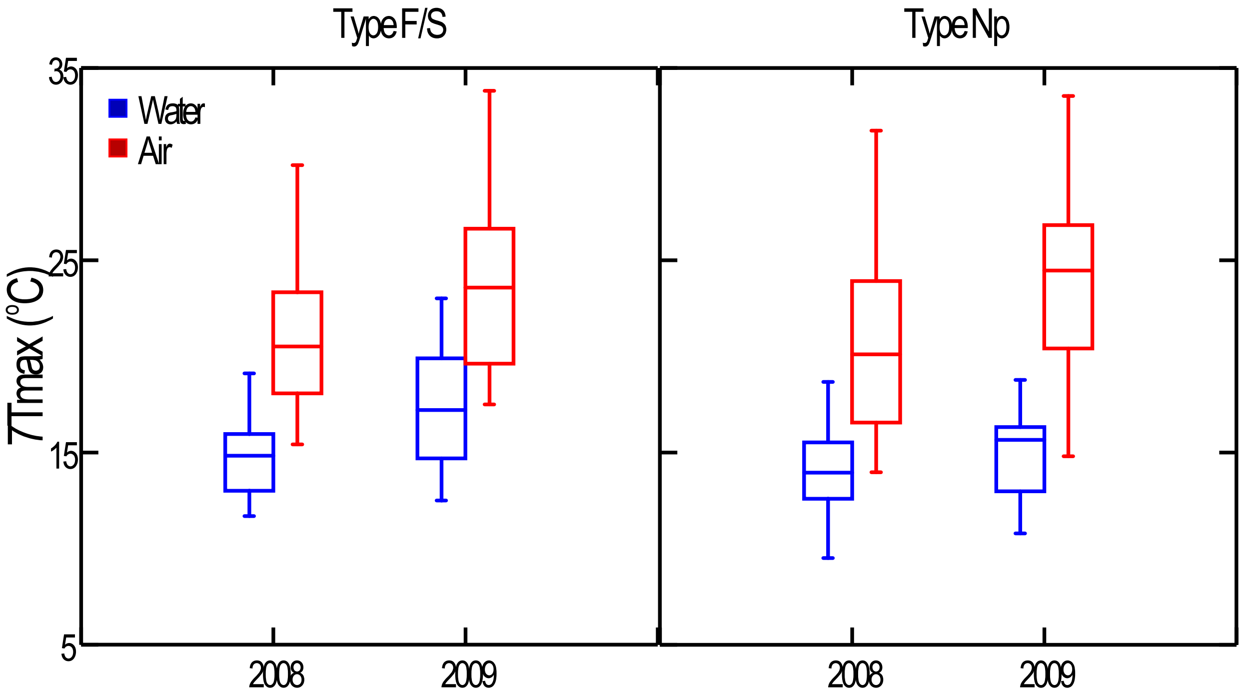


Figure 9. Seven-day average of daily maximum summer stream and air temperatures in Type F/S and Type Np streams sampled in both 2008 and 2009.

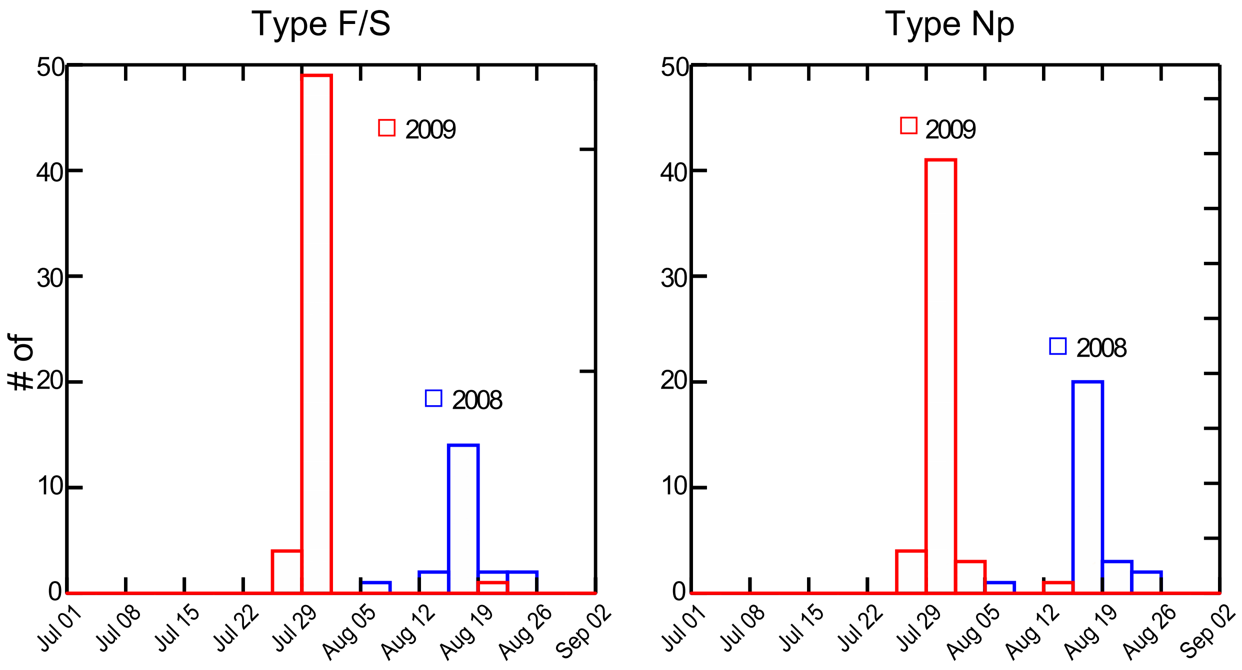


Figure 10. Date of maximum summer stream temperatures in 2008 (blue) and 2009 (red).

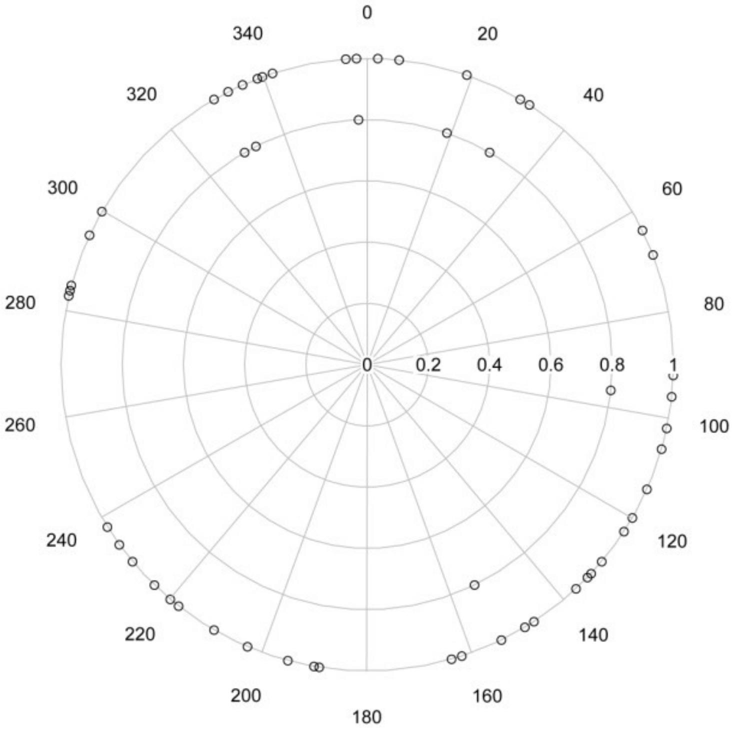


Figure 11. Reach aspect (in degrees) at Type Np temperature monitoring stations. Each unique aspect value is represented by a point plotted at radial distance = 1. Cases in which a given aspect was common to more than one study reach are represented by points plotted at radial distance = 0.8.

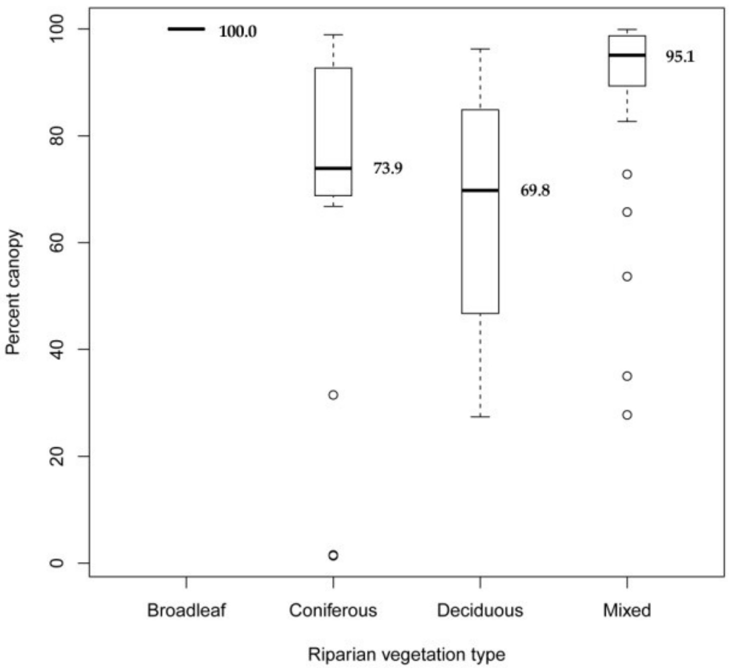


Figure 12. Percent riparian canopy closure by category of riparian vegetation encountered along Type Np study reaches at temperature monitoring stations. Box plots show medians, quartiles, extremes, and outliers. Samples sizes were 1, 15, 4, and 35 for broadleaf, coniferous, deciduous, and mixed vegetation types, respectively.

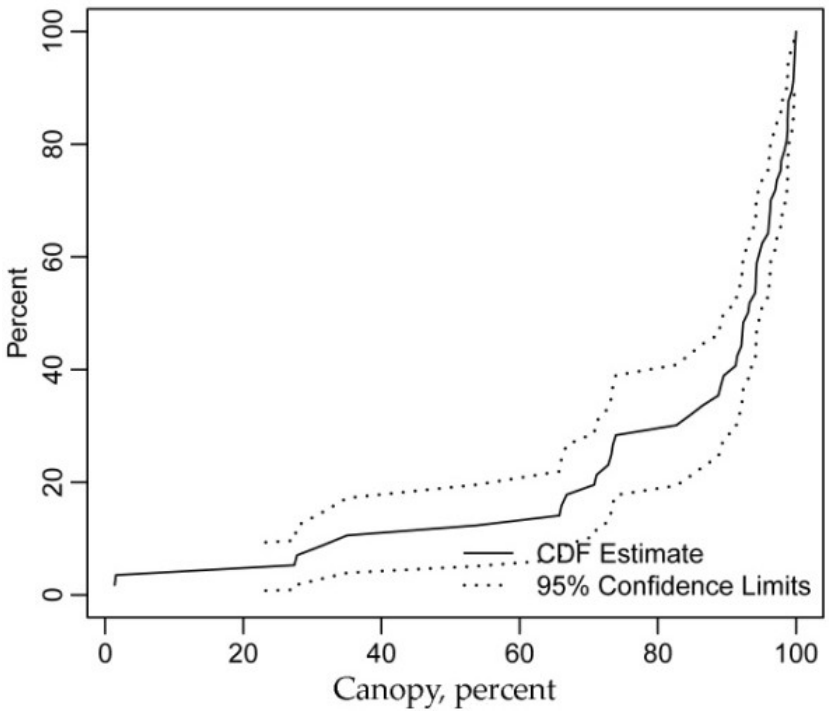


Figure 13. Cumulative distribution function (CDF) and 95% confidence limits for riparian canopy closure measured along Type Np study reaches at temperature monitoring stations.

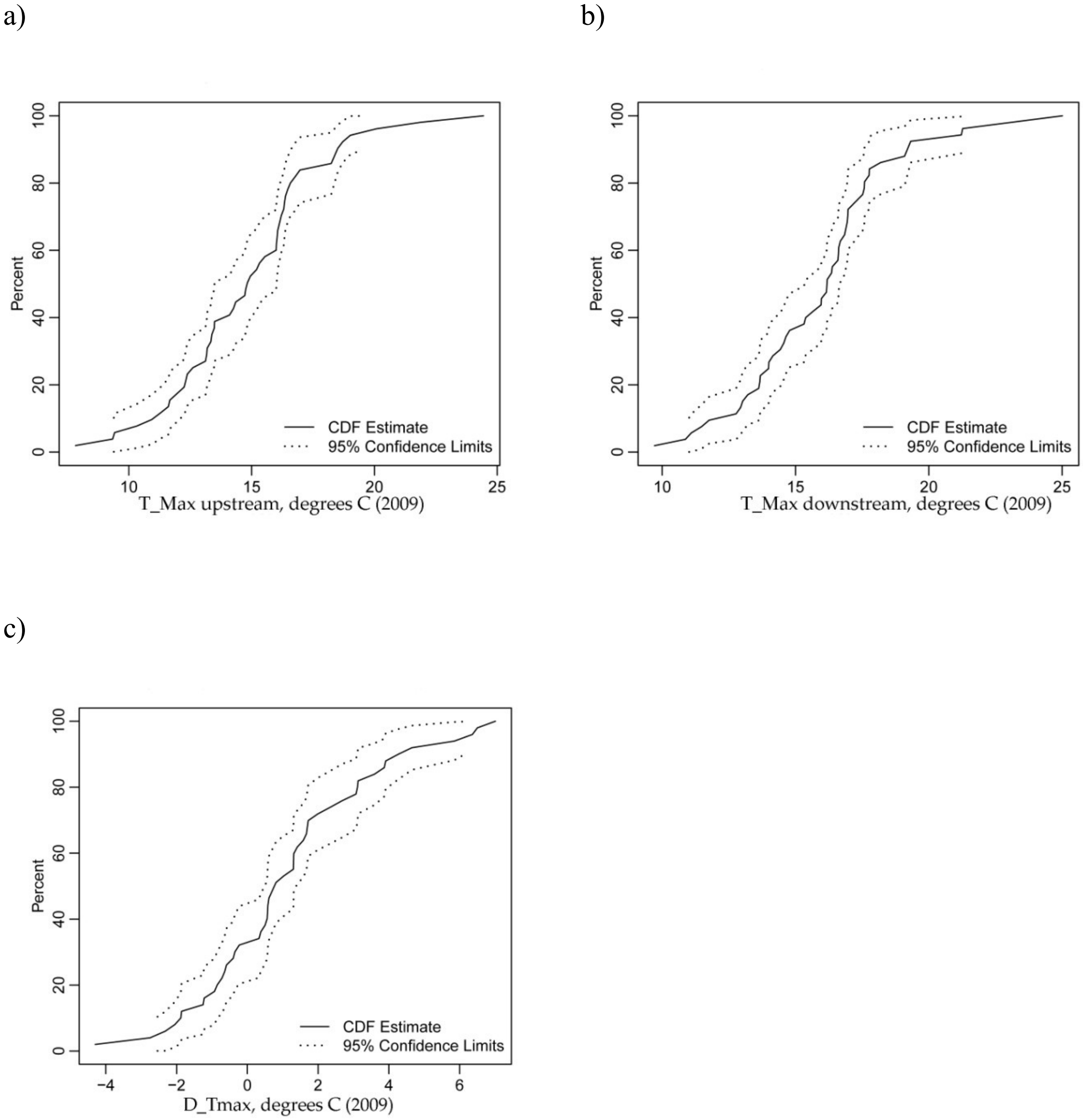


Figure 14. Cumulative distribution function (CDF) and 95% confidence limits for stream temperature metrics from the Type Np temperature monitoring stations. Panel a) shows maximum summer temperature at the upstream end of the study reaches, panel b) shows maximum summer temperature at the downstream end of the study reaches, and panel c) shows differences (by site) between upstream and downstream maximum summer temperatures.

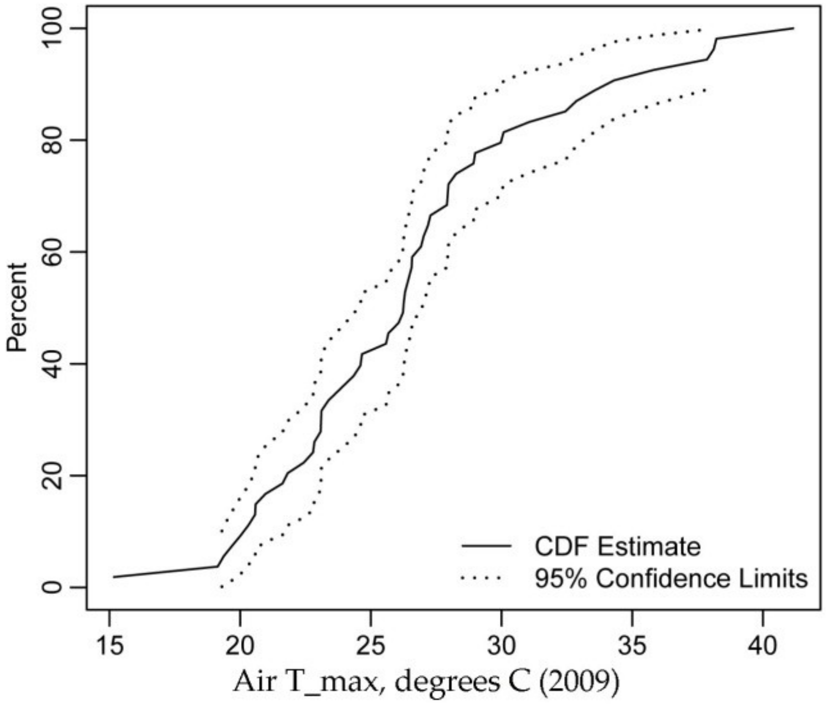


Figure 15. Cumulative distribution function (CDF) and 95% confidence limits for 2009 maximum summer air temperatures from the Type Np sites (*n* = 51).

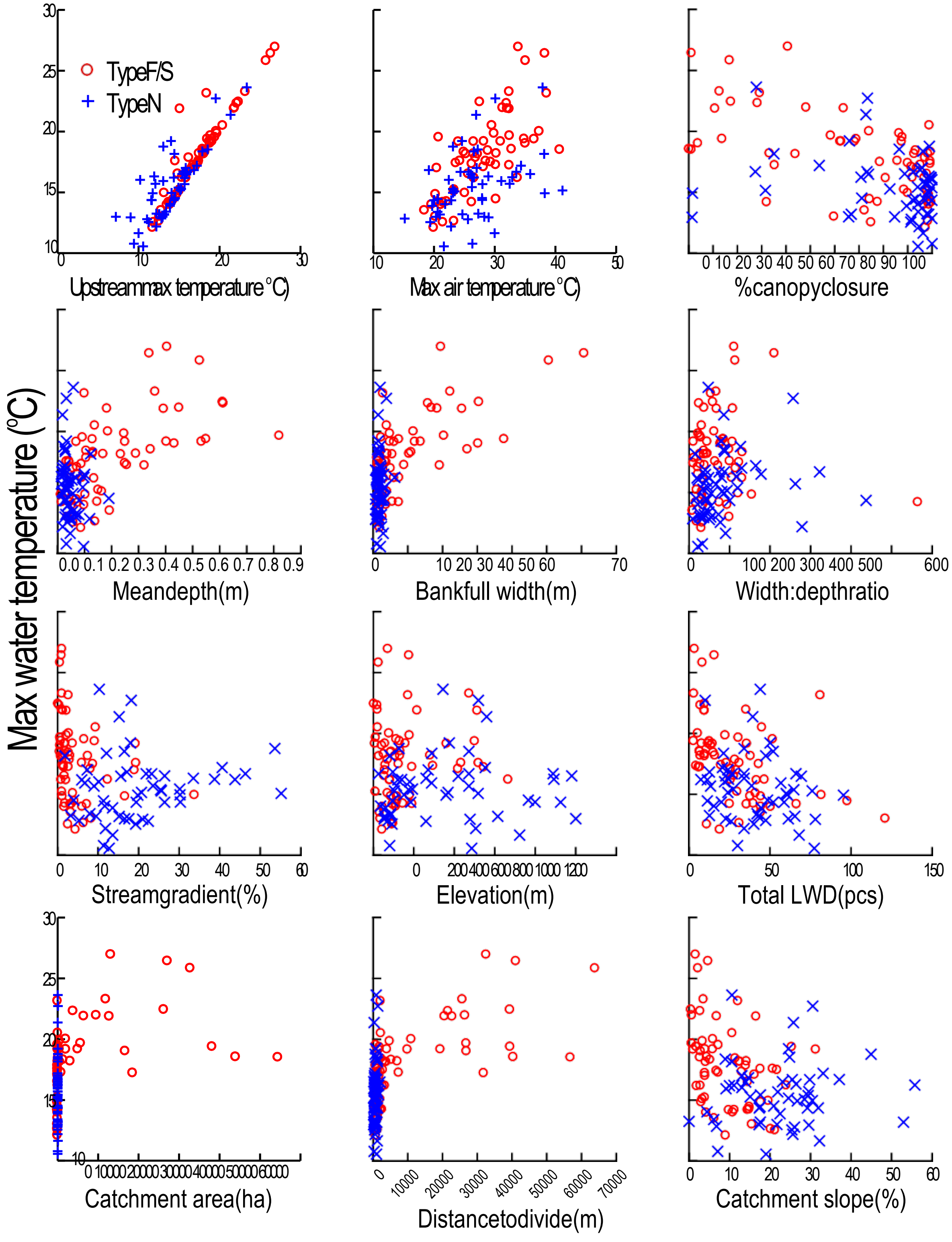


Figure 16. Scatterplots of maximum downstream water temperature versus upstream water temperature, air temperature, and habitat variables for Type F/S and Type Np streams.

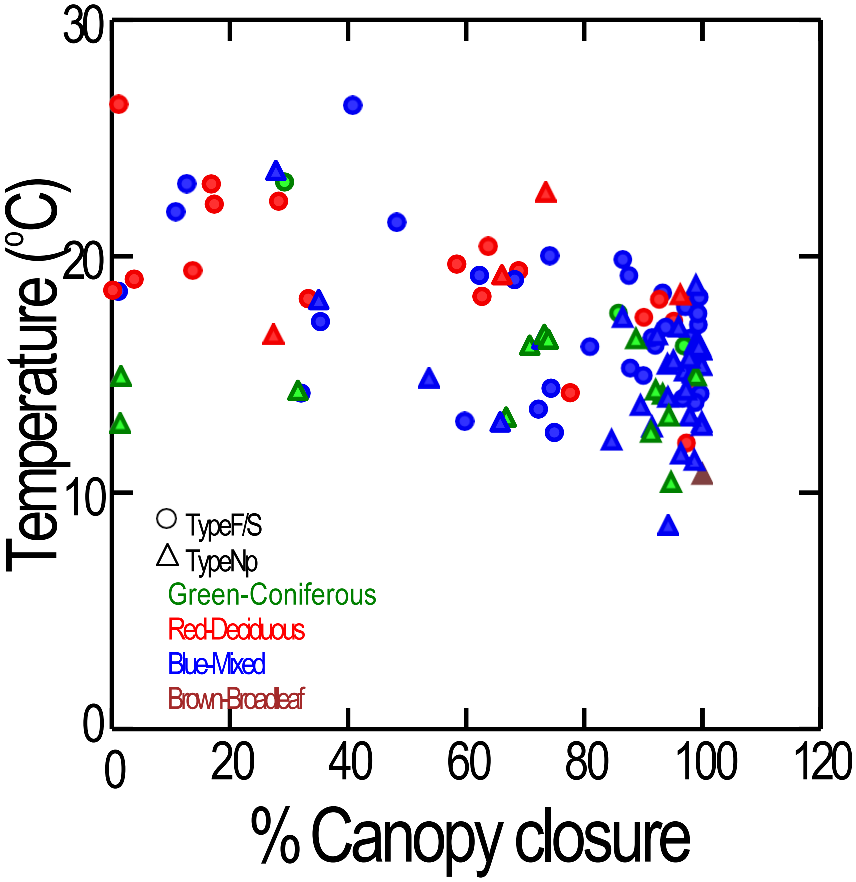


Figure 17. Seven-day average maximum stream temperature versus canopy closure for the 2009 sampling year.

Appendix A. ERST timeline and modules.

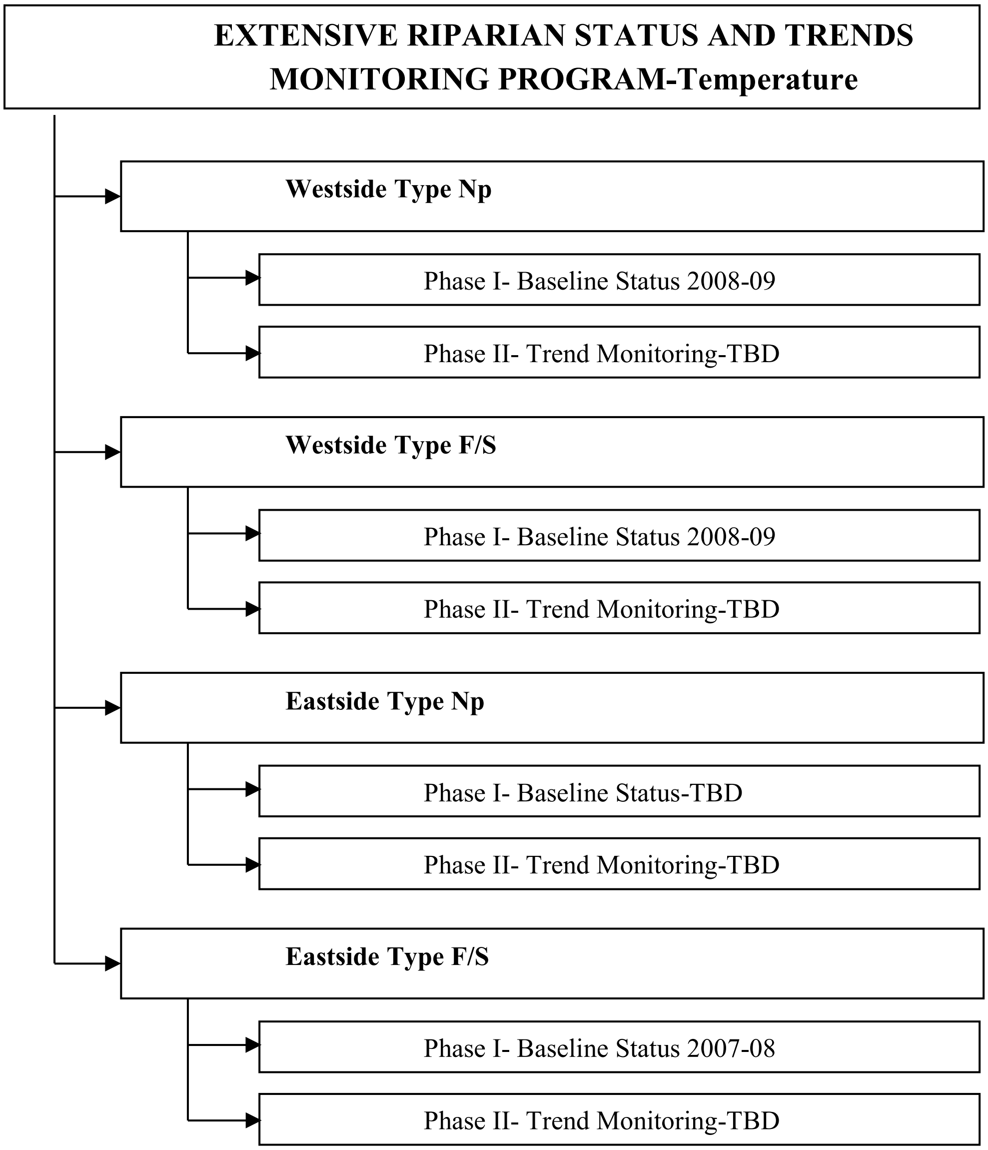


Figure A-1. Project implementation schedule. Data collection for the Westside Type F/S and Type Np Extensive Riparian Status and Trends monitoring program began in spring 2008 and was completed in spring 2010. The Eastside Type Np project is not scheduled at this time. Phase II monitoring implementation has not yet begun. Water types: F = fish-bearing, S = shorelines, Np = non-fish-bearing perennial (from Ehinger *et al.* 2007).

Appendix B. Survey design and sampling frame construction.

The Generalized Random Tessellation Stratified (GRTS) probability sampling design developed by the U.S. Environmental Protection Agency for the Environmental Mapping and Assessment Program (EMAP; see https://archive.epa.gov/emap/archive-emap/web/html/index.html) treats variability as intrinsic to natural resource indicators. Rather than attempt to remove or control for this variability, GRTS reports proportions of the resource, relative to the range of variability observed, as cumulative distribution function (CDFs). This means GRTS is not constrained by a need for experimental controls. Instead, a single application of GRTS describes the resource, as currently known, with associated confidence bands. Trends in resource condition follow from subsequent implementations of GRTS, as change between successive CDFs. As would be anticipated, GRTS easily adjusts to evaluating inter-annual variation through repeated monitoring at fixed sub-sets of sites.

Probability samples have the following distinct features:

- Each member of a target population has an inclusion probability > 0 (Stevens and Jensen 2007).
- Randomization allows statistically valid inferences from samples to populations (Overton *et al.* 1990; Diaz-Ramos *et al.* 1996).
- Inference to population results from design rather than statistical model (e.g., Smith 1976; Hansen *et al.* 1983).
- Apply to any point (i.e., discreet), linear, or areal (i.e., extensive) natural resource at a range of spatial scales (Diaz-Ramos *et al.* 1996).
- Translate population definition into a population frame.
- Estimate status, trend, or change in selected indicator with known confidence (Overton *et al.* 1990; Stevens 1994).
- Estimates are free from selection bias, if implemented as designed (e.g., Stevens and Jensen 2007).
- Theoretical justification for estimates is well-established by the Horvitz-Thompson Theorem (Horvitz and Thompson 1952).
- Very specific regarding what and where to sample and how to analyze the data (i.e., probability structures of sampling and analysis must match (Diaz-Ramos *et al* 1996).

Probability samples, implemented as designed, are representative of target populations, free of sampling bias, and useful for describing status and trends of resources at various spatial scales. These strengths are realized with sequential implementations of GRTS, which, if successful, offers additional advantages:

- Effectively increase sample size and trend detection power.
- More precise estimates than equally-sized simple random sample—i.e., incorporates target population spatial structure (i.e., spatial balancing; Stevens and Jensen 2007).

- Alternative to modeling for scaling stream temperature to landscapes.
- Inform need of states to periodically report status of impaired surface waters (EPA 2010).
- Analyses adaptable from equi-probability to variable probability after sampling is complete. Loss of a sampling site, common to natural resource studies, may thus be overcome[8].
- Spatial density pattern of sample matched to that of the resource (i.e., reverse hierarchical ordering; Stevens and Olsen 2001).

Conversely, there are tradeoffs. Population frame and sampling frame (**Figure B-1**) definitions must be sufficiently rigorous to minimize bias or contamination of estimates. That is, inclusion probabilities for undetected elements of a target population are zero. Also, sampling effort rises geometrically with increasing study complexity—a consideration even without stratification as random selection from the target population does not guarantee normal distributions of other associated variables. And, notably, what resulting data such as stream temperature represent must be considered, as do sample size and evaluation methods for sufficient precision and confidence in the resource estimate to match study objectives. Lastly, data must be analyzed with R[9].

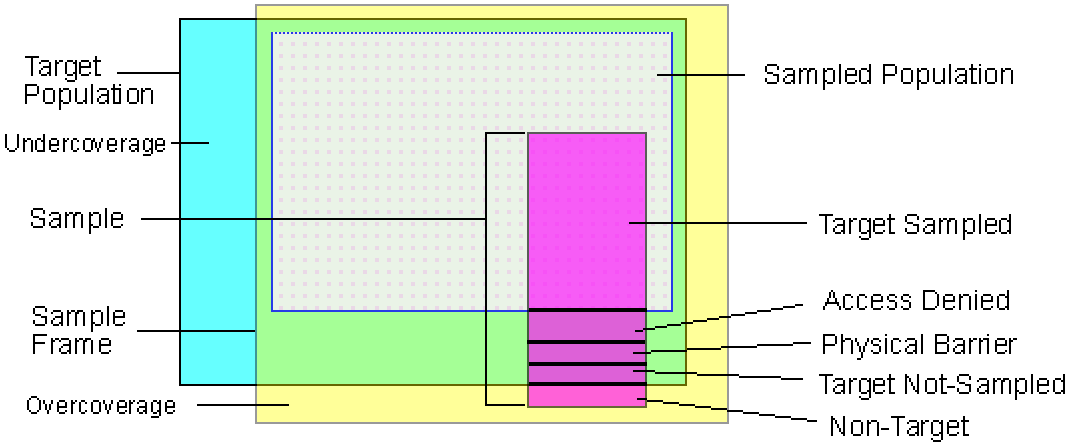


Figure B-1. Generalized GRTS sampling frame construction showing relationship of the target population to frame and sampling imperfections[10].

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[8] Non-target sites in a GRTS sample can be replaced by evaluating the next site in the sequence (assuming a sufficient oversample) until base sample size is achieved. Random spatial dispersion is thus maintained. However site replacement must be sufficiently described to a) correctly adjust survey design weights, b) account for any resulting selection stratification, and c) account for any resulting unequal probability of selection. Inaccuracies will affect computation of estimates of characteristics for target populations.

[9] www.r-project.org

[10] http://www.epa.gov/nheerl/arm/designpages/monitdesign/targetpopframe.htm

GRTS assumptions[11] include:

- Estimates from sampled sites apply to sampled population with no additional assumptions.
- Estimates from sampled population apply to remainder of target population within sample frame only if candidate sites are skipped independent of site characteristics (missing completely at random).
- Remainder of target population outside sample frame of same characteristics as sampled population.

Under these conditions, initial design weights need no adjustment unless base sample size and design sample size differ.

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Hansen, M.H., W.G. Madow, and B.J. Tepping. 1983. An evaluation of model-dependent and probability sampling inferences in sample surveys. *Journal of the American Statistical Association* 78:776-760.

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Stevens, D.L., Jr. and A.R. Olsen. 2001. Spatially-balanced sampling of natural resources in the presence of frame imperfections. Joint Statistical Meetings, Atlanta, GA, USA.

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[11] Aquatic Resources Monitoring, U.S. EPA, accessed 09 August 2011 http://www.epa.gov/nheerl/arm/analysispages/analysisadjwts.htm

Stevens, D.L., Jr. and S.F. Jensen. 2007. Sample design, execution, and analysis for wetland assessment. *Wetlands* 27:515-523.

Appendix C. ERST archive content.

Location: Washington Dept. of Ecology, Olympia, WA

Recipient: Environmental Assessment Program

Retention: compliance with agency policies

Archive content. =Includes available meta-data.

Category	Description	Format	Author
GRTS sample draw			
	design	.pdf	EPA
	WA hydrography, 24k	.shp	DNR
	statewide master sample	.shp	EPA
Evaluated sample			
	CMER/ FFR lands, West	.shp	mixed
	WA east-west divide	.shp	DNR
	Site list	spreadsheet	mixed
	Site evaluation orthos	.pdf	mixed
	Site validation forms	spreadsheet	mixed
	Type F/S (*n* = 120) and Type Np (*n* =228)	.shp	ECY
	Scanned data sheets, per site	.pdf	ECY
Analysis and Results			
	all raw data, temperature, 2008-2009	.mdb	ECY
	all raw data, other variables, 2008-2009	.mdb	ECY
	metric calculations	spreadsheet	ECY
	results summary	.csv, .pdf	ECY
Misc			
	method development	varies	mixed

Appendix D. Catchment characteristics and habitat variables.

Table D-1. Estimated 25%, 50%, 75%, and 95% cumulative distribution function (CDF) values for Type F/S catchment-scale characteristics and habitat variables as calculated using the R package *spsurvey*, where *n* = number of cases associated with a given percentile of the CDF. Means (se) are also reported.

Variable	n	Mean (se)	Minimum	25%-tile	Median	75%-tile	95%-tile	Maximum
Catchment area, ha	61	5970	9.5	67	193	5212	34279	54491
Elevation, m	61	149.5	5	49	94	178	511	668
Catchment slope, %	61	9.3	0.6	3.4	6.9	14.3	21.6	31.4
Canopy closure, %	61	68	1.3	39	78	97	99	99.1
Bankfull width, m	60	10.5	1.2	2.4	4.9	15.4	30.5	60.9
Gradient, %	61	4.6	0.2	1.2	2.3	5.8	18.2	33.9
Thalweg depth, m	60	0.4	0.0	0.2	0.3	0.6	1.0	1.5
Wetted width, m	60	7.5	0.2	1.6	3.0	9.1	25.6	44.4
Mean depth, m	60	0.2	0.0	0.1	0.1	0.3	0.6	0.8
Embeddedness, %	60	45.5	2.2	32.6	40.2	57.5	83.5	96.9
Particle size, mm, geometric mean	60	22.3	0.2	1.7	6.4	30.9	83.7	100.3
Distance to divide, m	61	11493	513	1458	2622	20910	40266	63975
LWD, down	61	20.3	1.6	7.3	15.4	29.4	46.6	76.7
LWD, suspended	61	7.0	0.0	0.8	2.5	8.0	18.4	75.3
LWD, jam	61	0.5	0.0	0	0	0.5	2.4	4.7
LWD, total	61	27.4	3.2	9.5	21.6	38.2	76.0	121.3

Table D-2. Estimated mean, 25%, 50%, 75%, and 95% cumulative distribution function (CDF) values for Type Np catchment-scale characteristics and habitat variables as calculated using the R package *spsurvey*.

Variable	n	Mean	Minimum	25%-tile	Median	75%-tile	95%-tile	Maximum
Catchment area, ha	54	20.0	1.3	4.5	10.9	26.3	60.4	83.1
Elevation, m	54	335	26.0	95.7	258.4	484.4	897.3	1000
Catchment slope, %	54	21.9	0.0	13.1	22.4	22.9	38.3	55.7
Canopy closure, %	54	82	1.4	73	93	98	99.8	99.9
Bankfull width, m	54	1.9	0.7	1.2	1.6	2.2	3.5	6.2
Gradient, %	54	19.6	1.8	11.3	17.1	25.1	44.2	55.2
Thalweg depth, m	54	0.1	0.03	0.04	0.07	0.10	0.18	0.25
Wetted width, m	54	1.1	0.4	0.7	0.9	1.3	2.7	2.9
Mean depth, m	54	0.05	0.00	0.02	0.03	0.05	0.10	0.19
Embeddedness, %	54	48.3	6.0	32.8	46.5	62.5	88.8	98.9
Particle size, mm, geometric mean	54	30.3	0.2	1.0	5.7	12.4	83.9	656.7
Distance to divide, m	54	719	156.2	384.2	614.2	936.6	1477.1	1976.1
LWD, down	54	25.5	4.0	14.7	20.4	32.5	58.4	68.0
LWD, suspended	54	13.1	0.0	3.7	7.0	19.4	37.4	67.3
LWD, jam	54	0.4	0.0	0	0	0.2	1.4	6.7
LWD, total	54	38.6	7.3	21.9	32.7	51.9	76.2	95.3

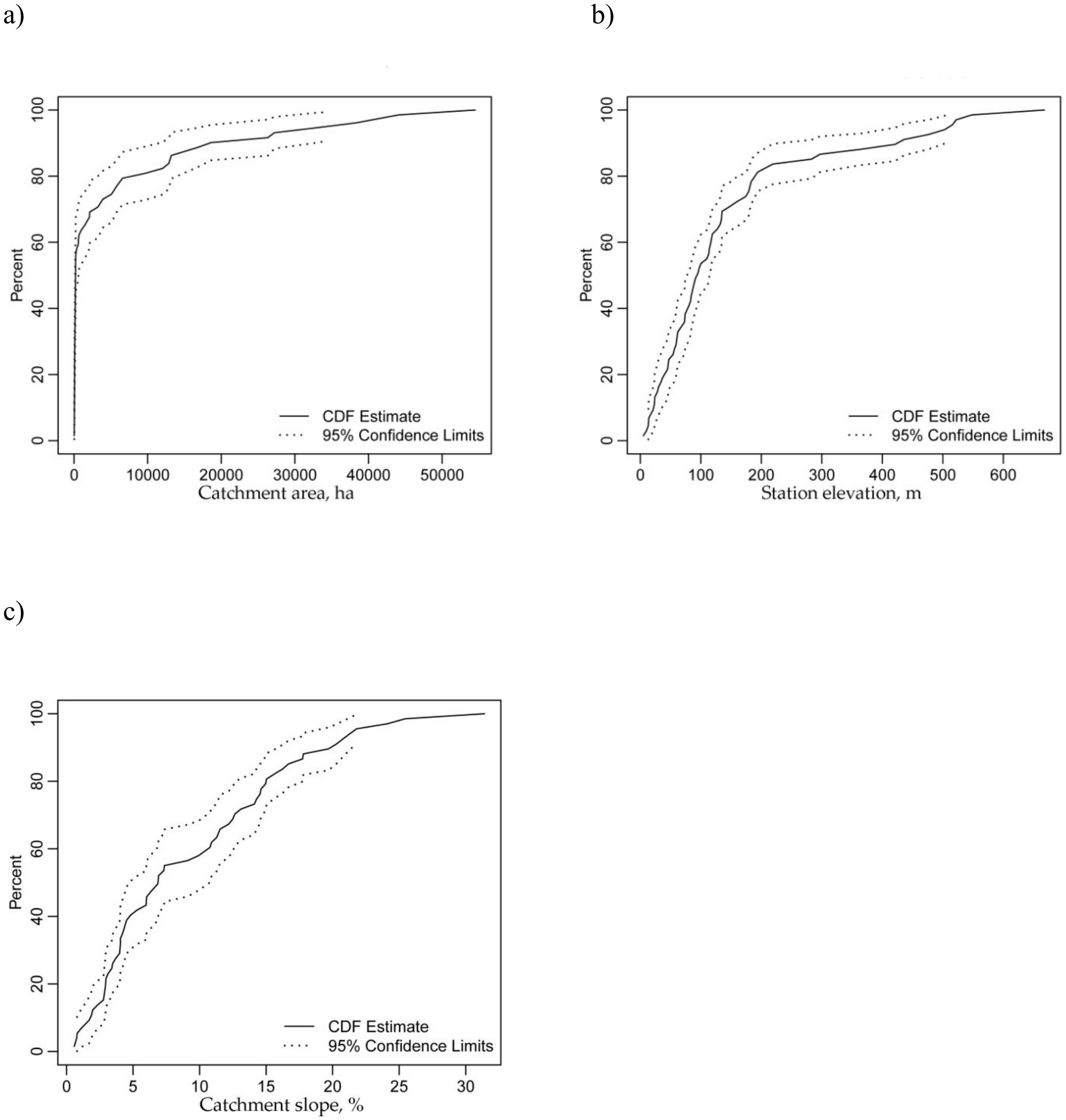

Figure D-1. Cumulative distribution function (CDF) and 95% confidence limits for Type F/S GIS-derived variables. Data are: a) planographic catchment area above monitoring station locations, b) elevation estimated from coordinates of the monitoring station using a 30 m DEM, and c) mean slope of catchment area upstream of monitoring station locations.

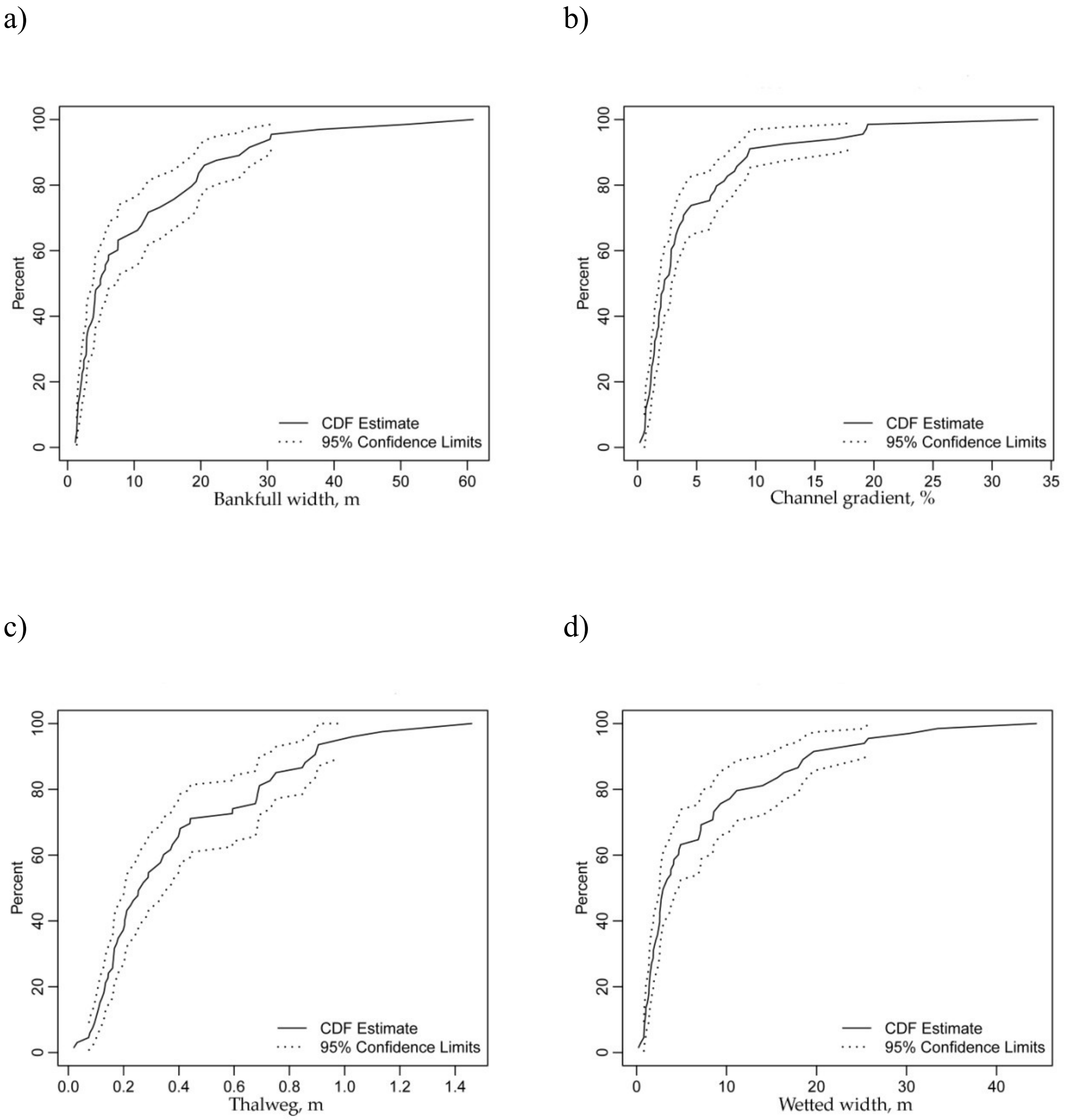

Figure D-2. Cumulative distribution function (CDF) and 95% confidence limits for Type F/S habitat variables. Data are: a) mean bankfull width, b) mean channel gradient, c) mean thalweg depth, and d) wetted width.

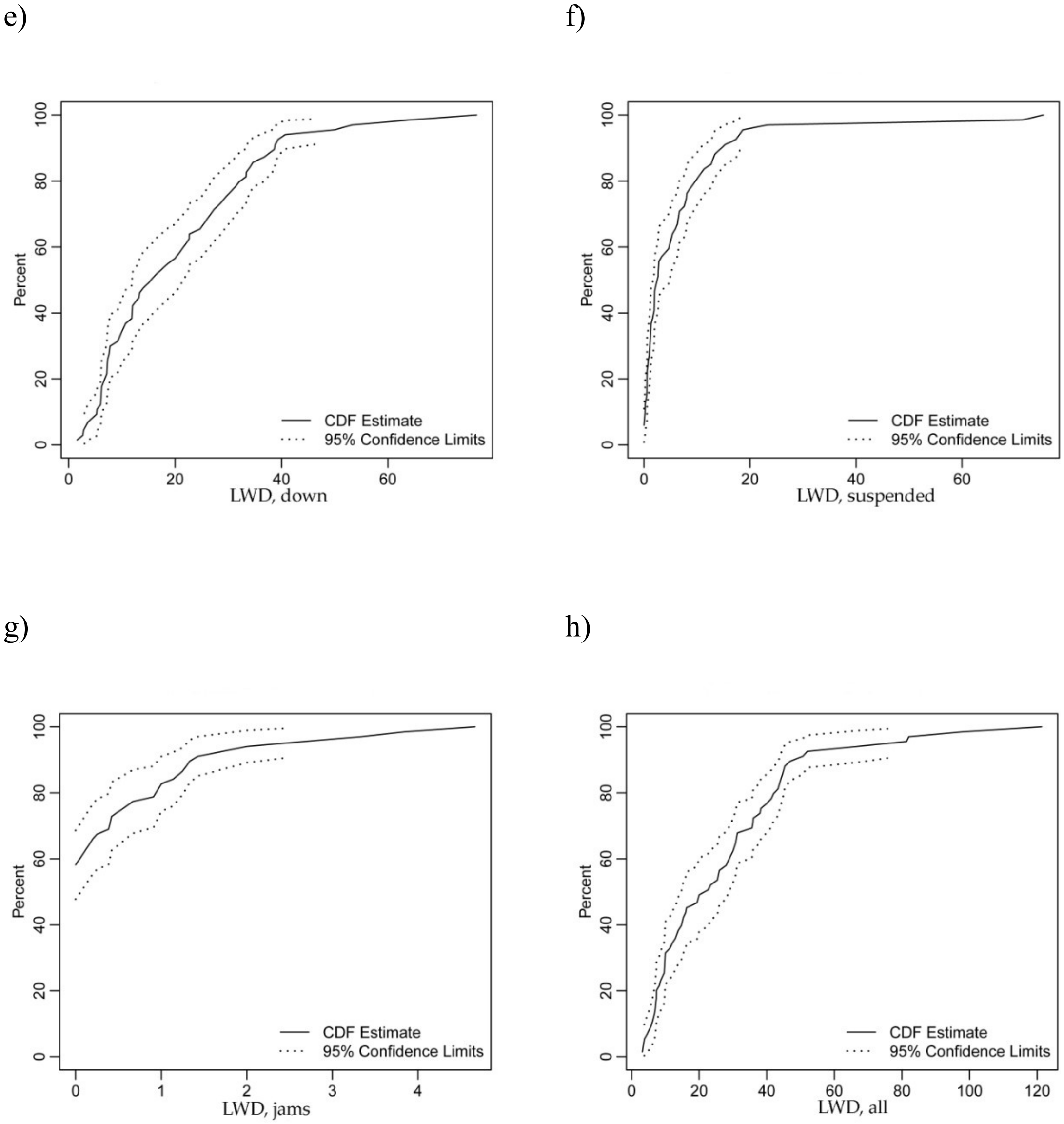

Figure D-2 (continued). Cumulative distribution function (CDF) and 95% confidence limits for Type F/S habitat variables. Data are: e) mean count of down, in-channel large woody debris (LWD), f) mean count of LWD suspended over the channel, g) mean count of LWD jams, and h) mean count of all categories of in-channel LWD inventoried.

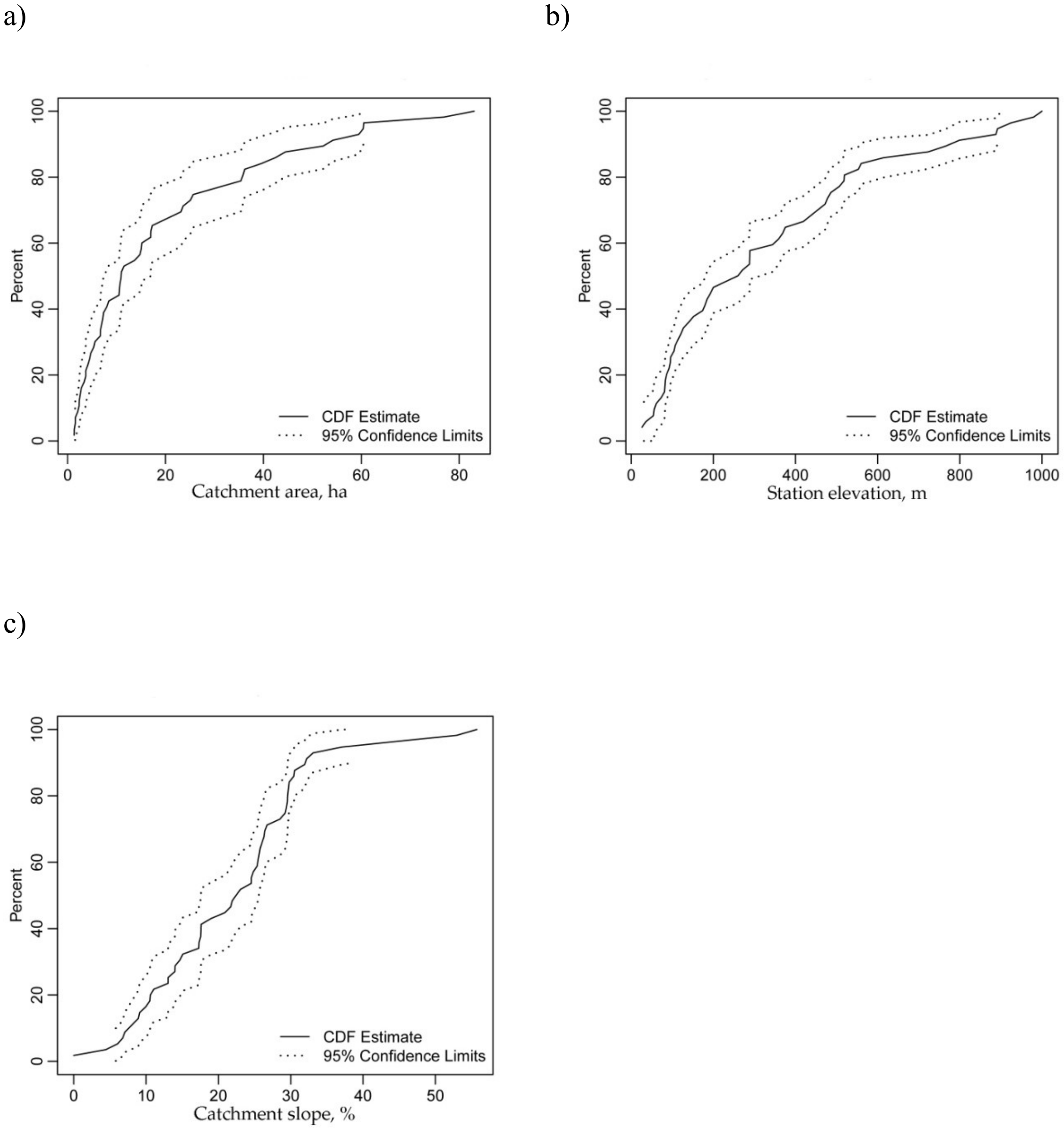

Figure D-3. Cumulative distribution function (CDF) and 95% confidence limits for Type Np GIS-derived variables. Data are: a) planographic catchment area above monitoring station locations, b) elevation estimated from coordinates of the monitoring station using a 30 m DEM, and c) mean slope of catchment area upstream of monitoring station locations.

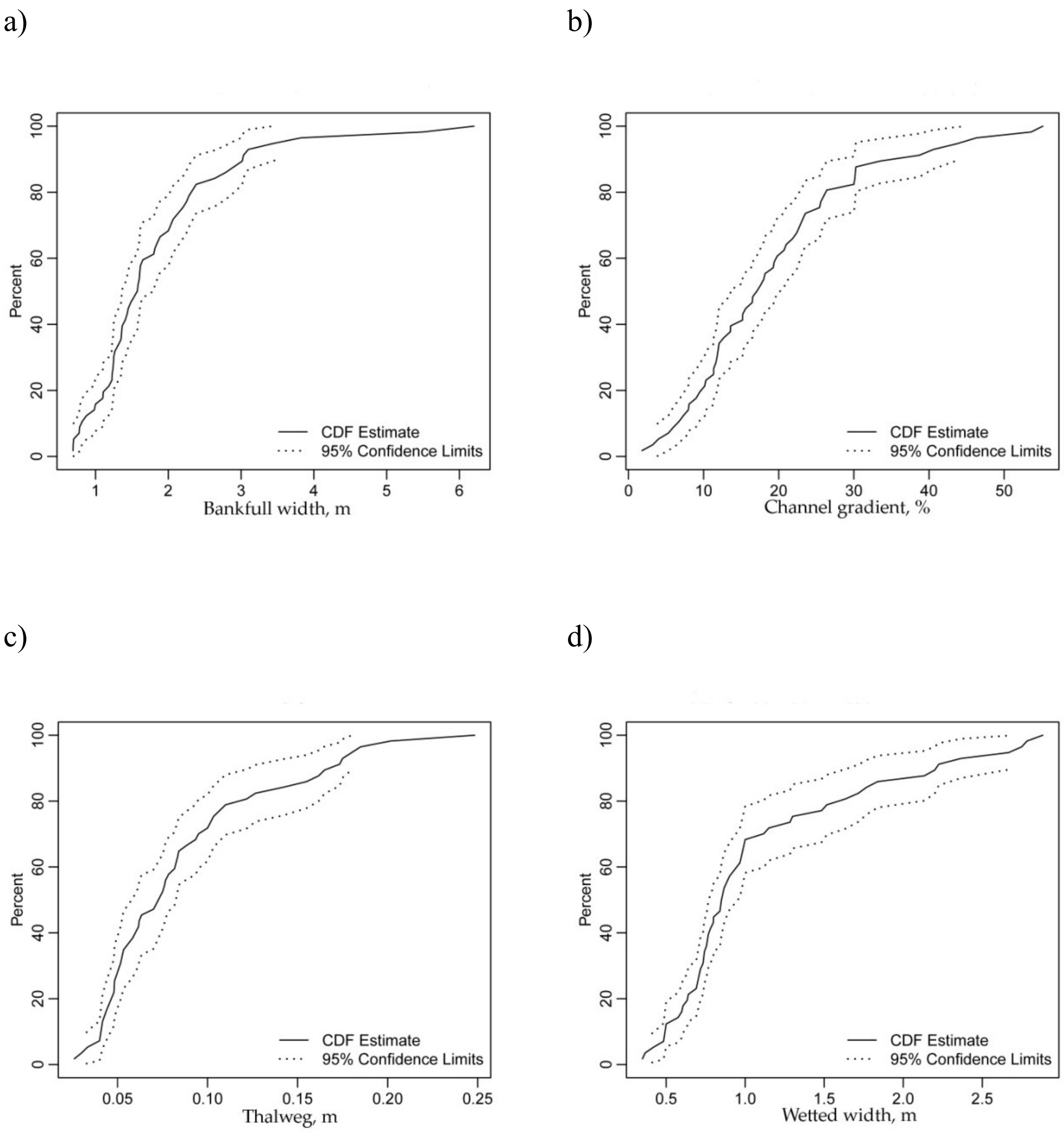

Figure D-4. Cumulative distribution function (CDF) and 95% confidence limits for Type Np habitat variables. Data are: a) mean bankfull width, b) mean channel gradient, c) mean thalweg depth, and d) wetted width.

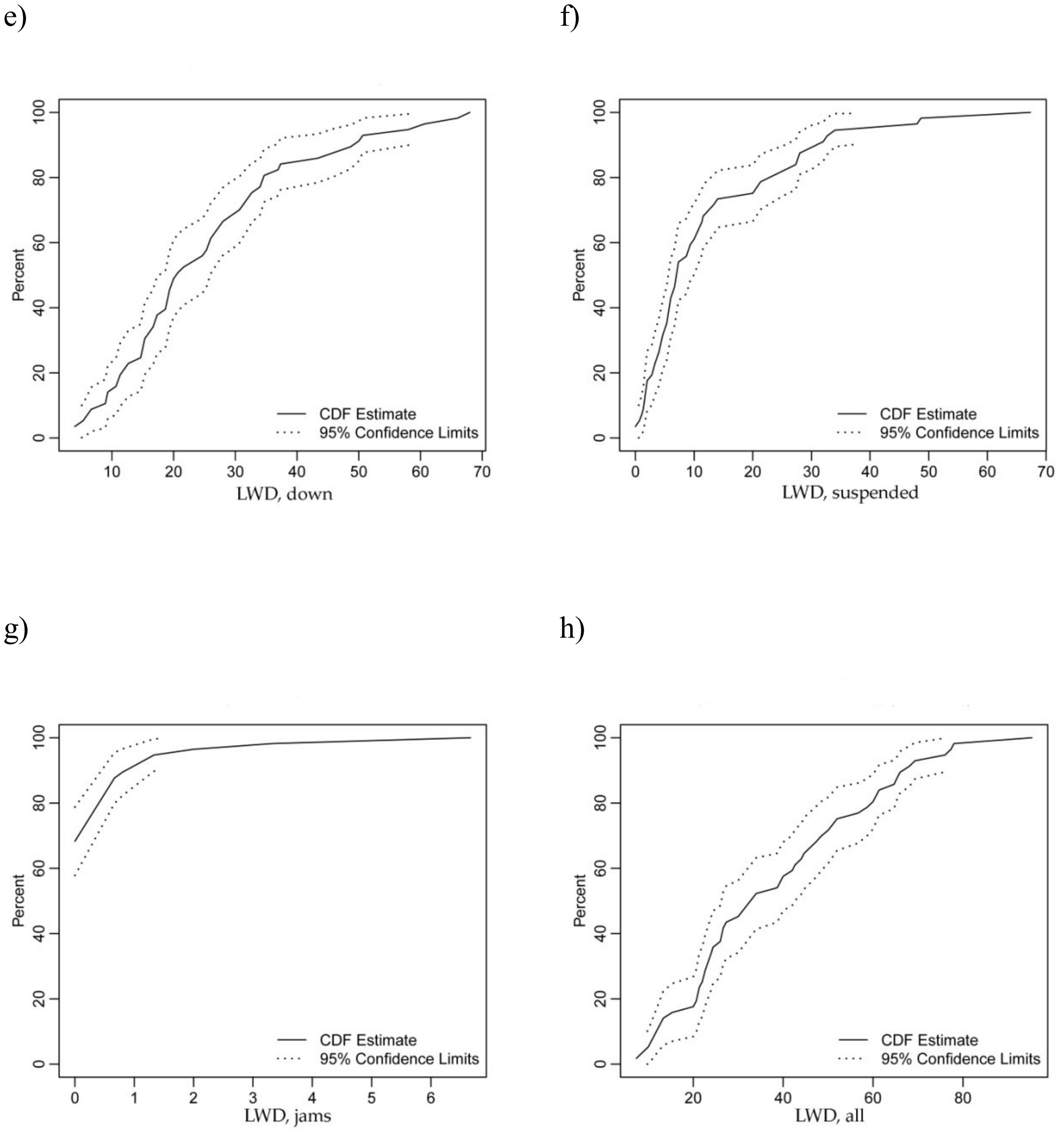

Figure D-4 (continued). Cumulative distribution function (CDF) and 95% confidence limits for Type Np habitat variables. Data are: e) mean count of down, in-channel large woody debris (LWD), f) mean count of LWD suspended over the channel, g) mean count of LWD jams, and h) mean count of all categories of in-channel LWD inventoried.

Appendix E. Inventory of temperature data gaps and data summaries.

Table E-1. Site-level catchment, canopy, and channel descriptions, collected 2008 and 2009, for Type F/S sites.

Site ID Number	Catchment Area (ha)	Catchment DTD (m)	Average Catchment Slope (%)	Reach Length (m)	Reach Gradient (%)	Site Elevation (m)	Site Aspect (degrees)	Canopy Cover (%)	Dominant Vegetation Type
22	98.2	1590.0	15.0	150	4.2	119	182	74.6	Mixed
78	171.3	2844.0	2.0	150	2.2	83	203	81.2	Mixed
98	205.3	2098.4	24.1	260	12.5	668	88	92.2	Mixed
101	122.5	2902.6	12.6	150	3.2	134	198	98.5	Deciduous
111	32844.6	63975.0	2.3	500	0.7	28	260	17.0	Deciduous
118	197.3	2435.5	11.5	150	2.8	87	204	93.4	Mixed
172	3220.0	7106.3	14.3	400	1.5	283	105	33.4	Deciduous
237	63.6	1279.7	4.0	150	1.2	13	341	88.7	Coniferous
270	16764.7	27012.2	3.0	500	0.7	45	228	4.0	Deciduous
286	30.4	1119.9	3.1	150	1.3	89	70	98.8	Mixed
315	54491.7	56932.5	2.8	768	0.6	91	290	1.3	Mixed
334	18620.7	31987.9	4.0	500	1.7	548	272	35.5	Mixed
346	29.0	659.1	15.6	150	8.4	37	44	59.9	Mixed
377	3912.0	21694.4	2.9	475	0.5	21	220	28.4	Deciduous
409	319.2	3738.1	12.5	175	7.6	110	84	92.9	Deciduous
429	22.0	601.2	17.8	150	16.8	119	100	98.7	Deciduous
489	52.5	1299.1	16.2	150	8.2	421	328	91.7	Mixed
577	226.1	1972.7	25.4	270	9.3	503	294	69.1	Deciduous
605	992.7	7493.6	7.3	350	2.8	194	149	95.4	Deciduous
650	63.2	1583.6	6.3	150	3.4	34	324	72.4	Mixed
699	5075.1	19495.0	6.0	500	3.8	160	154	62.5	Mixed
718	9.5	513.3	9.9	145	3.3	97	194	99.8	Mixed

Site ID Number	Catchment Area (ha)	Catchment DTD (m)	Average Catchment Slope (%)	Reach Length (m)	Reach Gradient (%)	Site Elevation (m)	Site Aspect (degrees)	Canopy Cover (%)	Dominant Vegetation Type
762	6576.4	20717.5	6.9	475	1.4	219	336	63.9	Deciduous
774	589.3	4899.2	3.5	150	2.3	181	194	86.7	Mixed
793	90.8	1437.7	21.3	150	2.7	95	251	75.1	Mixed
809	158.3	2374.0	10.8	150	9.5	24	134	99.1	Mixed
846	2108.4	10031.4	1.1	400	1.8	10	290	87.8	Mixed
884	209.0	2219.7	14.6	260	3.6	194	316	77.8	Deciduous
905	2092.1	11119.3	6.0	400	2.9	80	160	74.4	Mixed
950	670.8	3936.4	4.2	150	0.9	30	192	44.1	Mixed
969	49.5	911.0	7.4	150	6.7	116	184	88.0	Mixed
976	108.9	1770.4	31.4	150	19.3	364	265	68.4	Mixed
982	44.5	814.4	14.6	150	1.8	56	220	98.0	Mixed
1014	550.3	4097.6	4.1	150	2.0	60	248	62.8	Deciduous
1034	12855.0	22889.4	16.7	500	2.3	516	286	11.0	Mixed
1199	26315.6	39517.2	0.6	500	0.2	5	180	17.5	Deciduous
1217	38272.5	39579.1	1.9	500	0.9	132	150	13.9	Deciduous
1252	75.2	1037.3	10.9	150	6.2	113	225	99.0	Mixed
1261	202.8	2681.5	15.0	220	2.0	148	276	98.3	Mixed
1278	32.5	1461.1	11.3	150	7.3	114	109	32.2	Mixed
1284	9663.5	26567.7	0.8	500	1.1	23	234	48.5	Mixed
1324	123.6	2940.4	21.8	150	8.8	127	165	78.8	Deciduous
1366	145.8	2156.3	6.9	150	1.4	62	90	90.3	Deciduous
1513	12020.7	25841.2	3.7	500	1.2	476	224	12.8	Mixed
1530	5770.6	26945.1	0.8	500	0.7	14	218	58.6	Deciduous
1610	35.9	867.2	9.1	150	4.5	46	108	97.5	Deciduous
1633	13206.2	32679.5	1.7	500	1.2	74	150	41.0	Mixed
1658	159.1	2177.5	3.4	150	3.9	73	113	98.2	Deciduous

Site ID Number	Catchment Area (ha)	Catchment DTD (m)	Average Catchment Slope (%)	Reach Length (m)	Reach Gradient (%)	Site Elevation (m)	Site Aspect (degrees)	Canopy Cover (%)	Dominant Vegetation Type
1686	58.0	850.3	14.1	150	3.1	73	85	97.3	Mixed
1716	136.9	3528.4	2.9	150	1.0	84	171	97.1	Coniferous
1717	66.4	1495.9	13.1	150	1.6	297	285	99.5	Mixed
1738	27.3	541.8	20.3	150	6.5	100	244	98.5	Deciduous
1791	44077.5	40463.4	4.5	500	2.0	135	20	0.3	Deciduous
1816	1468.5	5389.2	5.3	400	1.9	54	347	99.7	Mixed
1833	169.0	1429.1	20.8	150	6.1	436	98	86.0	Coniferous
1856	67.4	1153.3	19.7	150	33.9	183	63	90.2	Mixed
1870	140.7	1753.9	4.3	150	1.8	47	125	96.8	Mixed
1873	38.1	1442.9	17.7	150	19.5	522	165	99.4	Mixed
1894	113.4	1876.0	4.1	150	19.1	59	250	94.0	Mixed
1923	63.4	2297.6	12.2	150	2.8	174	173	29.4	Coniferous
1929	27205.6	41236.4	4.8	500	1.1	179	348	1.3	Deciduous

Table E-2. Site-level catchment, canopy, and channel descriptions, collected 2008 and 2009, for Type Np sites.

Site ID Number	Catchment Area (ha)	Catchment DTD (m)	Average Catchment Slope (%)	Reach Length (m)	Reach Gradient (%)	Site Elevation (m)	Site Aspect (degrees)	Canopy Cover (%)	Dominant Vegetation Type
70	11.0	647.3	25.5	150	21.8	472	295	27.4	Deciduous
197	3.7	435.3	26.4	150	33.5	260	92	98.8	Mixed
263	39.6	1507.9	11.1	150	43.8	140	147	99.6	Mixed
310	10.9	889.8	20.9	130	4.0	766	283	71.1	Coniferous
319	10.5	583.3	44.9	150	53.6	127	284	98.9	Mixed
324	2.4	300.3	26.3	150	30.0	200	123	89.1	Mixed
389	17.0	994.9	19.0	150	12.7	486	358	94.2	Mixed
452	17.0	891.7	14.0	150	8.1	107	154	93.1	Mixed
482	7.0	514.1	29.6	150	21.0	478	96	1.4	Coniferous
506	2.8	250.0	17.6	150	9.5	56	114	66.8	Coniferous
553	1.6	224.0	24.6	150	20.7	369	120	31.5	Coniferous
625	36.2	1209.9	21.9	150	9.0	472	134	97.0	Mixed
629	7.3	361.8	9.1	150	6.7	288	130	98.8	Mixed
641	35.4	1219.9	8.9	150	12.1	289	342	96.3	Deciduous
653	15.1	817.7	28.5	150	55.2	518	336	98.3	Mixed
669	17.3	670.0	29.4	150	25.4	174	32	99.9	Mixed
697	5.0	228.8	30.2	150	20.7	56	69	92.2	Mixed
698	35.8	1207.4	10.5	150	1.8	82	220	35.0	Mixed
701	6.7	522.4	26.0	150	22.4	260	356	91.5	Mixed
715	59.5	1471.2	55.7	250	38.7	892	189	70.8	Coniferous
756	4.7	231.0	17.3	150	19.4	185	218	99.9	Mixed
770	8.4	521.1	13.0	150	10.1	180	300	99.9	Mixed
886	2.1	156.2	17.3	150	16.5	54	340	84.6	Mixed
933	25.7	906.7	10.6	150	10.3	344	154	27.8	Mixed

Site ID Number	Catchment Area (ha)	Catchment DTD (m)	Average Catchment Slope (%)	Reach Length (m)	Reach Gradient (%)	Site Elevation (m)	Site Aspect (degrees)	Canopy Cover (%)	Dominant Vegetation Type
942	8.0	605.0	6.8	150	5.3	73	234	99.9	Mixed
956	25.1	737.7	24.5	150	18.0	375	210	66.1	Deciduous
1037	15.2	701.9	10.0	150	6.0	121	133	99.4	Mixed
1062	1.4	216.7	23.1	150	26.4	980	2	88.8	Coniferous
1074	1.3	530.2	15.1	150	25.6	104	6	82.7	Mixed
1082	4.1	296.8	7.1	150	11.3	81	106	100.0	Broadleaf
1094	76.9	1074.9	52.9	150	15.2	615	230	98.7	Mixed
1113	42.4	1515.9	17.6	150	30.1	193	19	94.1	Mixed
1125	4.5	302.7	25.8	150	15.2	560	203	72.8	Mixed
1180	11.5	636.2	37.1	150	46.3	888	164	73.3	Coniferous
1192	10.6	596.8	25.6	150	11.8	506	333	94.7	Coniferous
1193	44.5	724.9	24.8	150	16.5	472	30	86.5	Mixed
1255	6.7	341.8	30.4	150	30.2	152	30	98.9	Coniferous
1323	23.1	953.6	29.8	150	23.2	26	96	92.4	Mixed
1341	7.2	540.7	33.1	150	40.6	553	339	53.7	Mixed
1374	23.6	700.2	21.7	150	17.6	1000	102	65.8	Mixed
1459	2.3	395.0	14.7	150	17.1	96	224	95.1	Mixed
1493	60.4	1217.1	32.2	150	13.6	723	162	96.4	Mixed
1535	2.6	296.2	17.6	150	11.3	95	285	93.3	Coniferous
1538	13.7	527.5	26.7	150	19.8	359	330	1.6	Coniferous
1565	3.7	396.0	29.5	150	23.6	114	238	97.8	Mixed
1582	83.1	1268.7	31.9	150	30.3	799	333	97.2	Mixed
1597	60.5	1369.0	30.5	150	18.2	519	149	73.5	Deciduous
1641	5.3	413.9	25.4	150	19.3	92	195	91.3	Coniferous
1653	54.2	1976.1	14.0	150	15.6	419	19	73.9	Coniferous
1781	3.4	383.0	13.1	150	7.3	271	330	96.0	Mixed

Site ID Number	Catchment Area (ha)	Catchment DTD (m)	Average Catchment Slope (%)	Reach Length (m)	Reach Gradient (%)	Site Elevation (m)	Site Aspect (degrees)	Canopy Cover (%)	Dominant Vegetation Type
1786	14.8	838.8	29.2	150	26.4	925	330	92.1	Coniferous
1817	10.7	360.6	4.4	150	11.6	36	190	94.2	Mixed
1859	52.2	677.1	0.0	150	3.2	83	358	97.9	Mixed
1862	5.6	329.0	6.1	150	8.0	86	64	94.3	Coniferous
1926	1.6	400.6	22.5	150	13.6	61	137	89.5	Mixed

Table E-3. Site-level temperature metrics for data collected July and August 2009, for Type F/S sites.

Site Number	Year	Air Tmax (°C)	Air 7Tmax (°C)	Upstream Tmax (°C)	Upstream 7Tmax (°C)	Downstream Tmax (°C)	Downstream 7Tmax (°C)	D_Tmax (°C)	D_7Tmax (°C)
22	2009	30.3	23.0	15.6	14.4	15.5	14.4	-0.1	0.0
78	2009	26.6	23.8	17.1	15.9	17.3	16.1	0.2	0.2
98	2009	26.6	25.8	15.7	15.4	16.4	16.2	0.7	0.8
101	2009	26.6	24.8	19.1	18.1	18.7	18.0	-0.4	-0.2
111	2009	35.2	29.9	27.9	25.8	26.3	23.0	-1.6	-2.8
118	2009	29.0	25.6	19.5	18.3	19.6	18.4	0.1	0.1
172	2009	30.3	28.6	17.9	17.5	18.4	18.2	0.6	0.6
237	2009	23.4	19.6	15.8	15.2	*	*	*	*
270	2009	35.1	30.4	19.7	18.9	19.8	19.0	0.1	0.1
286	2009	*	*	15.8	14.8	15.9	14.5	0.1	-0.3
315	2009	40.8	31.5	19.0	18.2	19.3	18.5	0.3	0.3
334	2009	32.5	30.3	17.2	16.8	17.6	17.2	0.4	0.4
346	2009	20.3	17.5	13.4	12.7	13.5	13.0	0.1	0.3
377	2009	32.0	26.3	23.6	22.2	23.7	22.3	0.1	0.1
409	2009	25.3	23.1	19.2	18.1	19.4	18.1	0.2	0.1
429	2009	20.3	19.0	15.0	14.8	14.8	14.4	-0.3	-0.4
489	2009	28.2	26.2	17.7	17.1	17.0	16.5	-0.7	-0.5
577	2009	36.6	34.5	19.6	19.1	19.5	19.3	-0.1	0.2
605	2009	30.3	26.9	18.0	17.2	18.0	17.2	0.0	0.0
650	2009	18.5	16.6	13.3	12.9	13.9	13.5	0.6	0.6
699	2009	31.1	28.7	19.4	18.8	19.7	19.1	0.3	0.3
718	2009	21.5	19.1	14.6	13.8	15.0	14.1	0.4	0.3
762	2009	32.1	29.0	22.7	21.9	21.1	20.4	-1.6	-1.5
774	2009	30.0	26.6	21.0	19.8	21.1	19.8	0.1	0.1

Site Number	Year	Air Tmax (°C)	Air 7Tmax (°C)	Upstream Tmax (°C)	Upstream 7Tmax (°C)	Downstream Tmax (°C)	Downstream 7Tmax (°C)	D_Tmax (°C)	D_7Tmax (°C)
793	2009	21.5	17.9	12.6	11.9	13.2	12.5	0.6	0.6
809	2009	29.6	27.2	22.2	20.5	*	*	*	*
846	2009	26.6	22.3	20.3	19.0	20.8	19.1	0.5	0.2
884	2009	20.6	18.5	*	*	14.9	14.2	*	*
905	2009	37.4	33.8	19.8	19.7	20.2	20.0	0.4	0.3
950	2009	27.3	22.8	19.4	18.1	*	*	*	*
969	2009	20.8	19.9	20.1	19.5	15.5	15.2	-4.6	-4.3
976	2009	24.1	22.5	20.0	19.1	19.8	19.0	-0.2	-0.2
982	2009	25.7	24.1	15.5	14.9	16.9	16.5	1.4	1.6
1014	2009	28.3	24.9	19.9	19.1	18.7	18.3	-1.2	-0.9
1034	2009	32.5	30.9	16.1	15.2	23.5	21.8	7.4	6.7
1199	2009	27.6	22.9	24.3	22.4	24.0	22.2	-0.3	-0.2
1217	2009	34.9	33.7	19.0	18.6	19.7	19.4	0.8	0.8
1252	2009	19.7	17.8	14.6	14.0	14.2	13.8	-0.5	-0.2
1261	2009	22.1	18.7	14.7	14.2	*	*	*	*
1278	2009	26.3	23.4	14.9	14.0	15.0	14.2	0.1	0.2
1284	2009	31.4	26.1	23.7	21.9	23.2	21.4	-0.6	-0.5
1324	2009	29.4	27.2	18.2	17.5	*	*	*	*
1366	2009	23.7	21.2	18.2	17.4	18.2	17.4	0.0	0.0
1513	2009	32.5	30.5	23.7	23.2	23.5	23.0	-0.1	-0.2
1530	2009	32.5	26.8	20.3	19.0	21.2	19.6	0.9	0.7
1610	2009	20.0	17.8	12.4	11.8	12.6	12.1	0.2	0.3
1633	2009	34.0	31.3	28.1	26.9	27.6	26.3	-0.5	-0.6
1658	2009	23.4	20.1	16.1	15.1	15.8	14.9	-0.3	-0.2
1686	2009	26.9	24.8	17.0	16.3	19.0	17.8	2.0	1.6
1716	2009	33.8	29.2	16.8	15.9	17.5	16.2	0.7	0.2

Site Number	Year	Air Tmax (°C)	Air 7Tmax (°C)	Upstream Tmax (°C)	Upstream 7Tmax (°C)	Downstream Tmax (°C)	Downstream 7Tmax (°C)	D_Tmax (°C)	D_7Tmax (°C)
1717	2009	26.3	23.8	18.5	17.3	18.0	17.1	-0.5	-0.2
1738	2009	23.4	20.3	13.3	12.6	*	*	*	*
1791	2009	32.9	29.0	18.7	18.0	19.3	18.5	0.6	0.5
1816	2009	25.0	23.1	19.4	18.3	19.2	18.2	-0.2	-0.1
1833	2009	24.3	22.6	18.3	17.5	18.2	17.5	-0.1	0.0
1856	2009	25.1	24.5	13.9	13.2	15.6	14.9	1.7	1.7
1870	2009	21.2	18.7	14.6	13.6	14.9	13.9	0.2	0.4
1873	2009	28.6	25.6	15.2	14.6	18.0	17.5	2.8	2.9
1894	2009	20.5	18.6	17.7	16.7	18.1	17.0	0.4	0.3
1923	2009	38.6	35.1	19.8	18.5	24.8	23.1	5.0	4.6
1929	2009	38.4	33.3	27.2	26.4	27.4	26.4	0.1	0.0
n	61	60	60	60	60	55	55	54	54

* Indicates datasets with less than 30 days of data from July through August 2009.

Table E-4. Site-level temperature metrics for data collected July and August 2009, for Type Np sites.

Site Number	Year	Air Tmax (°C)	Air 7Tmax (°C)	Upstream Tmax (°C)	Upstream 7Tmax (°C)	Downstream Tmax (°C)	Downstream 7Tmax (°C)	D_Tmax (°C)	D_7Tmax (°C)
70	2009	33.5	32.3	16.0	15.6	17.8	16.7	1.7	1.1
197	2009	28.9	25.6	12.3	11.9	17.0	16.3	4.6	4.4
263	2009	26.6	24.4	15.0	14.3	16.9	16.2	2.0	1.9
310	2009	27.9	26.8	14.8	14.5	*	*	*	*
319	2009	23.1	20.7	14.3	13.0	21.3	18.8	7.0	5.7
324	2009	*	*	*	*	*	*	*	*
389	2009	21.6	20.2	10.9	10.6	9.7	8.6	-1.2	-1.9
452	2009	*	*	*	*	*	*	*	*
482	2009	29.0	27.2	9.3	9.0	13.2	12.9	3.9	3.9
506	2009	24.7	22.5	13.4	12.5	14.0	13.2	0.6	0.7
553	2009	41.2	35.3	16.3	15.2	15.4	14.3	-0.9	-0.8
625	2009	28.0	24.7	16.8	15.7	16.2	15.2	-0.6	-0.5
629	2009	31.1	28.4	13.5	13.0	16.6	15.9	3.1	2.9
641	2009	26.6	24.6	18.5	17.9	19.3	18.4	0.8	0.5
653	2009	23.4	22.4	*	*	15.3	15.1		
669	2009	*	*	16.3	14.9	16.8	15.4	0.5	0.4
697	2009	*	*	*	*	*	*	*	*
698	2009	38.1	33.5	14.8	14.4	19.1	18.2	4.3	3.7
701	2009	25.6	22.0	11.3	11.0	13.6	12.8	2.3	1.7
715	2009	32.9	31.2	*	*	16.4	16.2	*	*
756	2009	22.8	19.4	15.5	14.3	13.7	13.0	-1.9	-1.4
770	2009	22.4	20.9	10.3	10.2	16.7	16.0	6.4	5.8
886	2009	20.3	17.5	13.5	13.0	12.8	12.2	-0.7	-0.7
933	2009	37.9	34.1	24.4	23.4	25.0	23.6	0.6	0.3
942	2009	15.2	14.8	13.2	12.8	12.9	12.8	-0.2	0.0

Site Number	Year	Air Tmax (°C)	Air 7Tmax (°C)	Upstream Tmax (°C)	Upstream 7Tmax (°C)	Downstream Tmax (°C)	Downstream 7Tmax (°C)	D_Tmax (°C)	D_7Tmax (°C)
956	2009	24.6	23.5	14.7	14.0	21.2	19.2	6.5	5.2
1037	2009	26.3	24.5	16.0	15.7	16.6	16.2	0.6	0.5
1062	2009	35.8	34.5	16.0	15.4	17.6	16.5	1.6	1.1
1074	2009	23.1	20.0	17.0	15.3	*	*	*	*
1082	2009	26.3	24.0	9.4	9.4	11.1	10.8	1.7	1.4
1094	2009	21.0	20.4	13.3	13.2	11.5	11.4	-1.9	-1.8
1113	2009	26.2	23.5	*	*	16.4	15.4	*	*
1125	2009	26.9	24.6	21.9	21.4	17.6	16.5	-4.3	-4.9
1180	2009	25.7	25.0	16.4	16.0	16.9	16.7	0.6	0.7
1192	2009	22.8	21.4	13.2	12.2	10.9	10.5	-2.3	-1.7
1193	2009	27.2	25.2	19.0	18.5	17.8	17.4	-1.3	-1.1
1255	2009	23.1	19.1	15.3	14.1	16.6	15.0	1.3	0.9
1323	2009	24.3	21.9	16.2	15.5	17.5	16.7	1.3	1.1
1341	2009	34.3	30.1	18.7	17.2	16.0	14.9	-2.8	-2.3
1374	2009	28.3	27.3	7.8	7.2	13.7	13.0	5.9	5.8
1459	2009	19.1	18.0	18.2	16.8	16.2	15.6	-2.0	-1.3
1493	2009	30.0	29.5	12.6	10.0	11.8	11.6	-0.8	1.7
1535	2009	20.6	17.9	16.1	14.5	15.7	14.2	-0.4	-0.3
1538	2009	38.2	33.4	12.4	11.7	16.0	14.9	3.6	3.2
1565	2009	32.4	30.1	12.3	12.1	16.2	15.7	3.9	3.6
1582	2009	27.9	25.7	11.7	11.6	14.8	14.4	3.1	2.8
1597	2009	30.1	27.9	20.1	19.5	23.2	22.7	3.1	3.2
1641	2009	19.4	16.8	11.6	11.3	13.0	12.6	1.4	1.3
1653	2009	26.1	23.5	16.6	15.9	17.0	16.5	0.4	0.6
1781	2009	27.0	23.9	16.5	15.8	18.2	17.0	1.7	1.2
1786	2009	20.0	19.4	12.0	11.6	14.6	14.3	2.7	2.7

Site Number	Year	Air Tmax (°C)	Air 7Tmax (°C)	Upstream Tmax (°C)	Upstream 7Tmax (°C)	Downstream Tmax (°C)	Downstream 7Tmax (°C)	D_Tmax (°C)	D_7Tmax (°C)
1817	2009	21.8	19.6	14.1	13.9	14.4	14.0	0.3	0.1
1859	2009	27.3	24.0	13.1	12.2	14.2	13.2	1.0	1.0
1862	2009	20.6	18.4	14.4	13.4	14.0	13.2	-0.3	-0.2
1926	2009	19.7	17.0	15.2	13.9	14.6	13.7	-0.6	-0.2
n	55	51	51	49	49	50	50	47	47

* Indicates datasets with less than 30 days of data from July through August 2009.

Appendix F. Quality assurance results.

In accordance with the study plan for the Extensive Riparian Status and Trends monitoring program, approximately 10% of the study sites underwent repeated measurements for quality assurance purposes. Riparian shade and in channel measurements across the reach length of each site were performed by different crew members at five randomly selected sites for each waters type.

Table F-1. Results of repeated sampling events at five Type F/S sites. Numbers are mean site values per visit. An 'R' following the site number indicates the second sampling event.

Site Number	22	22R	98	98R	270	270R	969	969R	1278	1278R	1873	1873R
Wetted width (m)	1.8	1.6	4.7	4.6	25.3	25.9	1.6	1.6	2.1	1.8	1.0	1.1
Bankfull width(m)	2.2	2.5	7.6	7.4	30.4	30.5	2.4	2.6	2.9	2.8	1.5	1.5
Thalweg depth (cm)	11.4	12.0	17.5	20.3	89.3	91.3	16.2	14.3	14.5	13.3	7.8	8.7
Particle size (mm)	2.6	2.6	79.4	79.7	14.4	8.5	8.2	4.4	1.8	4.7	34.2	33.4
Gradient (%)	4.2	4.6	12.5	14.8	0.7	0.8	6.7	5.6	7.3	7.0	19.5	20.5
Embeddedness (%)	47.8	69.5	38.7	36.0	31.1	45.8	42.1	47.4	68.6	62.4	34.8	44.7
Canopy closure (%)	74.6	70.3	92.2	76.8	4.0	19.3	88.0	88.4	32.3	34.3	99.4	99.7
Total LWD (pieces per 100 m)	98.0	89.3	47.3	57.3	14.0	9.2	52.0	36.0	66.7	75.3	23.3	22.0
Dominant vegetation class	Mixed	Mixed	Mixed	Mixed	Deciduous	Deciduous	Mixed	Mixed	Mixed	Deciduous	Mixed	Mixed

Table F-2. Standard deviation (SD), coefficient of variation (CV), and root mean square (RMS) for the five Type F/S sites that underwent quality assurance procedures.

Site Number	22			98			270			969			1278			1873		
	SD	CV (%)	RMS	SD	CV (%)	RMS	SD	CV (%)	RMS	SD	CV (%)	RMS	SD	CV (%)	RMS	SD	CV (%)	RMS
Wetted width (m)	0.2	9.0	1.7	0.1	1.8	4.7	0.4	1.5	25.6	0.0	0.4	1.6	0.2	11.1	2.0	0.1	8.9	1.1
Bankfull width(m)	0.2	10.1	2.4	0.1	1.9	7.5	0.1	0.3	30.5	0.1	3.4	2.5	0.1	2.8	2.9	0.0	0.0	1.5
Thalweg depth (cm)	0.4	3.6	11.7	2.0	10.5	19.0	1.4	1.6	90.3	1.3	8.8	15.3	0.8	6.1	13.9	0.6	7.7	8.3
Particle size (mm)	0.0	0.0	2.6	0.2	0.2	79.6	4.2	36.8	11.8	2.7	42.8	6.6	2.1	64.0	3.6	0.6	1.7	33.8
Gradient (%)	0.3	6.4	4.4	1.6	12.0	13.7	0.1	9.4	0.8	0.8	12.7	6.2	0.2	3.4	7.2	0.7	3.5	20.0
Embeddedness (%)	15.3	26.1	59.6	1.9	5.1	37.4	10.4	27.1	39.1	3.7	8.3	44.8	4.4	6.7	65.6	7.0	17.6	40.1
Canopy closure (%)	3.0	4.2	72.5	10.9	12.9	84.9	10.8	93.0	13.9	0.3	0.3	88.2	1.4	4.3	33.3	0.1	0.1	99.6
Total LWD (pieces per 100 m)	6.1	6.5	93.8	7.1	13.5	52.5	3.4	29.3	11.8	11.3	25.7	44.7	6.1	8.6	71.1	0.9	4.1	22.7

Table F-3. Results of repeated sampling events at five Type Np sites. Numbers are mean site values per visit. An 'R' following the site number indicates the second sampling event.

Site Number	698	698R	933	933R	1323	1323R	1597	1597R	1926	1926R
Wetted width (m)	1.5	1.8	1.8	1.8	0.7	0.7	1.3	1.2	0.8	0.7
Bankfull width (m)	1.6	1.8	2.0	2.1	1.4	1.4	3.8	3.2	1.5	1.6
Thalweg depth (cm)	18.5	19.7	12.7	15.0	4.2	5.0	7.3	7.3	5.8	5.0
Particle size (mm)	0.2	0.2	0.7	0.9	8.8	7.8	5.7	9.0	0.3	0.4
Gradient (%)	1.8	1.5	10.3	9.9	23.2	23.6	18.2	16.4	13.6	12.4
Embeddedness (%)	96.1	93.3	64.7	66.1	58.9	59.9	63.2	53.0	92.1	84.2
Canopy closure (%)	35.0	34.0	27.8	30.0	92.4	82.9	73.5	61.2	89.5	94.9
Total LWD (pieces per 100 m)	54.7	50.0	44.0	42.0	26.7	25.3	10.0	8.4	52.0	60.0
Dominant vegetation class	Mixed	Mixed	Mixed	Mixed	Deciduous	Deciduous	Mixed	Mixed	Mixed	Deciduous

Table F-4. Standard deviation (SD), coefficient of variation (CV), and root mean square (RMS) for the five Type Np sites that underwent quality assurance procedures.

Site Number	698			933			1323			1597			1926		
	SD	CV (%)	RMS	SD	CV (%)	RMS	SD	CV (%)	RMS	SD	CV (%)	RMS	SD	CV (%)	RMS
Wetted width (m)	0.2	9.9	1.7	0.0	2.7	1.8	0.0	2.0	0.7	0.1	5.2	1.3	0.0	4.8	0.8
Bankfull width(m)	0.2	9.2	1.7	0.1	3.4	2.1	0.0	1.5	1.4	0.5	13.3	3.5	0.0	3.2	1.6
Thalweg depth (cm)	0.8	4.4	19.1	1.6	11.7	13.9	0.6	12.3	4.6	0.0	0.0	7.3	0.6	10.5	5.4
Particle size (mm)	0.0	20.2	0.2	0.1	17.3	0.8	0.7	8.8	8.3	2.3	32.1	7.5	0.0	11.8	0.4
Gradient (%)	0.2	12.9	1.7	0.3	2.9	10.1	0.3	1.2	23.4	1.3	7.5	17.3	0.9	6.7	13.0
Embeddedness (%)	2.0	2.1	94.7	1.0	1.5	65.4	0.6	1.1	59.4	7.2	12.4	58.3	5.6	6.3	88.2
Canopy closure (%)	0.7	2.0	34.5	1.6	5.4	28.9	6.7	7.7	87.8	8.7	12.9	67.6	3.8	4.1	92.2
Total LWD (pieces per 100 m)	3.3	6.3	52.4	1.4	3.3	43.0	1.0	3.8	26.0	1.1	12.3	9.2	5.7	10.1	56.1

Appendix G. Sample R code used for Cumulative Distribution Functions.

```
#Explore Jack J. files for determining site weights for target population.

setwd("C:/Program Files/R/R-2.12.2/erst_n_09")

sfr.7.15 <- read.csv('ERST_W_N_rev2_parcelout_modi.csv', header=TRUE)
dim(sfr.7.15)
names(sfr.7.15) <- tolower(names(sfr.7.15))
names(sfr.7.15)

addmargins(table(sfr.7.15$strat_a))
addmargins(table(sfr.7.15$strat_b))
addmargins(table(sfr.7.15$status))
addmargins(table(sfr.7.15$t_nt))
addmargins(table(sfr.7.15$t_nt,sfr.7.15$strat_b))
addmargins(table(sfr.7.15$t_nt,sfr.7.15$status))
addmargins(table(sfr.7.15$strat_b,sfr.7.15$status))
addmargins(table(sfr.7.15$reason,sfr.7.15$strat_b))

plot(sfr.7.15$ww,sfr.7.15$bfw)

########################################
#explore cont.analysis using Tom's TinnR template:
# File: CDF_Estimates.R
# Purpose: Calculate CDF and percentile estimates and test for differences among
#         CDFs for the zzz survey
# Programmer: Tom Kincaid
# Date: May 17, 2011

# Create a text file for output
sink("Janish_CDF_Estimates.txt")
cat("CDF Estimation for the ECY temperature Survey\1.1")

# Read the file containing data for CDF estimates
cdf <- sfr.7.15 <- read.csv('ERST_W_N_rev2_parcelout_modi.csv', header=TRUE)
names(cdf) <- tolower(names(cdf))
dim(cdf)
names(cdf)
nr <- nrow(cdf)

temp <- geodalbers(cdf$longnad83h,cdf$latnad83h, sph="Clarke1866", clon=-96, clat=23,
sp1=29.5, sp2=45.5)
```

```
  dim(temp)
  head(temp)
cdf$xalbers <- temp$xcoord
cdf$yalbers <- temp$ycoord

 head(cdf$xalbers)
 head(cdf$yalbers)

#This sets up the adjusted weights we calculated separately;
cdf$final.wgt <- 0
cdf$final.wgt[cdf$strat_b=='IND' & cdf$status=='TS'] <- 587.4101
cdf$final.wgt[cdf$strat_b=='PUB' & cdf$status=='TS'] <- 216.3026
cdf$final.wgt[cdf$strat_b=='SFL' & cdf$status=='TS'] <- 1378.9293
cdf$final.wgt[cdf$strat_b=='MUN' & cdf$status=='TS'] <- 648.9079

#check weight assignments to cdf$final.wgt
addmargins(table(cdf$final.wgt))


sites.CDF <- data.frame(siteID=cdf$site_id,
                  #Use=cdf$t_nt[cdf$t_nt=='T'])
                  Use=cdf$status=='TS')

# Create the subpop data frame, which defines populations and subpopulations for
# which estimates are desired
subpop.CDF <- data.frame(siteID=cdf$site_id,
                   All_Sites=rep("All_Sites", nr),
                   pop1=cdf$strat_b)

# Create the design data frame, which identifies the stratum code, weight,
# x-coordinate, and y-coordinate for each site ID
design.CDF <- data.frame(siteID=cdf$site_id,
                   wgt=cdf$final.wgt,
                   #stratum=cdf$stratum,    above defined the subpopulations; no stratification in
the design
                   #xcoord=cdf$x,
                                   #ycoord=cdf$y,
                                               xcoord=cdf$xalbers,
                   ycoord=cdf$yalbers)

# Create the data.cont data frame, which specifies the variables to use in the
# analysis
data.cont.CDF <- data.frame(siteID=cdf$site_id,
                        thalweg=cdf$thlwg,         #you could just replace "var1" with thalweg and
"var2" with wetted width
                        wettedwidth=cdf$ww,
```

```
                                       bankfullwidth=cdf$bfw,
                                       gradient=cdf$grad,
                                       area_ha=cdf$area_ha,
                                       elevation=cdf$wa30,
                                       slope=cdf$slope_avg,
                                       aspect=cdf$aspect,
                                       lwd_d=cdf$lwd_down,
                                       lwd_s=cdf$lwd_sus,
                                       lwd_j=cdf$lwd_jams,
                                       total_lwd=cdf$t_lwd,
                                       canopy=cdf$pcan,
                       distance_divide=cdf$dtd_m,
                                       geo_mn=cdf$geo_mean,
                       embededness_mid=cdf$mid_emb)
                 # depth=cdf$depth_mn,
                 # distance_between=cdf$distance,
                 # bankfull_r=cdf$bf_rat,
                 # width_r=cdf$w_rat,
                 # embededness=cdf$emb,
                             # air_tmx_09=cdf$airtmx09,
       # dtempmx09=cdf$dtempmx09,
                             # air_7d_09=cdf$airt7d09,
                             # ustmx09=cdf$ustmx09,
                             # ust7d09=cdf$ust7d09,
                             # dstmx09=cdf$dstmx09,
                             # dst7d09=cdf$dst7d09,
                             # dtemp7d09=cdf$dtemp7d09)
                             # airtmx08=cdf$airtmx08,
                             # airt7d08=cdf$airt7d08,
                             # ustmx08=cdf$ustmx08
                             # ust7d08=cdf$ust7d08,
                             # dstmx08=cdf$dstmx08,
                             # dst7d08=cdf$dst7d08,
                             # dtempmx08=cdf$dtempmx08,
                             # dtemp7d08=cdf$dtemp7d08)

# Calculate the estimates
cat("\nCalculate Janish_CDF_estimates\n") # the \n are carriage returns
#needed unless you want one long line. \n\n creates two carriage returns.
sink()       #closes the diversion to the file; output again appears in the R window
if(exists("warn.df")) rm("warn.df")
Janish_CDF_Estimates <- cont.analysis(sites.CDF, subpop.CDF, design.CDF, data.cont.CDF,
   popsize=list("All_Sites"=49317,
          pop1=list(IND=37852.9605,
                PUB=2811.9342,
                SFL=7354.2895,
```

```
                     MUN=1297.8158)))
              # pop2=list("subpop1"=,
               #        "subpop2"=,
                #       "subpop3"=))

# Check for warning messages and print them if any exist
sink("Janish_CDF_Estimates.txt", append=TRUE) #opens the file again; the append
#adds the new output to the original output; without the append, the original would
#disappear.
if(exists("warn.df")) {
  cat("\nWarning messages generated during the call to cont.analysis:\n\n")
  warnprnt()
} else {
  cat("\nNo warning messages were generated during the call to cont.analysis.\n")
}

# Write CDF estimates as a comma-separated value (csv) file
write.table(Janish_CDF_Estimates$CDF, file="Janish_CDF_Estimates.csv", sep=",",
        row.names=FALSE)

# Create a PDF file containing plots of the CDF estimates
cont.cdfplot("Janish_CDF_Estimates.pdf", Janish_CDF_Estimates$CDF)

# Write percentile estimates as a csv file
write.table(Janish_CDF_Estimates$Pct, file="Janish_Percentile_Estimates.csv", sep=",",
        row.names=FALSE)

## Close the output text file
sink()
# Test for differences among CDFs which I didn't do in the example
#

CDF_Tests <- cont.cdftest(sites.CDF, subpop.CDF, design.CDF, data.cont.CDF,
   popsize=list("All_Sites"=49317,
              pop1=list(IND=37852.9605,
                     PUB=2811.9342,
                     SFL=7354.2895,
                     MUN=1297.8158)))
                 #      "subpop4"=),
              # pop2=list("subpop1"=,
               #        "subpop2"=,
                #       "subpop3"=)))

# Write CDF test results as a csv file
write.table(CDF_Tests, file="CDF_Tests.csv", sep=",", row.names=FALSE)
```

```
# Close the output text file
sink()
# cont.analysis(sites=mysites, subpop=mysubpop, design=mydesign,
# data.cont=mydata.cont, popsize=mypopsize)

/////////////////////////////////////////////////////////////////
#temp comparisons

setwd("C:/Program Files/R/R-2.12.2/erst_07")

sfr.7.15 <- read.csv('between_yrs.csv', header=TRUE)
dim(sfr.7.15)
names(sfr.7.15) <- tolower(names(sfr.7.15))
names(sfr.7.15)

addmargins(table(sfr.7.15$strat_a))
addmargins(table(sfr.7.15$strat_b))
addmargins(table(sfr.7.15$status))
addmargins(table(sfr.7.15$t_nt))
addmargins(table(sfr.7.15$t_nt,sfr.7.15$strat_b))
addmargins(table(sfr.7.15$t_nt,sfr.7.15$status))
addmargins(table(sfr.7.15$strat_b,sfr.7.15$status))
addmargins(table(sfr.7.15$reason,sfr.7.15$strat_b))
plot(sfr.7.15$ustmx07,sfr.7.15$dstmx07)

 ##########################################
#explore cont.analysis using Tom's TinnR template:

# File: CDF_Estimates.R
# Purpose: Calculate CDF and percentile estimates and test for differences among
#          CDFs for the zzz survey
# Programmer: Tom Kincaid
# Date: May 17, 2011


# Create a text file for output
sink("between_yrs.txt")
cat("CDF Estimation for the ECY temperature Survey\1.1")


# Read the file containing data for CDF estimates
cdf <- sfr.7.15 <- read.csv('between_yrs.csv', header=TRUE)
names(cdf) <- tolower(names(cdf))
dim(cdf)
names(cdf)
nr <- nrow(cdf)
```

```
temp <- geodalbers(cdf$longnad83h,cdf$latnad83h, sph="Clarke1866", clon=-96, clat=23,
sp1=29.5, sp2=45.5)
  dim(temp)
  head(temp)
cdf$xalbers <- temp$xcoord
cdf$yalbers <- temp$ycoord

 head(cdf$xalbers)
 head(cdf$yalbers)

#This sets up the adjusted weights we calculated separately;
cdf$final.wgt <- 0
cdf$final.wgt[cdf$strat_b=='IND' & cdf$status=='TS'] <- 33.78102
cdf$final.wgt[cdf$strat_b=='PUB' & cdf$status=='TS'] <- 34.9441
cdf$final.wgt[cdf$strat_b=='SFL' & cdf$status=='TS'] <- 58.0077

#check weight assignments to cdf$final.wgt
addmargins(table(cdf$final.wgt))


sites.CDF <- data.frame(siteID=cdf$site_id,
                    #Use=cdf$t_nt[cdf$t_nt=='T'])
                    Use=cdf$status=='TS')


# Create the subpop data frame, which defines populations and subpopulations for
# which estimates are desired
subpop.CDF <- data.frame(siteID=cdf$site_id,
                    All_Sites=rep("All_Sites", nr),
                    pop1=cdf$year)

# Create the design data frame, which identifies the stratum code, weight,
# x-coordinate, and y-coordinate for each site ID
design.CDF <- data.frame(siteID=cdf$site_id,
                    wgt=cdf$final.wgt,
                    #stratum=cdf$stratum,    above defined the subpopulations; no stratification in
the design
                    #xcoord=cdf$x,
                    #ycoord=cdf$y,
                    xcoord=cdf$xalbers,
                    ycoord=cdf$yalbers)

# Create the data.cont data frame, which specifies the variables to use in the
# analysis
data.cont.CDF <- data.frame(siteID=cdf$site_id,
```

```
               #  thalweg=cdf$thlwg,         #you could just replace "var1" with thalweg and
"var2" with wetted width
               #  wettedwidth=cdf$ww,
                             # bankfullwidth=cdf$bfw,
                             #  gradient=cdf$grad,
                             # elevation=cdf$wa30,
                             # slope=cdf$slope_avg,
                             #  area=cdf$area_ha,
                             #  aspect=cdf$aspect,
                             # lwd_d=cdf$lwd_down,
                             #  lwd_s=cdf$lwd_sus,
                             # lwd_j=cdf$lwd_jams,
                             #  lwd_t=cdf$t_lwd,
                             #  canopy=cdf$pcan)
                             # air_m_07=cdf$airtmx07,
                              air_7d_07=cdf$airt7d07)
                              # ustmx07=cdf$ustmx07,
                            #  ust7d07=cdf$ust7d07,
                            # dstmx07=cdf$dstmx07,
                            #  dst7d07=cdf$dst7d07
                            # dtempmx07=cdf$dtempmx07,
                            #    dtemp7d07=cdf$dtemp7d07,
                            #  airtmx08=cdf$airtmx08,
                            #  airt7d08=cdf$airt7d08,
                             # ustmx08=cdf$ustmx08)
                             #  ust7d08=cdf$ust7d08,
                             # dstmx08=cdf$dstmx08,
                             #  dst7d08=cdf$dst7d08,
                             # dtempmx08=cdf$dtempmx08,
                             #  dtemp7d08=cdf$dtemp7d08)

# Calculate the estimates
cat("\nCalculate Janish_CDF_estimates\n") # another section of the output file; the \n are
carriage returns
#needed unless you want one long line. \n\n creates two carriage returns.
sink()        #closes the diversion to the file; output again appears in the R window
if(exists("warn.df")) rm("warn.df")
between_yrs_results <- cont.analysis(sites.CDF, subpop.CDF, design.CDF, data.cont.CDF)
   #popsize=list("All_Sites"=7224,
          #pop1=list(IND=1487.745,
           #        PUB=1211.669,
           #       SFL=4524.586))
          #         "subpop4"=),
          # pop2=list("subpop1"=,
          #         "subpop2"=,
           #        "subpop3"=))
```

```
# Check for warning messages and print them if any exist
sink("between_yrs.txt", append=TRUE) #opens the file again; the append
#adds the new output to the original output; without the append, the original would
#disappear.
if(exists("warn.df")) {
  cat("\nWarning messages generated during the call to cont.analysis:\n\n")
  warnprnt()
} else {
  cat("\nNo warning messages were generated during the call to cont.analysis.\n")
}

# Write CDF estimates as a comma-separated value (csv) file
write.table(between_yrs_results$CDF, file="between_yrs_results.csv", sep=",",
         row.names=FALSE)

# Create a PDF file containing plots of the CDF estimates
cont.cdfplot("between_yrs_results.pdf", between_yrs_results$CDF)

# Write percentile estimates as a csv file
write.table(between_yrs_results$Pct, file="between_yrs_percentiles.csv", sep=",",
         row.names=FALSE)

## Close the output text file
sink()
# Test for differences among CDFs which I didn't do in the example
#

CDF_Tests <- cont.cdftest(sites.CDF, subpop.CDF, design.CDF, data.cont.CDF,
   popsize=list("All_Sites"=7224,
            pop1=list(T07=7224,
                   T08=7224)))
                #    SFL=4524.586)))
               #      "subpop4"=),
            # pop2=list("subpop1"=,
             #        "subpop2"=,
              #        "subpop3"=)))

# Write CDF test results as a csv file
write.table(CDF_Tests, file="CDF_Tests.csv", sep=",", row.names=FALSE)

# Close the output text file
sink()
```