Empirical Evaluation of Temperature Effects on Bull Trout Distribution in the Northwest

FINAL REPORT
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to
Donald M. Martin
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Bruce E. Rieman and Gwynne L. Chandler
U.S. Forest Service, Rocky Mountain Research Station
316 E. Myrtle St., Boise, Idaho 83702

Phone:(208) 373-4340
e-mail: brieman@fs.fed.us

Introduction

Temperature is one of the fundamental elements describing suitable and available habitat for fishes (Magnuson et al. 1979). Temperature directly influences physiological processes with obvious implications for growth, behavior, and distributional or habitat preferences (Shuter and Post 1990 ; Welch et al. 1998). It also may influence biotic interactions such as competition and predation (Destaso and Rahel 1994; Taniguchi et al. 1998). Temperature appears to be a particularly important factor influencing bull trout (Salvelinus confluentus). At least temperature is frequently cited as a critical element defining habitats for bull trout (Rieman and McIntyre 1993; Buchanon and Gregory 1997) and has become a central concern in environmental management for this species.

Temperature may be no more important for bull trout than for other species, but its role may be more obvious. Bull trout seem to have lower temperature preferences or requirements than other salmonids (Rieman and McIntyre 1993) that may in turn restrict the amount of suitable habitat. Much of the recent work with bull trout also has been conducted on the southern limits of the species range where temperature may be particularly obvious in defining suitable/available habitat (Rieman et al. 1997). The influence of temperature on bull trout has been inferred primarily from distributional information. The occurrence of bull trout has been strongly associated with elevational (Rieman and McIntyre 1995; Dunham and Rieman In Press) and thermal (Pratt 1984) gradients in streams and thermal gradients in individual habitats (Bonneau and Scarnnechia 1996). There also are repeated anecdotal observations that bull trout do not occur or are much less frequently observed above certain threshold temperatures (e.g. Fraley and Shepard 1989; Rieman and McIntyre 1993).

The current interest in temperature and bull trout is based in two issues. First, despite the evidence that temperature is important and that bull trout use or require lower temperatures than other species, we have relatively little empirical information useful in estimating critical temperatures of temperature regimes that actually define suitable habitat. Second, if temperature does restrict bull trout to less extensive habitats, changes in stream temperatures resulting from land use or climate change may lead to population declines and local extinctions (Rieman et al. 1997). Because many bull trout populations are already believed to be at risk, temperature may be a critical element in the persistence of many populations.

Temperature criteria are often established in environmental regulations designed to protect coldwater fishes. Those criteria often take the form of thresholds not to be exceeded during some period of time. Often the criteria are based on temperature tolerances estimated in laboratory studies. This particular approach has been criticized for several reasons. First, laboratory responses may not accurately reflect the influence of temperature in the more complex ecological context. Temperatures that allow fish to merely survive may not allow a population to thrive in the face of natural disturbances or other environmental challenges. Temperatures that are associated with optimal growth or behavioral preferences may shift dramatically with variation in forage, competition, or other ecological issues (e.g. Magnuson 1979; Welch et al. 1998).

Second, fishes have evolved with seasonally varying temperature “regimes”, not some uniform pattern implied by a temperature threshold or optimum. Local and regional adaptations in behavior and life history are likely tied to predictable patterns in environmental variation (Poff and Ward 1990). Plasticity in life history or behavior allow for flexibility, but the bounds of that flexibility are poorly known. Maintenance of the temperature regime characteristic of natural patterns may be key to the maintenance of resilient and adaptable populations.

Third, empirical information is often limited. Thresholds based on limited or anecdotal information must necessarily be conservative. The fact that individuals or populations can be observed at higher temperatures leads to contentious debate, but lacks any relevant context for interpretation of the risks such temperatures may represent.

In an attempt to develop a basic understanding of temperature requirements for bull trout two general approaches have been proposed. First, is the identification of temperature relationships based on laboratory studies. This approach should allow validation of apparent differences between bull trout and other species and provide the first approximation of optimal temperature ranges. Preliminary studies are subject to the first two concerns described above and ultimately may require more complex studies that consider environmental variation in some detail. Second, is work that explicitly relates ecological patterns or processes to natural temperature gradients or regimes in the wild. Such correlative field studies also are vulnerable to the confounding effects of uncontrolled variables, but do provide the potential for more generalizable models and an important context for understanding environmental variation. Ultimately both approaches are probably necessary and complimentary.

Eaton et al. (1995) provide an example of the second approach by estimating temperature tolerances from field observations of species occurrence and associated temperature records. The general approach proposed by Eaton et al. is appealing in power provided by a large sample. A signal evident in the noise of highly variable environments and sample error is often robust and generalizable. Arguably, a large number of temperature observations associated with a broad representation of a species distribution provide a description of the temperature regime that is associated with an equally broad range of environmental conditions. The distribution of temperatures represents an estimate of the natural environmental variability associated with suitable habitat. One limitation of this approach is the reliance on existing data and the lack of an *a priori* sampling design. Although the distribution of temperatures where bull trout occur provides an approximation of the range of suitable temperatures it is difficult to draw inferences about preferred or optimal temperatures. One solution may be to incorporate information on both the presence and absence of bull trout to consider the relative probability of occurrence at different temperatures.

In this report we summarize progress in an effort to develop empirical descriptions and models of the temperature regimes associated with the occurrence of bull trout. The current concerns and information needs and the growing body of temperature records from inexpensive data loggers stimulated our interest in a pilot project. In 1997 at the annual workshop of the *Salvelinus Confluentus Curiosity Society* we proposed a collaborative project to determine whether such an approach was useful (Appendix A). A number of biologists currently maintaining thermograph networks across the range of bull trout expressed interest. Our objectives in this project were as follows:

1) To construct a database of consistent, reliable, temperature records associated with the occurrence of bull trout; screen the data for potential outliers; verify observations and sampling protocols; and store in a standardized format.

2) To develop preliminary summaries and data that can be shared among biologists; provide preliminary description of temperature regimes associated with suitable habitat that may be used for local perspective.

3) To make recommendations for further work.

Methods

Data Acquisition

Our general approach was based in the accumulation of thermograph records throughout the current range of bull trout. In the fall of 1997 we requested data in electronic format from biologists who indicated an interest in the project (Appendix A).

Minimum information required for each record was as follows: name and address of the source; records of at least 1 month in duration; initiation date; uniform sampling interval of not less than 4 instantaneous observations per day; site location resolvable within 1 minute of longitude and latitude; status of bull trout within 500 m of the site (unknown was a potential response; Appendix A). Bull trout distributions and the influence of temperature may vary with life stage, and seasonally with some life stages (Rieman and McIntyre 1995; Dunham and Rieman In Press). From our own observations, juveniles move far less than subadult or adult fish that may use some habitats only seasonally. Because juveniles and resident forms may reside in some stream segments or local networks for several years or more, it is less likely that small bull trout (i.e. <150mm) will persist at sites solely through the exploitation of small thermal refugia. We assumed that the occurrence of small bull trout should be more closely associated with the thermal regimes we seek to describe. For that reason we asked that biologists document the occurrence/ non-occurrence of juvenile or small bull trout whenever possible.

Optional information that we requested included elevation at the site; presence of other fish species; wetted width; and availability of other more detailed information related to the site or aquatic community (Appendix A).

All data, the header information and metadata were stored in Oracle[1] tables linked by *site_id* (Appendix B). Because the available records varied in format and sampling interval we summarized the raw data to standardize observations daily mean, maximum and minimum in C. The "standardized" data set was used for all further summary and analysis and is the primary format that will be made available for general use (The complete data set can be made available on request).

[1]The use of trade or firm names in this paper is for reader information only and does not imply endorsement of an product or service by the U. S. Department of Agriculture

Verification and Quality Control

We took several steps to consider the accuracy and quality of the data. After incorporation into the complete database all records were plotted and inspected visually to identify unusual observations that might indicate malfunction of the thermograph (e.g. rapid rise in temperature associated with dewatering). We used numeric filters to identify any observations >30 C or <-1C or any series of observations with a rate of change >3C per hour. The latter rate was based on the maximum rate of change observed in over 150 thermograph records from our own network. All observations and the standardized daily observations were inspected in scatter plots to identify outliers from the generalized thermal regime. Finally all remaining records with observations falling in the upper or lower 5% of observations in any day were flagged as potential outliers.

Each header sheet, the plot of the daily observations for each record, and the list of observations flagged through the analysis described above, were returned to the source for inspection and verification. Each source was asked to consider the flagged observations and justify their inclusion/exclusion from the data set. Each source was also asked to review their protocols for thermograph calibration and deployment (all records) with special reference to known problems (e.g. lack of calibration, clear housings, placement subject to unusual conditions). Verification was initiated by letter and followed by direct contact via phone or internet.

At the time of this report, verification with the data sources was still in progress. Final analysis of the data set will not proceed until verification is complete. Records that cannot be verified will remain flagged as suspect in any further analysis.

We considered the potential bias in the daily summary observations based on the minimum of only four instantaneous observations per day. Two sites with 96 observations per day were resampled repeatedly at the rate of four observations of uniform interval. The summary statistics were compared between the complete and subsampled data sets. The absolute error for any of the metrics ranged from 0.00 to 0.03 C. The potential bias was greatest for the summer maximum (Table 1). We considered the potential magnitude of error in all metrics to be insignificant and retained all observations with the minimum interval.

Table 1. Resampling comparison of two sites from the Salmon River, Idaho. Each iteration represents a new starting point for six hour interval sampling. N is the number of instantaneous readings per day.

Site	Reach	Iteration	n	Summer Mean	Summer Maximum	Summer Maximum 7-Day Mean
Salmon River	1	0	96	16.03	16.72	16.23
		1	4	15.97	16.52	16.18
		2	4	16.05	16.61	16.25
		3	4	16.03	16.56	16.22
		4	4	16.02	16.56	16.22
Salmon River	4	0	96	16.20	17.19	16.52
		1	4	16.20	16.91	16.53
		2	4	16.25	16.97	16.57
		3	4	16.18	16.92	16.49
		4	4	16.14	16.89	16.45

Preliminary Analysis

Because the verification is incomplete we conducted only a preliminary summary and analysis of the data.

We plotted the temporal and spatial distribution of all observations to consider the representation in the existing data set. All locations were converted to UTMs to provide unbiased spatial coordinates in any further statistical analysis.

We generated scatter plots of all observations to consider the thermal regime characteristic of bull trout habitat. We focused the more detailed summaries on summer temperatures for two reasons. Bull trout are thought to be particularly dependent on colder water and any constraint on the distribution associated with high temperatures should be particularly apparent during that period. There are substantially more observations available during the summer-fall period than other times of the year (Figure 1). The complete data set show a unimodal distribution of temperatures centered between July 15 and August 31 (day 196 to day 243). To simplify our preliminary analysis of relationships between bull trout and temperature we further summarized each record to single observations for that period; the mean of all observations, the maximum of all daily maximums, the maximum of the seven day moving mean of daily means, and the number or proportion of days with daily mean exceeding 12 ^{o}C.

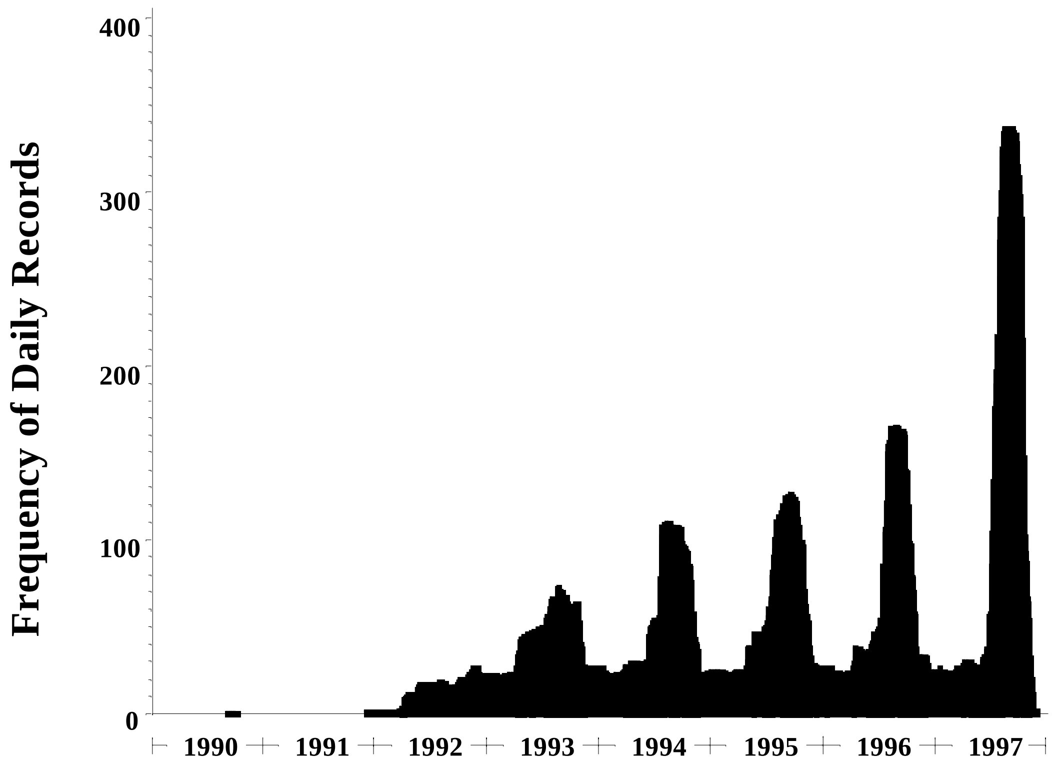

Figure 1. Frequency distribution of daily temperature records by year and day.

Selection of any particular one may be more important for regulatory debates than in considering the fundamental hypothesis about temperature and fish distribution. We chose a variety here simply to demonstrate the range of results that may be produced. The metrics we selected for this summary were arbitrary, but are similar to those used in other analyses or the development of temperature criteria in environmental regulations. Although any number of temperature statistics might be considered, we anticipate that many will be strongly correlated. Until a broad range of statistics can be evaluated generated scatter plots and correlation coefficients to compare the potential redundancy among our choices.

We used frequency distributions of the summary statistics to identify the range and distribution in temperatures associated with the occurrence of juvenile/small bull trout.

Results

Twenty-five biologists (Appendix C) provided information for the development of the data base. A total of 581 sites and 908 records (site/year observations) are included in the current version. Data for approximately 350 more records and sites have either been submitted to us or are readily available, but were not included in the current version of the data base because of time constraints. The observations span 4 years, with more observations available during summer and in recent years (Figure 1). The current data provide a broad representation of sites in the southern part of the species range, but are weak to the north (Figure 2). These observations should represent a wide range of environmental and ecological conditions associated with the southern limits of the species' range.

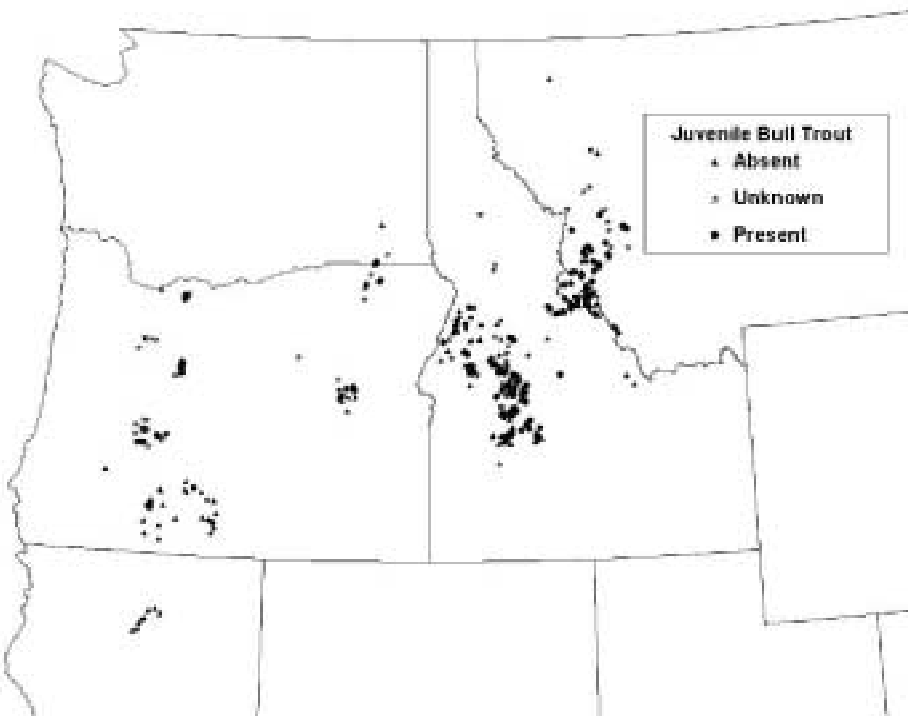

Figure 2. Distribution of thermograph sites with at least four instantaneous readings per day over a thirty day period.

The verification is still in progress. At the time of this report 7 sources have verified their potential outliers and 4 of these sources have verified their protocols. This leaves much of the data set unverified. The summaries that follow include flagged observations and records that remain unverified.

The maximum temperatures associated with the occurrence of juvenile bull trout ranged from 0 to almost 30 °C, although 95% of the observations were less than 18 °C and the majority were less than 14 °C (Figure *3*). There was a similar pattern (but obviously lower values) with the observations of daily means (max < 23 °C; 95% <14 C; most <9 °C) (Figure 4). A clear seasonal pattern was evident in the data set with the warmest period between mid-July and late August, the period we refer to as “summer” in the remainder of the report. The frequency distributions of the summer daily observations (Figure 5) and the summary statistics (single value for entire summer) (Figures 6,7,8,9) were generally unimodal and lower where juvenile/small bull trout occurred than where they did not.

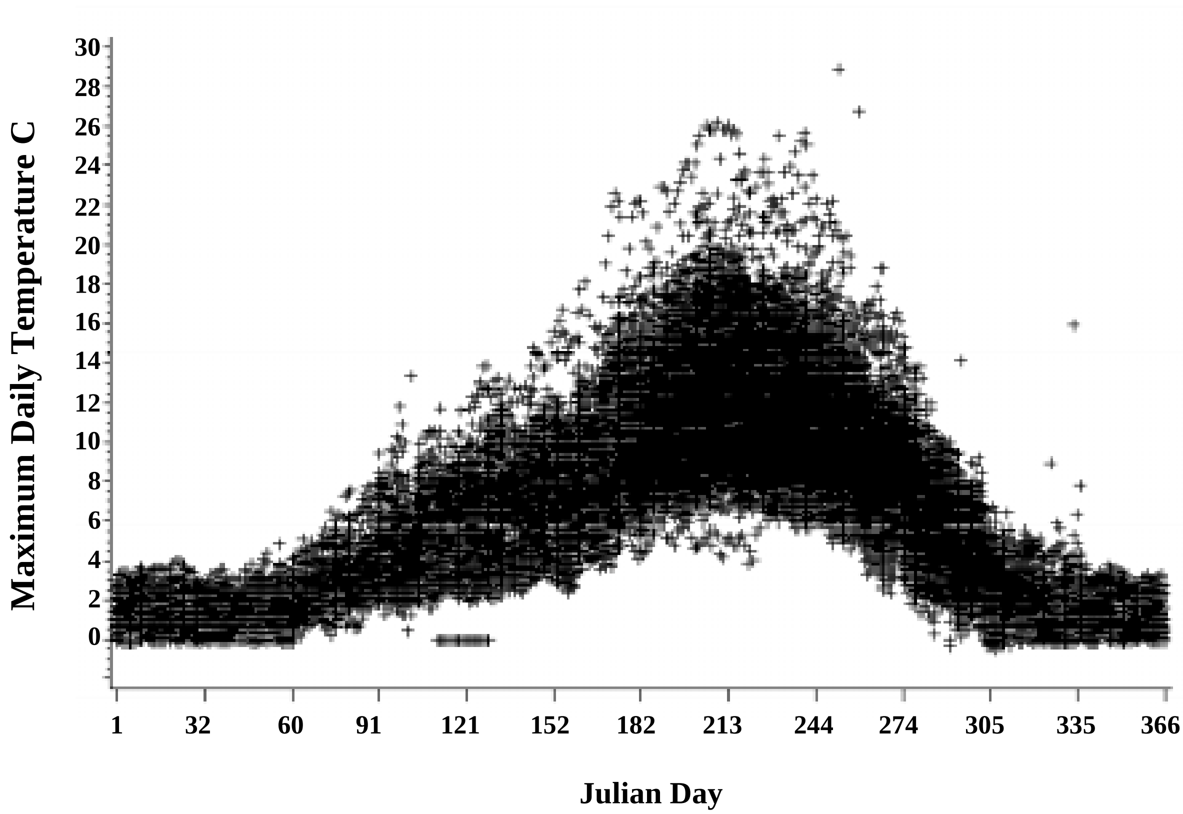

Figure 3. Scatter plot of maximum daily temperatures by day at sites with juvenile or small bull trout.

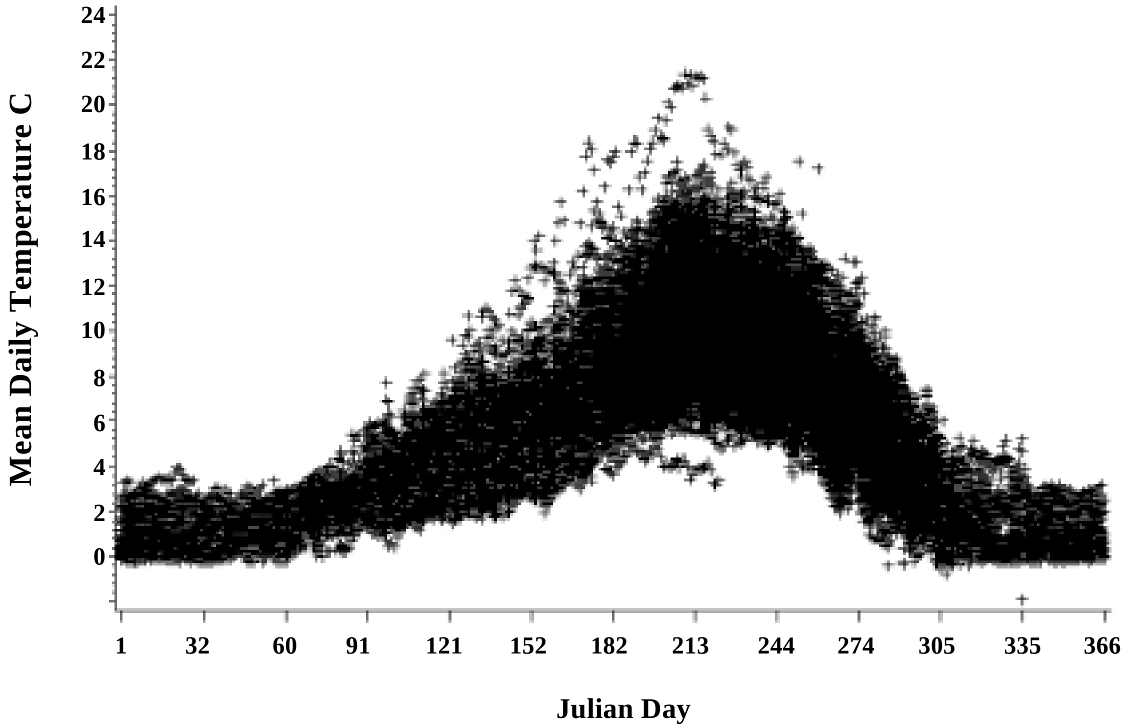

Figure 4. Scatter plot of mean daily temperatures by day at sites with juvenile or small bull trout.

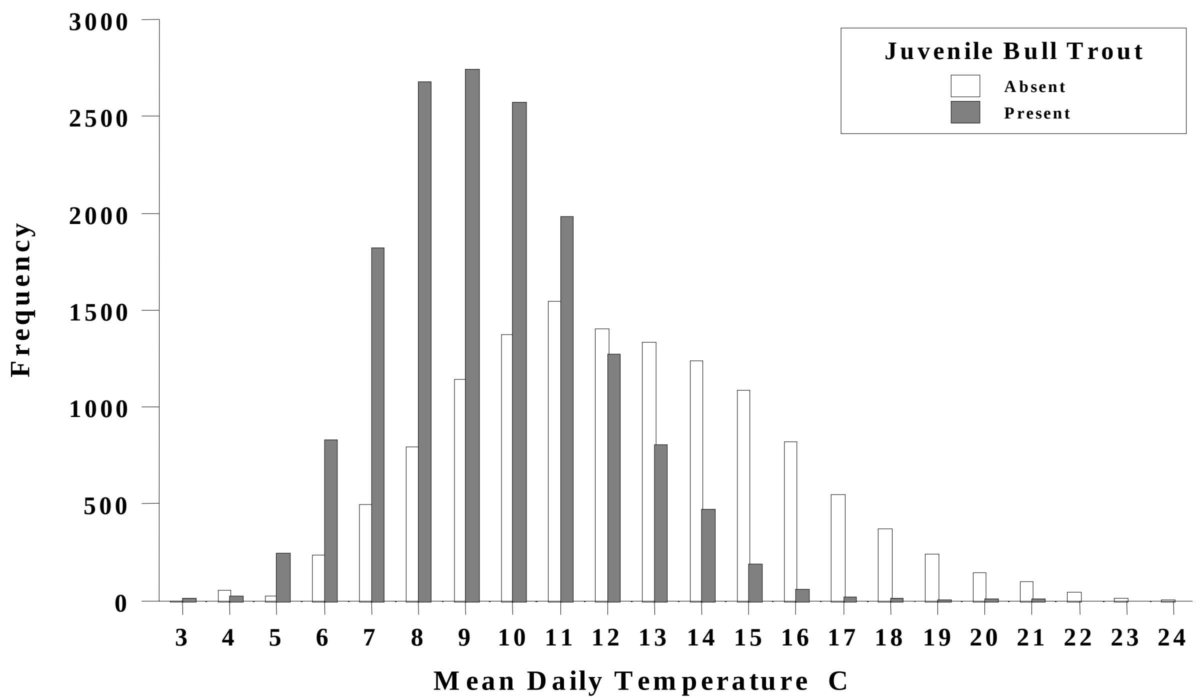

Figure 5. Frequency distribution of summer daily mean temperatures at sites with and without juvenile or small bull trout.

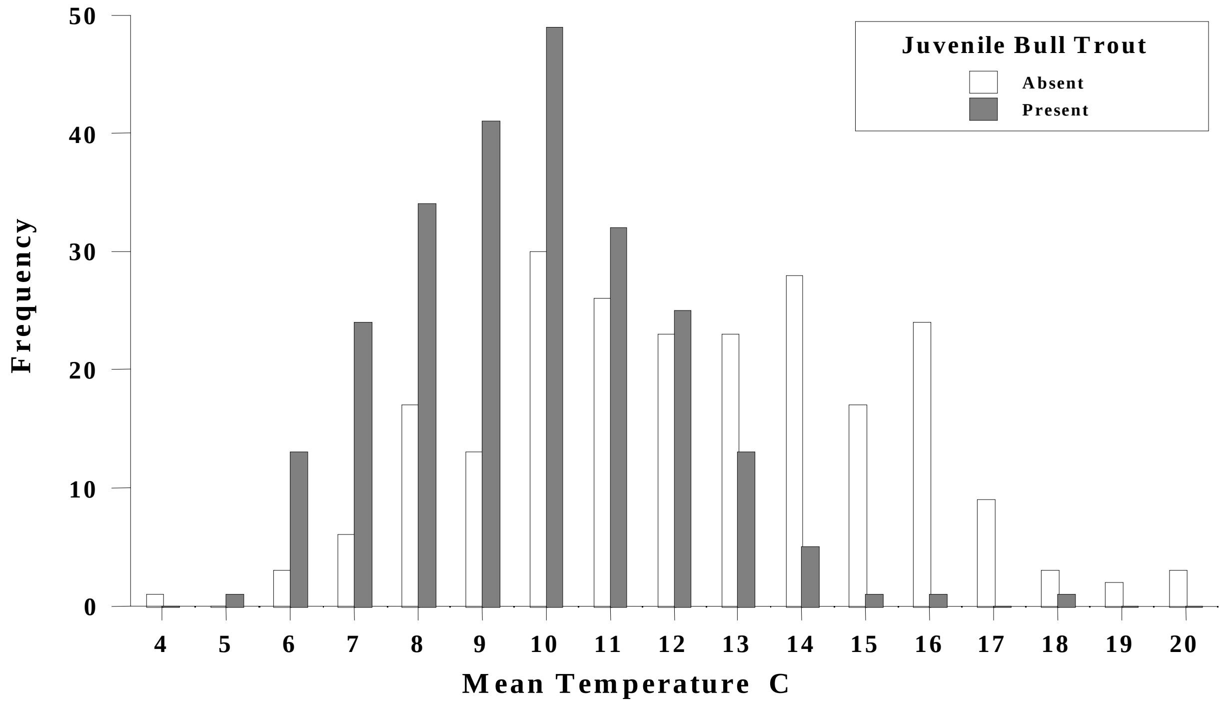

Figure 6. Frequency distribution of the overall summer mean temperature at sites with and without juvenile or small bull trout.

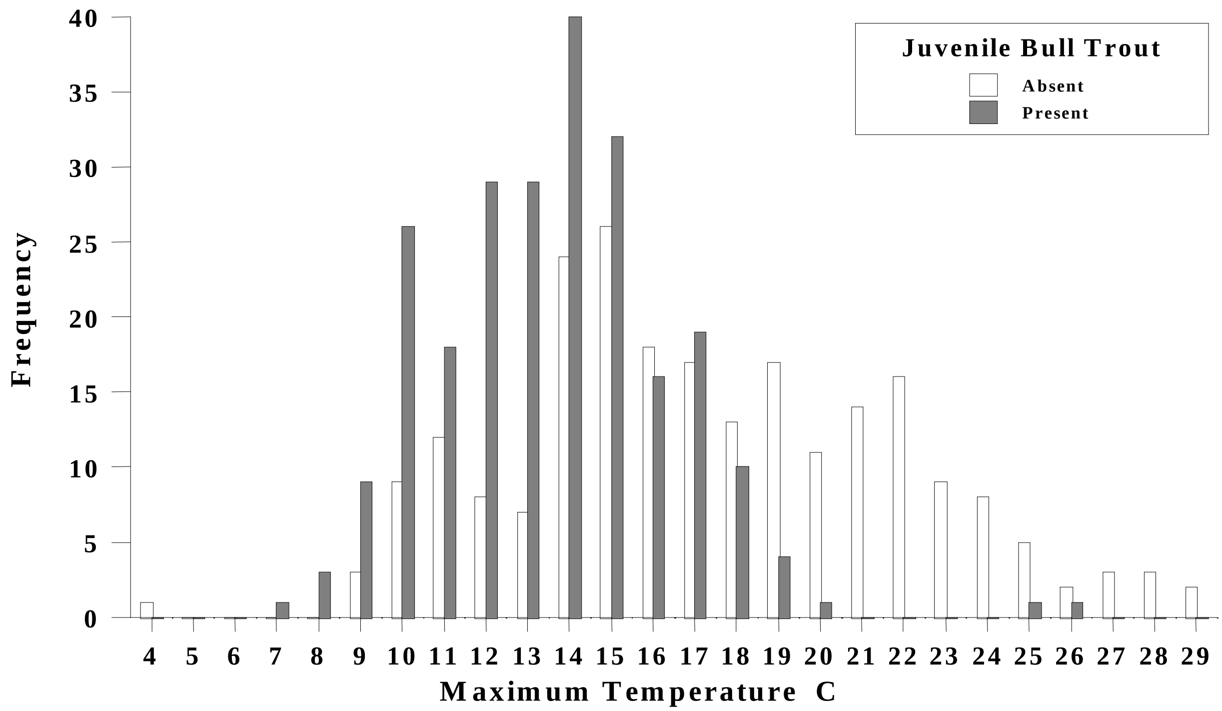

Figure 7. Frequency distribution of the summer maximum temperature at sites with and without juvenile or small bull trout.

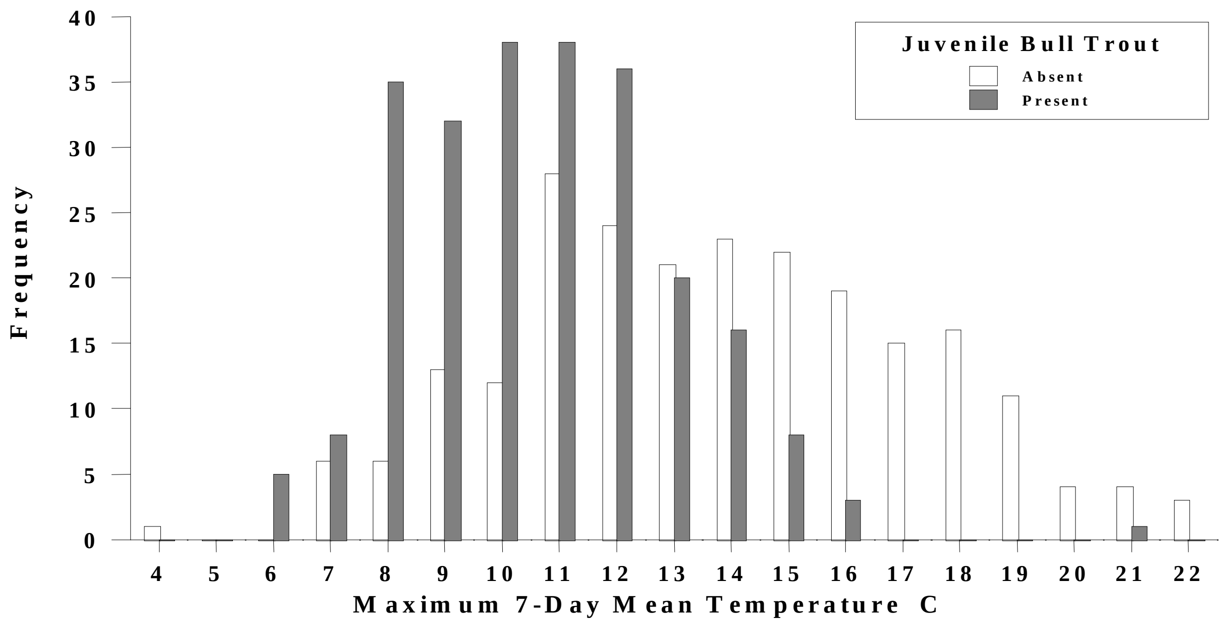

Figure 8. Frequency distribution of the summer maximum 7-day mean of daily mean temperature for sites with and without juvenile or small bull trout.

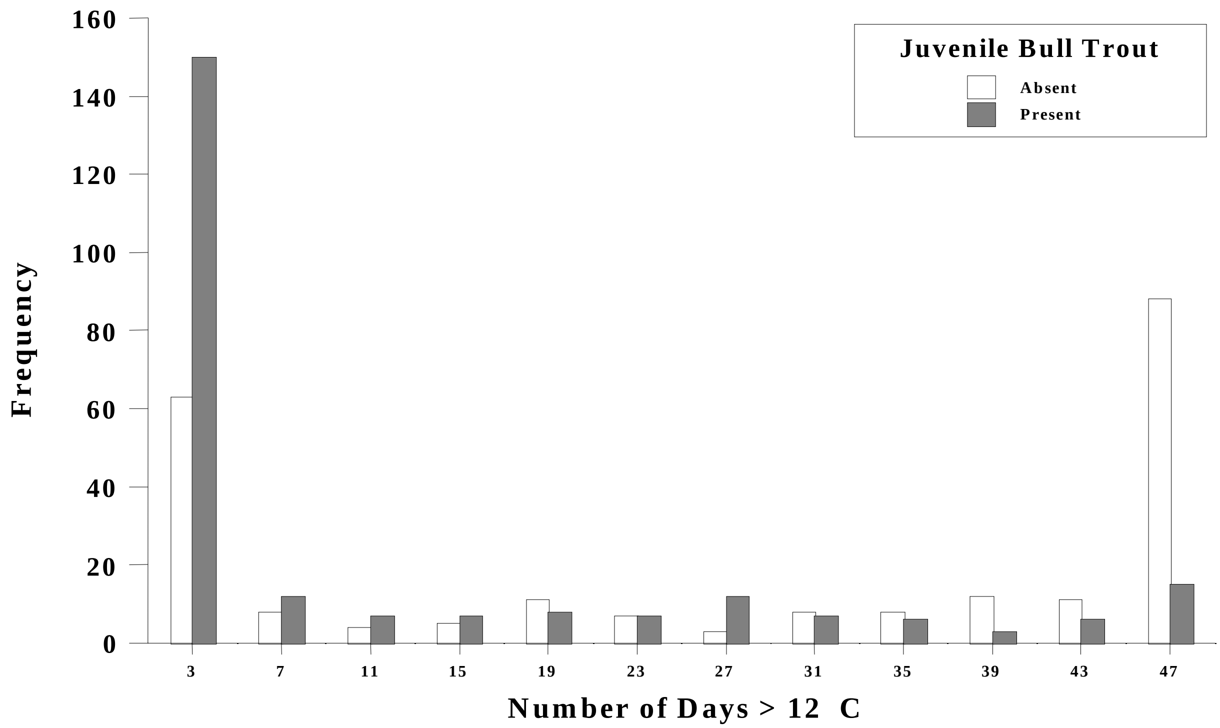

Figure 9. Frequency distribution of the number of days in the summer that the mean daily temperature exceeded 12 C at sites with and without juvenile or small bull trout.

The proportional representations of the same data (Figure 10) indicate that the probability of occurrence declines at higher temperatures especially if observations with limited sample sizes (n<10) are ignored. Juvenile/small bull trout appeared most likely to occur at summer- mean temperatures of 6-9 ^{o}C, summer-maximum 7 day means of about 8-10 ^{o}C, single maximums of 11-14 ^{o}C, or at sites where the daily mean exceeded 12 ^{o}C for less than 15-30 days.

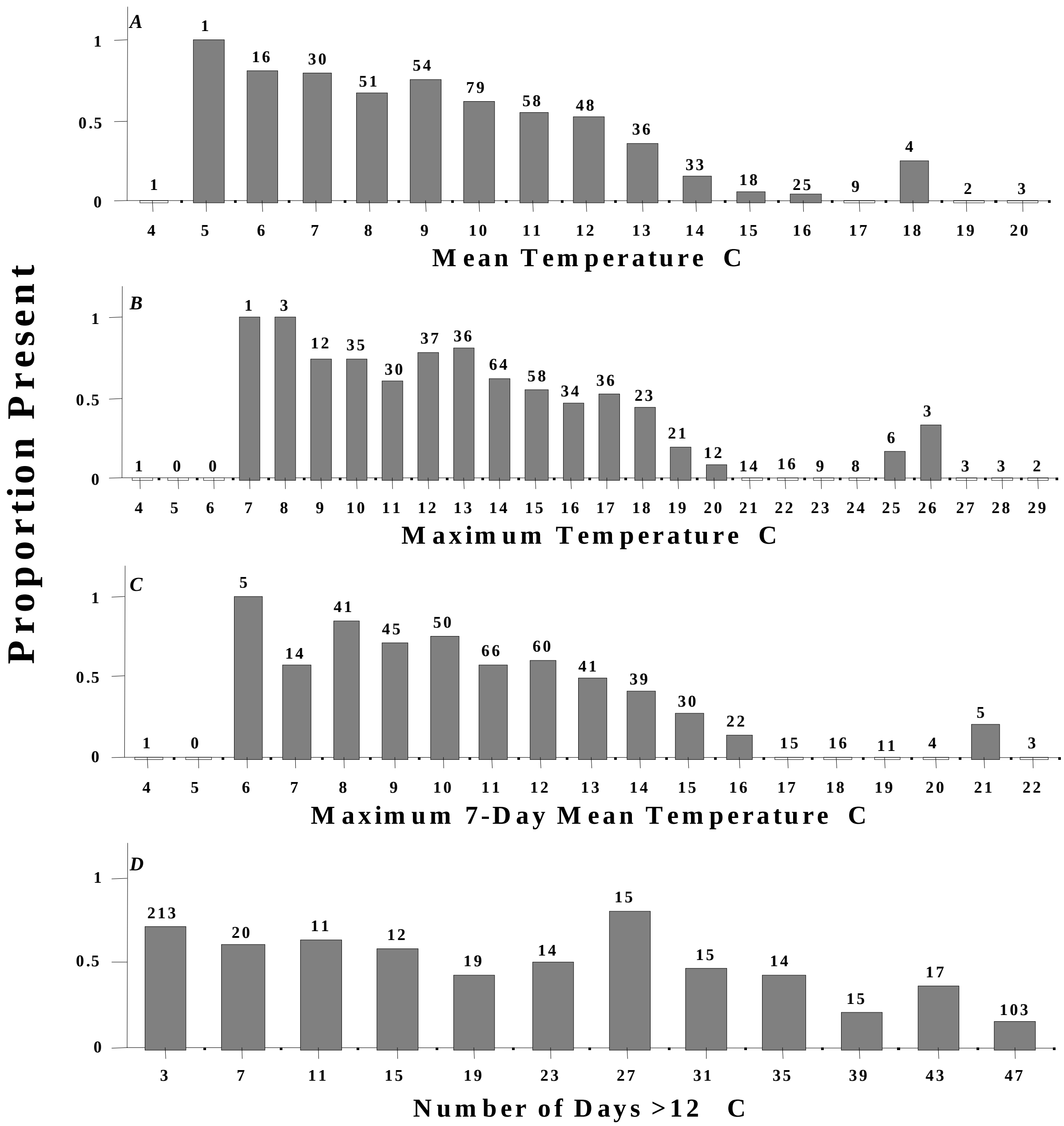

Figure 10. Proportional representation of juvenile or small bull trout present for the four temperature metrics used in this report. A is the summer mean temperature; B is the summer maximum temperature; C is the summer maximum 7-day mean temperature; and D is the number of days the mean daily temperature exceeded 12 C.

All of the temperature metrics were strongly correlated (Figure 11). This was expected as the metrics used in this report are not independent. There are other temperature metrics that could be used to describe fish distributions; a logical next step would be to explore those that are not strongly correlated with the more traditional measures.

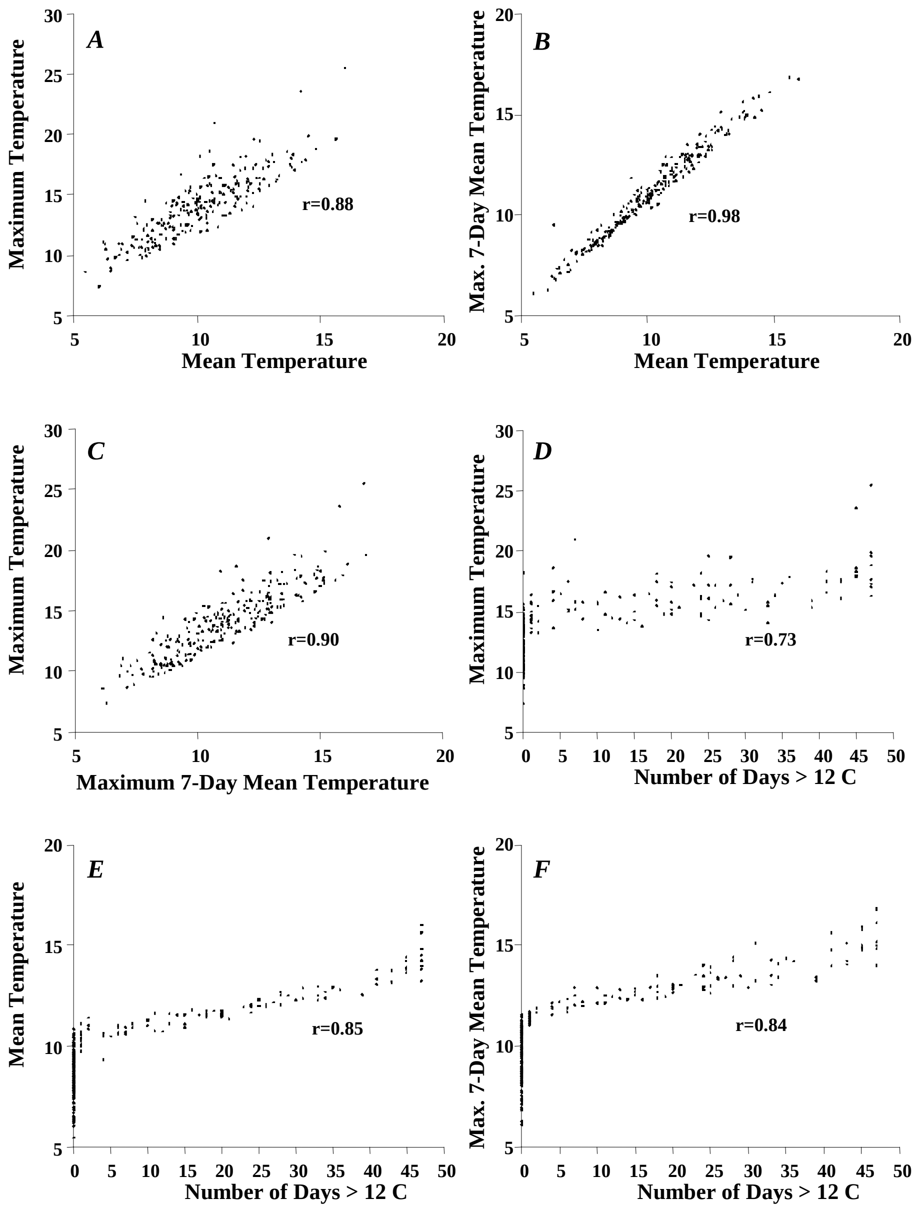

Figure 11. Scatter plots of the temperature metrics used in this report. A is summer maximum temperature by summer mean temperature; B is summer maximum 7-day mean of daily means by summer mean temperature; C is summer maximum temperature by summer maximum 7-day mean of daily means; D is summer maximum temperature by number of days the daily mean exceeded 12 C; E is the summer mean temperature by the number of days the daily mean exceeded 12 C; and, F is the summer maximum 7-day mean of daily means by the number of days the daily mean exceeded 12 C.

Discussion

A collaborative approach was successful in generating a large data set on temperature and bull trout distribution. Verification of observations and methods has been more difficult than anticipated and remains incomplete. Because verification requires involvement of biologists who have other responsibilities and are participating out of professional interest rather than formal obligation, progress has been slow. We are optimistic, however, that all of the biologists who made the initial effort to participate will find it useful to continue to support the project. Many of those who have responded to date have commented on the utility of the data in providing a perspective for their own systems and populations.

The current data provide a broad representation of the species' potential distribution that should also encompass a broad range of environmental and ecological conditions. We believe the completed data set will provide a new and generalizable picture of the thermal environments characteristic of suitable bull trout habitats. Preliminary summaries suggest for example that juvenile/resident bull trout occur across a wide range of "summer" temperatures and at temperatures considerably higher than commonly indicated in the available literature. The distribution of observations, however, also indicates that the occurrence of bull trout at higher temperatures is not particularly common. For example, bull trout were observed more frequently and appear more likely to occur at summer means of about 6-9 ^{o}C or with summer maximums less than about 13-14 ^{o}C. These values are similar to existing observations associated with rearing and habitat preference (e.g. Buchanan and Gregory 1997; Bonneau and Scarnecchia 1996). Although the larger data set should help refine estimates of critical temperatures for bull trout it should also provide an important context of the spatial and temporal variation in temperature associated with bull trout habitats. Models of occurrence across a broad range of environments might be particularly useful in describing the expected suitability of different temperatures given the uncertainty in other ecological conditions.

The information provided in this report is only a preliminary summary to demonstrate progress in development of the data set. Verification of the data set is necessary to correct any errors in the data transfer/entry and to identify and remove erroneous and misleading observations. Further analysis or interpretation is not warranted until that verification is complete. Until then the data cannot be used or referenced in any application.

We have chosen not to pursue the formal analysis because the data are incomplete, but also because it is beyond the scope of the original plan of work. Once the data set is complete it will be made available to all participants and interested parties. Our intent was to support a variety of analyses and comparisons that may illuminate temperature relationships with bull trout. We see several important issues for further work.

One particular issue to consider in any analysis will be the lack of a formal sampling design in the generation of the observations. The thermograph data are essentially the result of monitoring efforts initiated for a variety of reasons. Even though we have generated a lot of observations across a broad region, those observations may still produce a biased representation of bull trout habitats. We see two possibilities for addressing this problem. First, "found data" analytical methods (Overton et al. 1993) might be used to consider the magnitude of and correct for any bias in the summary distributions of temperature. Second, the application of categorical methods (e.g. logistic regression) to model patterns of occurrence as a probability rather than simple frequencies. The results displayed in figure 10 suggest that this could be a useful approach. This type of analysis may be particularly valuable because it can provide an estimate of the relative suitability of different temperatures or temperature regimes given a complex range of ecological conditions.

Other issues include unbalanced representation of sites (some have more years than others) and uncertainty in the most useful/relevant summary statistics (e.g. max temp. vs. frequency of exceedence). Further work might also consider resampling techniques to mitigate the problem of non-independence in replicate observations with sites. Selection of summary statistics might be based in an analysis of the covariance and discriminatory power of the alternatives.

Given a careful verification and analysis we believe the existing data can provide an important, general model of the temperatures representative of suitable bull trout. Despite that apparent utility, the approach has some limitations.

Observations are not necessarily linked to the occurrence of fish precisely at that site. Because stream temperatures are not uniform and because fish may exploit relatively small thermal refugia (Torgersen et al.; Bonneau and Scarnecchia 1996), recorded temperatures may not be representative of what fish actually experience. This might lead to an overestimation of suitable temperatures.

The approach is essentially correlative and the apparent patterns could be spurious, resulting from relationships with some other confounding variables. Introduced species, or habitat degradation, for example, may have displaced bull trout upstream into colder waters. Whether such a response represents a shift in thermal optima linked to some ecological interaction (e.g. Magnuson et al. 1979) or merely a displacement into a region that happens to be colder cannot be known from the simple association. This could lead to an underestimation of suitable temperatures.

In any case, limitations such as these will accompany virtually any empirical analysis and simply mean that the initial results must always be interpreted with caution. Further research will always be useful to corroborate patterns and to look for confounding or modifying effects. We plan to continue the verification of the existing data and make the following recommendations for further work:

- “Found data” methods should be explored as a means of considering the bias in the distribution of observations. The data are spatially referenced and can be easily linked to existing GIS coverages of landscape and hydrologic characteristics within the potential distribution of bull trout. By considering the distribution of existing sites across potentially important environmental gradients it may be possible to detect and even estimate the relative bias.

- A number of independent river basins are well represented in the current data. Incorporation of “regional effects” into the models or analysis and comparison among subsets of the data base may clarify the generality of the data and help identify confounding effects. Incorporation of other effects in the models (i.e. occurrence of brook trout) should also be explored. Additional variables on many sites are available from the original data sources.

- A variety of temperature statistics have been used or proposed in the general literature or environmental regulations. There is no clear logic that favors any particular approach. Selection from many statistics may be unimportant if they are strongly correlated. Further work should consider both covariation and relative discriminatory power of different temperature statistics.

- No single approach can clearly resolve all of the questions about the influence of temperature on fish distributions or populations. Laboratory and field studies have different limitations that may lead to complimentary results. A collaborative effort to compare and contrast the results from variety of approaches including laboratory and both broad and fine scale field studies should be pursued.

- The sites chosen to explore the question of the number of instantaneous readings required in a day were from a single river system. The daily variation of temperature may not be representative of the dataset as a whole. A more detailed analysis of the potential bias resulting from sampling interval should be completed.

Acknowledgments

Development of the data set is the direct results of work and support by the biologists named in Appendix C. Debby Myers, Dona Horan, Sharon Parkes, Kelly Gillogly, and Lori Leatherbury helped with acquisition of data and construction of the data base.

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Appendixes

Appendix A. Cover letter and header sheet mailed to potential participants as a request for data.

DRAFT
September 5, 1997
MEMORANDUM

TO: Concerned Scientists Interested in Bull Trout

FROM: Donald M. Martin, Aquatic Ecologist, USEPA, Boise
Bruce Rieman, Fisheries Research, USFS-Rocky Mtn. Station, Boise

SUBJECT: Development of a Regional Database of Temperature Records

The U.S. Environmental Protection Agency (EPA) recently promulgated temperature criteria for bull trout in Idaho's waters. During that process it became apparent that relatively little empirical information could be summarized to support the resulting criterium. The criterium is specific for bull trout spawning and juvenile rearing. The Final Rule as published in the Federal Register and Technical Justification from the Administrative Record are attached. With the advent of computerized recording thermographs, temperature monitoring has become common place. Consequently a large body of data should be available for application to this and similar problems. Eaton et al. (1995) outlined an empirical approach for defining fish temperature tolerances from temperature monitoring data associated with the presence of individual species. By considering species presence and absence, as well as the occurrence of specific life stages it should be possible to develop more rigorous models or even contrast patterns of habitat use across the species range. Biologists associated with the *Salvelinus confluentus* Curiosity Society (SCCS) and several natural resource agencies have indicated an interest in collaborating to develop a database that could serve this purpose. Based on the initial response and interest in the proposal it should be possible to develop hundreds if not thousands of records (The U.S. Forest Service Rocky Mountain Research Station can contribute more than 120 stream-year observations from work over the last 4 years in southern Idaho).

We are developing a broad-based collaborative effort to develop such a database for bull trout. Based on the initial response and interest in this effort, it should be possible to develop hundreds if not thousands of records. The EPA-Region 10 is providing some funding for the development of the database. The Rocky Mountain Research Station of the U.S. Forest Service in Boise, Idaho is also providing support and is coordinating the initial development. The intent is to develop information to be shared by all who participate. Any analyses could be independent or collaborative. Pending results those participating could decide to continue the effort or drop it in favor of more localized efforts.

To facilitate this project we propose some simple criteria for data, a metadata template, and a protocol for development of the database. Data can be shipped on diskette in the mail or by e-mail. We propose to hold the first version of the database open until December 15, 1997. With some time for data entry and solving typical problems of consistency and compatibility an initial version could be ready for distribution sometime in the spring of 1998. Any analyses and summaries could be presented and discussed at the 1998 SCCS meeting in Nevada. Those interested in collaboration on further analyses or continued development of the database could propose and discuss that work at the meeting. The intent would be to generate a database useful to those who contribute information, but because Federal funds would be used in the process the information would be available to anyone. We propose simply to maintain a record of contributors and users to fully acknowledge any work.

Proposed Criteria and Format:

Thermograph Records- Any records (F or C) from electronic, recording thermographs with a minimum of 4 observations per day, or the daily maximum and minimum, for at least 1 month. Data provided in ASCII, SAS, QuatroPro, EXCEL, Lotus, Paradox or Oracle format. Files must include a thermograph generated date and time code (e.g., HOBOtemp) or the initiation date, time, and recording interval (e.g., Ryan Tempmentor). Because the recording intervals for the data are likely to vary widely, we propose to summarize only the daily mean, daily maximum, and daily minimum for inclusion in the database.

Bull Trout Occurrence- Each thermograph record should be associated with presence or absence (or unknown occurrence) for bull trout. In our own work (e.g. Rieman and McIntyre 1995) we've observed a strong association between the occurrence of bull trout and elevation/climate/stream temperature. The pattern seems to be particularly strong for juvenile fish. Although adults and subadults are also associated with colder waters, seasonally they may range widely and have been found at higher temperatures than juveniles. For this reason we propose to characterize thermograph records based on three life stages: 1) occurrence of juveniles (pre-migrant) or permanent residents, 2) migration corridors, or 3) spawning. To strengthen potential analyses we also propose to include records for waters where bull trout could (i.e., they are physically connected to bull trout habitat) but do not occur. Recognition of "juveniles” is problematic because fish may migrate at age 0 and mature at less than 150mm. In our own work we have assumed that fish less than 150 mm were either juveniles or residents. The point is to identify stream habitats that fish use throughout the year vs. those that are used

only seasonally or not at all. The criteria for recognizing those areas may need some local modification. Each record should be characterized as follows:

Required Information

Juvenile/Resident Rearing- Yes/No/Unknown- Juvenile or resident fish presence/absence has been documented within 500 meters of the thermograph site and bull trout are presumed to (occur/not occur) at or near the thermograph site year round.

Migratory Corridor or Seasonal Habitat- Yes/No/Unknown -Bull trout have been documented to occur on a seasonal basis either during migration to and from natal habitats or in wintering/summering/staging. If yes include the approximate time of occurrence (months of the year).

Spawning- Yes/No/Unknown- The presence/absence of spawning has been documented with 500 meters of the thermograph site and bull trout spawning is presumed to (occur/not occur) at or near the thermograph site. If yes include the month of peak spawning activity.

Location- Appropriate, unique site/record identification, stream and basin name, longitude and latitude in degrees and minutes (UTM with zone ok) or a map that can be used to develop lat and long.

Permanent Contact- Name, address (mail or e-mail), phone, of permanent contact responsible for the data.

Optional Information

Elevation- Above mean sea level in meters

Other species- Presence of other fish and amphibians (e.g.,cutthroat trout, tailed frogs).

Width- Wetted stream width (to the nearest meter) at base flow at the thermograph site

Other Available Data- Identification from a check list of other data available for the site (i.e. abundance estimates, habitat characterization, discharge records, management history).

Appendix A. Continued.

Attached is a template for the metadata to accompany each thermograph record. If you prefer we can e-mail an electronic copy.

If you simply cannot pull your records together by the closure date, but still have data that you are willing to contribute to the effort please let us know. If there is enough interest it may be possible to continue the effort or get some help summarizing records.

References:

Eaton, J. G., and six co-authors. 1995. A field information-based system for estimating fish temperature tolerances. Fisheries 20(4):10-18.

Rieman, B. E. and J. D. McIntyre. 1995. Occurrence of bull trout in naturally fragmented habitat patches of varied size. Transactions of the American Fisheries Society 124:285-296.

Appendix A. Continued.

Template for Temperature Data (To Accompany Each Thermograph Record)

Required Information:
Stream Name: _______________________ Basin: ______________________________
Unique Site/Record Identification: ____
Longitude: ________________ and Latitude: ________________ (degrees, minutes, seconds)
OR
UTM coordinates: _______________________ and zone: ____ Map Included: (Y or N)

Permanent Contact: _________________________
Address: _________________________
____
Phone: __________________ E-mail: _______________________

Filename of temperature data:___________________ F° or C° (circle one)
Format of temperature data (i.e. ASCII, QPRO, SAS, etc.): _________________________
Type of thermograph used: __________________________________
Year, Month, Day of initiation:__________________ Time interval of records: __________

Bull Trout (documented presence within 500m of thermograph site):
Juvenile/Resident rearing: Yes   No Unknown
Migratory corridor or seasonal habitat: Yes No Unknown
    If yes - months of use: ____________________________
Spawning: Yes   No Unknown
    If yes - months of use: ____________________________

Optional Information:
Elevation of site (in meters): __________ Wetted stream width at site (in meters): ________

Other aquatic vertebrates present (list):____
____

Other available data (circle where appropriate or add to list):
- habitat/riparian characterization
- discharge records
- management history
- disturbance history
- bull trout density or abundance data
- ____

Appendix B. Metadata variable descriptions for the ORACLE tables used for this database. All tables are linked using the site_id variable.

Table: HEADER_TEMP

Variable Name	Description
SITE_ID	Unique site number assigned to each site as data was received.
SITE	Site descriptor provided by the participant (this generally was the site in the raw data file as it was received).
STREAM_NAME	Stream Name where the thermograph was deployed.
BASIN	Watershed basin where the stream is found.
STATE	State in which the stream is found.
FOREST	National Forest, if applicable where the stream is located.
THERMO_ID	Thermograph ID, especially useful if more than one thermograph was placed in the same stream.
LONGITUDE	Longitude (degrees, minutes, seconds or decimal degrees) where the thermograph was located.
LATITUDE	Latitude (degrees, minutes, seconds or decimal degrees) where the thermograph was located.
UTM_XCOORDINATE	UTM east-west coordinate for the thermograph site.
UTM_YCOORDINATE	UTM north-south coordinate for the thermograph site.
UTM_ZONE	UTM zone for the thermograph site.
QUAD_NAME	USGS 7.5 minute quad name where the thermograph was located.
MAP	Logical field to denote if a map of the site was included.
LAST_NAME	Last name of permanent contact person for the data.
FIRST_NAME	First name of permanent contact person for the data.
ADDRESS1	Address of permanent contact person.
ADDRESS2	Second line of address of permanent contact person (if needed).
CITY	Mailing city of permanent contact person.
STATE_CONTACT	State of permanent contact person.
FILE_NAME	File name of the temperature data.
TEMP	Temperature format (F or C).
FILE_TYPE	Type of file submitted (i.e. spreadsheet, ASCII, etc).
THERMO_TYPE	Type of thermograph used.
DATE_INIT	Date of initiation with time of initiation included.

Appendix B. Continued.

Variable Name	Description
TIME_INT	Time interval of temperature recordings.
BULLT_RES	Logical field for juvenile bull trout presence.
BULLT_SEAS	Logical field for bull trout seasonal use (i.e. migration).
SEAS_MON	If BULLT_SEAS is yes then the months of use are entered
BULLT_SPA	Logical field for bull trout spawning use.
SPAWN_MON	If SPAWN_MON is yes then the months of spawning use are entered.
ELEV	Elevation of site in meters.
WIDTH	Wetted stream width (m) at thermograph site.
VERTS1-VERTS10	Listing of other vertebrate species present.
HABITAT	Logical field to denote if habitat data is available.
DISCHARGE	Logical field to denote if discharge data is available.
MANAGE	Logical field to denote if management history is available.
DISTURB	Logical field to denote if disturbance history is available.
BULLT_DEN	Logical field to denote if bull trout density or abundance information is available.
OTHER_INFO	List of other information that is available for the thermograph site.
COMMENTS	Comment field.

Appendix B. Continued.

Table: RAW_DATA

Variable Name	Description
SITE_ID	Unique site number assigned to each site as data was received.
DATE	Date of thermograph recording.
TIME	Time of sample.
TEMP_C	Temperature in Celcius.
TR_FLAG	Truncate flag used to flag tails of observations before the thermograph was placed in the water or after the thermograph was removed from the water.
TEMP_30	Flag used when the temperature reading was greater than 30C.
TEMP_1	Flag used when the temperature reading was less than -1C.
TEMP_3HR	Flag used when the rate of temperature change was greater than 3C per hour.

Table: TEMP_SUMMARY

Variable Name	Description
SITE_ID	Unique site number assigned to each site as data was received.
DATE	Date of observation.
MEAN_D	Mean daily temperature.
MAX_D	Maximum daily temperature.
MIN_D	Minimum daily temperature.
NO_OBS	Number of observations taken that day.
MEAN_3	Flag used when the mean temperature varied by more than 3C on consecutive days.

Appendix C. List of participants that supplied temperature records to include in the database. An asterisk by the name denotes information has been received but not incorporated at this time.

Don Anderson	Idaho Department of Fish and Game
Beth Gardner	USFS, Swan Lake Ranger District
Brian Connors	Middle Fork Irrigation District
Dan Garcia	USFS, Salmon Ranger District
Mike Northrop	USFS, Walla Walla Ranger District
Rodger Nelson	USFS, Payette National Forest
Skip Rosquist	USFS, Lolo National Forest
Steve Gerdes	USFS, Beaverhead - Deerlodge National Forest
Thomas Herron	Idaho Department of Environmental Quality
Beth Sanchez	Crescent, OR
Chris Clancy	USFS, Bitterroot National Forest
Debby Myers*	USFS, Rocky Mountain Research Station
Larry Dominguez	Washington Department of Natural Resources
Mike Riehle*	USFS, Deschutes National Forest
Ray Perkins*	Oregon Department of Fish and Wildlife
Russ Thurow	USFS, Rocky Mountain Research Station
Steve Bachman	USFS, Shasta-Trinity National Forests
Terry Smith	USFS, Winema National Forest
Nicola Swanson	USFS, Rigdon Ranger District
Tim Burton	USFS, Boise National Forest
Fred Partridge*	Idaho Department of Fish and Game
Shanda Fallau Dekome*	USFS, Panhandle National Forest
Bill Stack*	USFS, Wallowa - Whitman National Forest
Gretchen Sausen*	USFS, Wallowa - Whitman National Forest
Sam Brenkman*	NPS, Olympic National Park