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Water temperature is a significant determinant of stream fish distribution due to its impact on fish metabolism, reproduction, and behavior. Because stream thermal regimes are susceptible to warming due to anthropogenic influence, stream temperature is an important focus of surface water quality regulation. The goal of thermal regulation is to maintain a thermal regime suitable for aquatic life. This goal is achieved by identifying and preventing surface water warming that would result in acute or chronic deleterious effects on fish individuals or populations. In this thesis, I use laboratory-derived upper thermal thresholds of Wyoming fish species alongside field-derived data on the same species' average thermal distributions to propose a revised surface water temperature standard for the State of Wyoming. To develop this proposed standard, I cluster all Wyoming fish species into five thermal management tiers and develop an acute and chronic numeric criterion for each tier. I also compare three stream classification approaches and identify an approach based on modeled stream temperatures as that which achieves the best balance between protection of fishes from thermal impairment and attainability of thermal criteria under Wyoming's natural thermal regime. Finally, I compile the species-specific thermal threshold values that were used in my analyses into a database to serve as a reference for future temperature tolerance research.

DEVELOPMENT OF THERMAL TIERS AND REGULATORY CRITERIA FOR WYOMING STREAM FISHES

by

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INTRODUCTION

Stream temperature is a major driver of fish biology and ecology (Brett 1956; Fry 1971; Magnuson et al. 1979). Every fish species has a temperature of optimal growth that is bracketed by a wider range of thermal conditions under which it can survive at a reduced level of growth and functioning (Magnuson et al. 1979). As temperature diverges from a species' optimal thermal range, individuals experience reductions in growth and reproduction, which ultimately result in individual mortality as well as extirpation of the population (Cherry et al. 1977). It is well known that thermal optima and maxima vary substantially among species (Brungs and Jones 1977; Hokanson et al. 1977; Armour 1991). As a result, the preservation of a diverse stream thermal regime is essential to protect distinct species assemblages along the thermal gradient (Rahel and Hubert 1991; Wehrly et al. 2003; Lyons et al. 2009; Parkinson et al. 2016).

Stream thermal regimes are driven by a variety of natural factors, including solar radiation, air temperature, elevation, groundwater input, channel morphology and shading, and stream flows (Caissie 2006; Webb et al. 2008). In addition, water temperature is often increased by anthropogenic influences such as riparian zone alteration (Ryan et al. 2013), dams and diversions (Hester and Doyle 2011), land use change (Herb et al. 2008), and the direct input of thermal effluent (Walsh 2005). Models predict that climate change is likely to further increase stream temperatures (Ficke et al. 2007; Chu et al. 2008; Isaak et al. 2010). Temperature is therefore an important focus of surface water quality regulation, and the majority of regulatory efforts are intended to protect aquatic species from elevated water temperatures.

With the establishment of the Clean Water Act in 1972, the U.S. Environmental Protection Agency (EPA) required state agencies to develop and enforce surface water quality standards, which often include temperature regulations (United States Code: 33 USC § 1251).

The diversity of species assemblages, thermal regimes, and management goals across the country has resulted in a wide variety of regulatory approaches. Nevertheless, it is possible to identify some commonalities in regulations between states. A majority of states have chosen to simplify the development of regulations by dividing fish species into tiers of similar thermal requirements. Each tier is then associated with a set of regulatory criteria, which may be either numeric or narrative. Bodies of water are assigned regulatory criteria based upon the tier observed or expected to be present. The taxonomic composition and regulatory criteria of thermal tiers are expected to vary regionally in accordance with varying species assemblages and available thermal habitat.

The current Wyoming temperature standards recognize two thermal tiers: cold-water game species, and warm-water and nongame species (WDEQ/WQD 2001a). The cold-water tier includes burbot, grayling, trout, salmon, char, and whitefish; the warm-water/nongame tier includes all other species expected to be found in the state (WDEQ/WQD 2001b). Each tier is associated with two numeric criteria: a maximum allowable temperature and a maximum temperature increase (WDEQ/WQD 2001a). Waters classified as cold-water may not exceed 20°C and may not be increased by more than 1.1°C; waters classified as warm-water/nongame may not exceed 30°C and may not be increased by more than 2.2°C (WDEQ/WQD 2001a).

Wyoming streams are currently classified based upon the presence or absence of fish species as recorded in a 2000 Wyoming Game and Fish Department (WGFD) database (WDEQ/WQD 2001b). The presence of any cold-water species designates a stream as a cold-water fishery. If there are no cold-water species present, then the presence of any warm-water or nongame species designates a stream as a warm-water/nongame fishery. Waters with no observed fish species fall into two categories: 1) waters that were surveyed and found to not

support any fish species, but that may still support other forms of aquatic life such as mussels or macroinvertebrates; and 2) waters that have not been surveyed for fish species. In both cases, waters with no recorded fish species are designated for aquatic life other than fish and assigned narrative regulations that prohibit alteration of water temperatures to levels that would be detrimental to aquatic life (WDEQ/WQD 2001a).

The Wyoming Department of Environmental Quality (WDEQ) is interested in revising three components of their thermal regulations: 1) the number and taxonomic composition of thermal tiers recognized; 2) the regulatory criteria applied to these tiers; and 3) the classification approach by which streams are assigned a regulatory tier. The goal of this thesis is to propose a new thermal standard that revises the three components recognized above. This is accomplished through three chapters:

In Chapter One, I identify Wyoming fish species' thermal tolerances through a review of the literature, focusing on a clearly defined list of study outputs that can be standardized to produce acute and chronic species-specific criteria.

In Chapter Two, I develop a system to classify Wyoming species into thermal tiers. I address WDEQ's requirement that the proposed thermal tiers effectively represent the thermal diversity of Wyoming streams by integrating field-derived data on species' thermal distributions with the laboratory-derived thermal tolerance data produced in Chapter One. After classifying species into tiers, I use the species-specific acute and chronic criteria from Chapter One to develop tier-level regulatory criteria.

In Chapter Three, I discuss multiple stream classification approaches and use a database of paired fish species assemblage surveys and temperature records to evaluate the protectiveness and attainability of each approach.

The three chapters are followed by a conclusion that discusses the proposed thermal standards in context of national trends in thermal management and suggests considerations for further temperature standard development.

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CHAPTER ONE:
Identification of thermal tolerances of Wyoming fishes

Introduction

Laboratory testing of fish thermal tolerance has been common since the early 20th century (examples of early compilations include Hathaway 1928; Fry et al. 1946; Coutant 1977; and Spotila et al. 1979). A diverse selection of study designs and output data have been used to investigate the many elements of the relationship between fishes' physiology and their surrounding water temperature. Upon passage of the Clean Water Act (33 U.S.C. § 1251) in 1972, which mandated state agencies to develop water quality criteria to protect aquatic life, protocols were developed for calculating acute and chronic criteria for any species from a specific set of acceptable laboratory thermal tests (NAS/NAE 1973; Brungs and Jones 1977). As a result thermal testing became more standardized, with an emphasis on identifying species' upper thermal limitations in terms of both short-term thermal shock as well as long-term population persistence.

Modern thermal testing, while continuing to investigate species' physiological limits, has developed several new areas of focus including previously understudied species (often native, nongame species), the interaction between temperature and other variables such as food intake and the presence of contaminants, and more complex characteristics of temperature such as daily and seasonal fluctuation (Sullivan et al. 2000). These new research directions provide a more nuanced understanding of species' thermal needs. However, because acute and chronic criteria have broad applicability and relatively simple implementation, they seem likely to remain the

foundation of thermal regulation into the foreseeable future. Species-specific acute and chronic criteria serve three primary purposes for thermal regulation:

1. Species-specific criteria can inform the development of thermal tiers, either in conjunction with or independent of data on species' thermal distributions in the field.
2. If a regulatory agency chooses to develop thermal tiers as part of their temperature standard, species-specific criteria can be compiled for each tier and used to develop tier-level regulatory criteria.
3. Species-specific criteria can be used by regulatory agencies to develop site-specific regulations where necessary.

The objective of Chapter One is to calculate an acute and chronic criterion for every Wyoming fish species by compiling thermal tolerance data from the literature and then using reproducible protocols based on EPA guidance to develop the species-specific criteria.

Methods

Literature Review. I conducted a review of laboratory studies reporting single-species thermal tolerance values and compiled the results in the Wyoming Temperature Database (WTD). I applied three main strategies: 1) targeted searches for original sources cited in early thermal tolerance compilation studies; 2) targeted searches for original sources cited in temperature standards currently implemented by regulatory agencies in the United States; and 3) general database searches using Google Scholar and Web of Science with relevant keywords. Because the purpose of the WTD is to inform the development of an acute and chronic thermal

criterion for each species expected to be found in Wyoming, I targeted studies whose major output was one or more of the biological endpoints accepted by the criteria development protocols in current EPA guidance (NAS/NAE 1973; Brungs and Jones 1977). Study outputs acceptable for inclusion in the WTD are listed and defined in **Table 1-1**. Accepted studies comprise two broad categories: studies that examine species' thermal optima, and studies that examine species' thermal maxima. Data on species' optima are primarily used to inform the development of chronic thermal standards, and data on species' maxima are primarily used to inform the development of acute thermal standards.

Studies that produced one or more of the outputs listed in Table 1-1 were not immediately accepted; I also wanted to ensure that the outputs consisted of reliable data. Experimental design criteria that I considered to be evidence of a reliable study are listed in **Table 1-2**. Studies that met the criteria of both Table 1-1 and Table 1-2 were included in the WTD. If some but not all of the Table 1-2 criteria were met, a study was not automatically excluded, but its merits were considered critically in relation to its shortcomings. A small number of studies that investigated thermal tolerance with an approach other than those listed in Table 1-1 were retained in the WTD for future standards revisions or validation, but these were clearly marked as excluded from the calculations of species-specific criteria. All other studies that did not meet the Table 1-1 and Table 1-2 criteria were excluded from the WTD.

The WTD format, and many included journal articles, were taken directly from the Colorado Temperature Database (CTD) (CWQCD 2007), which was developed in response to the Colorado Department of Public Health and the Environment Water Quality Control Commission's (CWQCC) recent standards revision process. The CWQCC revisions process was initiated in 2001, the first revisions were adopted in 2007, and further revisions are ongoing

(Todd et al. 2008; CWQCC 2011). The database format and journal articles used in the development of the WTD were taken from the most current version of the CTD as of summer 2015. Both the CTD and WTD are organized by species. Each fish species expected to be present in the state has one database page where information pertaining to its biological endpoints is collected and its acute and chronic criteria are calculated.

Calculation of species-specific criteria. All study outputs included in the WTD were chosen for their utility in calculating species-specific upper acute and chronic criteria. EPA guidance for calculating species-specific criteria from laboratory thermal endpoints was first outlined in 1972 and continues to be recommended without substantial alterations (NAS/NAE 1973; Brungs and Jones 1977; USEPA 1986; Armour 1991; Sullivan et al. 2000). Independent review of the EPA guidance has found it to be objective, reproducible, and protective (Sullivan et al. 2000). For both acute and chronic criteria, the EPA approach is characterized by three steps: the identification of a numeric threshold, the definition of an appropriate averaging time for the evaluation of stream temperature against the numeric threshold, and the application of a safety factor to ensure survival of individuals exposed to elevated temperatures (Sullivan 2000). Acute criteria are typically expressed as daily maximum (DM) temperatures with a short averaging period, and chronic criteria are defined over a longer averaging period.

Agencies responsible for developing surface water thermal standards have in some cases refined and expanded upon the EPA criteria calculation methods to develop standards more appropriate for particular ecological regions or species assemblages. In calculating species-specific criteria for Wyoming species, I preserved most alterations to the EPA methodology adopted by the CWQCC during their revisions process (Todd et al. 2008; CWQCC 2011). Following these CWQCC protocols, I defined the acute criterion for each species as a daily

maximum temperature (DM) and the chronic criterion as a maximum weekly average temperature (MWAT). The full procedures for calculating species-specific criteria are included in **Figure 1-1** (acute) and **Figure 1-2** (chronic), and any alterations to the basic EPA guidance introduced by CWQCC are noted.

Results

Literature review. The completed WTD contains information on 78 species, 52 of which are also in the CTD and 26 of which are unique to the WTD. Of the 221 articles cited in the WTD, 140 were retained from the CTD and 57 are new articles. Twenty-four of these articles (15 retained from the CTD and nine new) were retained in the database but excluded from the calculation of thermal criteria. The majority of studies unique to the WTD provide information on species not included in the CTD, and the rest provide supplementary information on species included in the CTD. Twelve species present in Colorado but not expected to be present in Wyoming were excluded from the WTD. The full WTD is included as **Appendix A**.

Species-specific criteria. The WTD contains sufficient information to calculate acute criteria (DM) for 58 of the 78 species in the WTD and chronic criteria (MWAT) for 40 of the 78 species. Eighteen species in the WTD have insufficient data to calculate any thermal criteria. The species included in the WTD are listed along with their acute and chronic criteria, criteria calculation method, and criteria calculation sample size in **Table 1-3**.

Discussion

Applications of criteria. The species-specific acute and chronic criteria calculated using the WTD provide a basis for the development of surface water thermal standards, and Chapter Two will address their application for developing regulatory tiers and tier-level numeric criteria. It is important to note that species-specific criteria can serve as a tool for thermal regulation in ways outside the scope of this thesis. In particular, they provide a crucial foundation for the development of site-specific standards, based upon known species assemblages, when necessary. Further, the raw study outputs data used to develop the species-specific criteria will remain available in the WTD to be used in new ways as the temperature standards development process continues to be refined.

Interpretation of criteria. In order to be meaningfully applied to water bodies, each acute and chronic criterion must have three defined components: a magnitude, duration, and frequency. Magnitude, the numeric temperature limit associated with the criterion, is explicitly defined in the acute and chronic criteria I have developed. Duration is defined as the time period over which temperatures are to be averaged when testing water bodies for compliance. In the case of the chronic criterion, expressed as an MWAT value, duration is also explicitly defined: daily average stream temperatures are to be averaged on a rolling seven-day basis (Sullivan et al. 2000; CWQCC 2011). The duration for the acute criterion, expressed as a daily maximum (DM) is less clear. Because the exposure period in Upper Incipient Lethal Temperature testing is not well defined (**Table 2-1**), the length of exposure to temperatures above species' upper limit required to cause lethality is not standardized among studies. It will therefore be necessary to define a duration before implementing the acute species-specific criteria calculated using the WTD. Frequency is defined as the maximum allowable number of times, within a given time

period, that the criteria are allowed to be exceeded. Frequency, unlike magnitude and duration, is rarely explicit in the definition of a criterion. Instead it is a policy decision, based on factors such as typical seasonal and year-to-year variation, intended monitoring and enforcement protocols, and the anticipated sources of thermal impairment.

Limitations of criteria. Many recent studies have investigated the difference between species' theoretical thermal distributions, determined through laboratory testing, and their actual thermal distributions observed in the field (e.g. Eaton et al. 1995; Wehrly et al. 2003; Lyons et al. 2009). Most species display an altered thermal niche in the field, often due to constraints in habitat or food availability, thermally-mediated species interactions, or behaviors which take advantage of natural habitat heterogeneity to mitigate the impact of warm temperatures (Magnuson et al. 1979; McCullough 2010). In light of these studies, I emphasize that the WTD criteria represent species' physiological limits in an idealized environment, which may differ from their limits in a natural environment. Laboratory testing of species' thermal tolerances in an idealized environment does, however, offer a unique opportunity to observe species' responses to more extreme temperatures than those available in their natural habitat. This understanding of species' response to extreme temperatures is useful for predicting species' responses to impaired stream temperatures. In Chapter Two I discuss the integration of laboratory-derived and field-derived data in the development of thermal regulations.

The WTD criteria are further limited by their focus on adult fish exposed to summer thermal regimes. The body of research on species' thermal limitations in the winter is smaller and less standardized than research on species' thermal limitations in the summer. Similarly, there are not enough studies on species' thermal requirements at early life stages to create a standardized criterion that could be compared among species. I retained some studies of thermal

requirements at early life stages and in colder seasons in the WTD for future reference, and I will discuss some approaches for considering life stages and seasonality in tier-level criteria in the Conclusion.

Confidence in criteria. It is important to note that the criteria calculated for each species are not equally robust. Species in the WTD differ greatly in number and output type of available studies (**Table 1-3**). CWQCC emphasized during the Colorado standards revision process that a study's robustness could be a factor in the choice to accept or reject it for the CTD, but that all studies would be considered equally valid once accepted (CWQCC 2011). I take the same approach with the development of WTD criteria. Nevertheless, the variability of criteria sample size and calculation method are worth noting. An acknowledgement of this variability is useful both for discussing confidence in criteria and for determining future research priorities.

The number of studies used to calculate species' DM criteria ranges from one to 33, and the number of studies used to calculate species' MWAT criteria ranges from one to 35. Criteria developed with a large sample size tend to be more robust. For example, Brown Trout (*Salmo trutta*) has an MWAT of 19.32°C (n = 35) and a DM of 24.92°C (n = 33). Removing the single warmest Brown Trout UILT study from the WTD produces a relatively negligible change in Brown Trout's MWAT (19.31°C; n = 34) and DM (24.90°C; n = 32). Flannelmouth Sucker (*Catostomus latipinnis*) is an example of a species with less robust criteria. Removing the single warmest Flannelmouth Sucker UILT study changes its MWAT from 26.22°C (n = 4) to 25.27°C (n = 3) and its DM from 31.15°C (n = 2) to 28.87°C (n = 1).

The method used to calculate species' criteria also contributes to the level of confidence that can be placed in criteria. Both MWAT and DM have one preferred calculation method and

one or more methods to be used if the type of data necessary for the preferred method is not available. The choice of calculation method can significantly alter a species' criteria. The MWAT for Cutthroat Trout (*Oncorhynchus clarkii*), for example, was calculated with the preferred method, 1/3 rule using Optimum Temperature as the optimum value, to be 18.10°C; if its MWAT had been calculated with the least preferred method, Upper Optimum, it would be 17.00°C.

Twenty-three species had sufficient data to calculate the DM using each of the two potential DM calculation methods (**Table 1-4**). For 19 of these 23 species, the least-preferred of the two methods produced a warmer DM value than the preferred method (preferred method mean DM = 29.73°C, least-preferred method mean DM = 31.42°C, t = -5.02, p = 0.00006). These results suggest that the 30 species with sufficient data in the WTD to calculate a DM using the preferred method may be afforded more conservative protection than the 28 species whose DM values had to be calculated using the least-preferred method.

For the 17 species with sufficient data to calculate the MWAT using both the preferred and second-most-preferred method, the difference between the second- and most-preferred methods ranged widely (4.02°C to -1.68°C) but there was no significant difference between the average MWAT produced by the two methods (t = 0.42, p = 0.68). For the nine species where a comparison between the preferred and third-most-preferred method was possible, the third-most-preferred method produced higher MWAT values than the preferred method (preferred method mean MWAT = 27.67°C, third-most-preferred method mean MWAT = 31.77°C, t = -3.6, p = 0.007). And for the six species where the comparison between the first- and fourth-most preferred methods could be made, the difference between values produced by the between the fourth- and most-preferred MWAT methods ranged from -1.15°C to 3.64°C, but there was no

significant difference between the average MWAT produced by the two methods (t = -1.2, p = 0.295). Taken as a whole, these comparisons suggest that variation in MWAT calculation method results in a high degree of variability, but not always in a way that is consistent among species (**Table 1-4**).

Additions to EPA guidance. The novel CWQCC additions to the basic EPA guidance for criteria development (**Figures 1-1** and **1-2**) are valuable because they allow for the inclusion of a greater number of study outputs in the standards development process. The trade-off to this benefit is that robustness of the resulting criteria is less consistent. Consistency of criteria robustness could be improved through further testing and refinement of the novel CWQCC criteria development protocols. I identify two main areas where the new protocols could be improved:

1. Use of CTM data for calculating Lethal Values. The original EPA guidance for criteria development did not allow CTM data to be used in calculating Lethal Values (Brungs and Jones 1977). When the CWQCC discovered that a large number of thermal studies tested species' CTM but not their UILT/UUILT, they decided that the benefits of making use of the available CTM data outweighed the risks of losing some degree of consistency in the criteria development process (Todd et al. 2008). The CWQCC established 0.8ºC as the default conversion factor by calculating the median difference between the median UILT/UUILT and median CTM for species with published values for both metrics (CWQCC 2011). For species of particular concern, CQWCC developed species-specific conversion factors by calculating the difference between median UILT/UUILT and median CTM for each species individually (Johnson 2006; Todd et al. 2008; CWQCC 2011). I agree that the ability to utilize CTM values in the development of species-specific criteria is a major benefit afforded by the application of

conversion factors. Confidence in the reliability of 0.8ºC as a conversion factor should be tempered, however, by noting that differences between median CTM and median UILT/UUILT values for species with both types of data range from -5.0ºC to 7.3ºC (Johnson 2006). Several authors have discussed the need to develop a more appropriate conversion factor, but this has not yet been accomplished (CWQCC 2011; Yoder 2012). For this reason, I prioritize the use of UILT/UUILT values over CTM values whenever possible.

2. Margin of Safety calculations. EPA guidance established 2ºC as a default margin of safety for acute criteria based on studies suggesting that 100% survival of study organisms typically occurs at temperatures 2ºC lower than a species' UILT/UUILT (Black 1953; Coutant 1977; Armour 1991). CWQCC noted in their revision process that this default was established based upon a limited number of species, and that 2ºC typically equated to approximately 1/5 of the thermal distance between the median UILT/UUILT and the median upper optimum for the species tested (Todd et al. 2008). For some Colorado species, this thermal distance was much lower than 2ºC (Todd et al. 2008). Criteria developed with a smaller margin of safety would afford these species sufficient protection and achieve greater attainability. I agree with this reasoning and therefore apply the "1/5 rule" margin of safety equation for all species with sufficient data, and the 2ºC margin of safety for all other species. Still, I recommend further testing of the relationship between a species' median UILT/UUILT and the threshold at which it attains 100% survival.

Conclusion. The WTD is the first comprehensive collection of thermal data on Wyoming fish species that has been compiled, standardized, and summarized. This body of knowledge should prove useful for general standards development as well as the creation of site-specific standards.

Tables

Table 1-1. Definitions of the 11 study outputs included in the Wyoming Temperature Database (WTD). These outputs were chosen because of their well-known relationships to biologically meaningful acute and chronic thermal endpoints (WTD format is adapted from CWQCD 2007; CWQCC 2011).

Biological Endpoint	Definition
	Thermal Optimum Metrics
Avoided High	The avoided high temperature is defined as the upper temperature that a study organism, given the opportunity to move between temperatures, will avoid. It is dependent upon acclimation temperature (Coutant 1977; Yoder 2012).
Avoided Low	The avoided low temperature is defined as the lower temperature that a study organism, given the opportunity to move between temperatures, will avoid. It is dependent upon acclimation temperature (Coutant 1977; Yoder 2012).
Preferred Average	To test for a species' preferred average temperature, study organisms are given the opportunity to move between temperatures and their final preference is recorded. The study duration should be long enough that acclimation temperature does not affect the final result (Fry et al. 1946; Jobling 1981; Yoder 2012).
Preferred Low	The preferred low temperature represents the lowest end of the thermal range ultimately selected by study organisms, regardless of acclimation temperature.
Preferred High	The preferred high temperature represents the highest end of the thermal range ultimately selected by study organisms, regardless of acclimation temperature.
Optimum	Optimum experiments typically test either growth or performance. In growth optimum tests, fish are allowed to live and feed at a range of temperatures and measured to see which temperature maximizes growth (Hokanson 1977; Todd et al 2008). In performance optimum tests, metrics such as swimming ability are compared at various temperatures (Lee et al. 2003; Todd et al 2008).
Lower Optimum	The lower optimum is generally the temperature at the low end of a species' optimum range after which the growth or performance metric being measured begins to drop relatively quickly.
Upper Optimum	The upper optimum is generally the temperature at the high end of a species' optimum range after which the growth or performance metric being measured begins to drop relatively quickly.

Thermal Maximum Metrics	
Upper Incipient Lethal Temperature (UILT)	To test for a species' UILT, study organisms are acclimated over a period of days or weeks to an acclimation temperature, which should ideally represent their general expected temperature in the field. Study organisms are then transferred instantly into water of a higher temperature. They are continually transferred through a series of higher temperatures until the desired thermal endpoint of the study. The UILT is the temperature which causes death in 50% of study organisms. The exposure period required to confirm 50% lethality varies between studies but is often defined as a 24-hr period (Brett 1952; Brett 1956; Brungs and Jones 1977; Fry 1942; Fry et al. 1946; NAS/NAE 1973; Yoder 2012).
Ultimate Upper Incipient Lethal Temperature (UUILT)	The UUILT is the highest value of the UILT that can be obtained by increasing the acclimation temperature before beginning the transfer to higher temperatures (Brungs and Jones 1977; Yoder 2012).
Critical Thermal Maximum	To test for a species' CTM, study organisms are acclimated to a temperature expected to represent their general field distribution. Organisms are then subjected to steady temperature increase (generally between 0.5ºC/hour and 1ºC/hour) until loss of equilibrium is observed (Hutchinson 1979; McCullough 1999; Todd et al. 2008; Yoder 2012).

Table 1-2. Experimental design criteria considered when deciding whether to include a journal article in the WTD are listed here in approximate order of importance. These criteria, based on those used by the Colorado Water Quality Control Commission, were developed to determine the reliability of a study's results (Todd et al. 2008; CWQCC 2011).

Criteria	Description
Primary Considerations	
External review	The study must be published in scientific journal, report, or graduate thesis or dissertation.
Laboratory environment	Studies conducted in the field are not acceptable because they contain many uncontrolled variables and are difficult to compare directly with standardized laboratory studies.
Appropriate methods	Methods should be consistent throughout the study.
Life stage	Life stage of the fish should be recorded. Studies investigating the thermal requirements of eggs, embryos, or larvae may be included in the WTD but should be excluded from criteria calculations.
Acclimation	Temperature and rate of acclimation should be recorded. Studies with acclimation temperatures outside the normal summer range for the species being considered (7-23ºC for species conventionally considered cold-water species and 15-30ºC for species conventionally considered warm-water species) should be excluded.
Secondary Considerations	
Endpoint	The range of temperatures used in thermal testing should be recorded.
Nutrition	Feeding or fasting of fish should be noted.
Replications	Experimentation should be replicated appropriately.

Table 1-3. Alphabetical listing of all species included in the WTD. Maximum weekly average temperature (MWAT) refers to species-specific chronic criteria and daily maximum (DM) refers to species-specific acute criteria. "Method" indicates the method used to calculate the criterion, where 1 refers to the most preferable method and 4 refers to the least preferable. For MWAT, the methods in order of preference are: 1) 1/3 rule using Optimum Temperature; 2) 1/3 rule using Preferred Average; 3) 1/3 rule using Avoided High; 4) Upper Optimum. For DM, the methods in order of preference are: 1) Median UILT/UUILT as Lethal Value; 2) CTM – Conversion Factor as Lethal Value (see **Figures 1-1** and **1-2** for more detail). *n* indicates the number of unique tests used in the criteria calculation. MOS indicates the method used to calculate the margin of safety used in the DM calculation, where 1 refers to calculation with the 1/5 rule and 2 refers to the default margin of safety (2°C) (see **Figure 1-1** for more detail).

Common Name	Scientific Name	MWAT			DM			MOS
		MWAT	Method	*n*	DM	Method	*n*	
Arctic Grayling	*Thymallus arcticus*				21.00	1	3	2
Bigmouth Shiner	*Notropis dorsalis*				33.80	2	1	2
Black Bullhead	*Ameiurus melas*				35.30	2	1	2
Black Crappie	*Pomoxis nigromaculatus*	26.56	2	3	32.10	2	1	2
Bluegill	*Lepomis macrochirus*	31.59	1	13	33.14	1	9	1
Bluehead Sucker	*Catostomus discobolus*	25.00	4	1				2
Brassy Minnow	*Hybognathus hankinsoni*							2
Brook Stickleback	*Culaea inconstans*				28.60	1	1	2
Brook Trout	*Salvelinus fontinalis*	18.34	1	13	21.68	1	10	1
Brown Trout	*Salmo trutta*	19.32	1	35	24.92	2	33	1
Burbot	*Lota lota*	19.59	1	10	25.42	2	8	1
Central Stoneroller	*Campostoma anomalum*	27.82	2	6	33.84	2	1	1
Channel Catfish	*Ictalurus punctatus*	32.38	1	17	35.76	2	16	1
Common Carp	*Cyprinus carpio*	29.84	1	5	33.88	1	4	1
Common Shiner	*Luxilus cornutus*	24.20	2	11	28.97	1	5	1
Creek Chub	*Semotilus atromaculatus*				28.60	1	9	2
Cutthroat Trout	*Oncorhynchus clarkii*	18.10	1	13	22.31	1	9	1
Emerald Shiner	*Notropis atherinoides*	28.86	1	18	30.15	1	14	1
Fathead Minnow	*Pimephales promelas*	28.78	2	16	31.88	1	7	1
Finescale Dace	*Phoxinus neogaeus*				30.00	1	5	2
Flannelmouth Sucker	*Catostomus latipinnis*	26.22	1	4	31.15	2	2	1
Flathead Catfish	*Pylodictus olivaris*							2
Flathead Chub	*Platygobio gracilis*							2
Freshwater Drum	*Aplodinotus grunniens*	30.19	2	3	32.02	1	1	1
Gizzard Shad	*Dorosoma cepedianum*	30.30	2	2	30.72	2	1	1
Golden Shiner	*Notemigonus crysoleucas*	27.71	1	10	31.56	1	8	1
Golden Trout	*Oncorhynchus aguabonita*				25.50	2	3	2
Goldeye	*Hiodon alosoides*							2

Grass Carp	*Ctenopharyngodon idella*	29.96	1	3	35.95	1	1	1
Green Sunfish	*Lepomis cyanellus*	31.05	2	15	35.12	2	8	1
Hornyhead Chub	*Nocomis biguttatus*				32.80	2	1	2
Iowa Darter	*Etheostoma exile*							2
Johnny Darter	*Etheostoma nigrum*	25.37	2	15	29.04	2	13	1
Kendall Warm Springs Dace	*Rhinichthys osculus thermalis*				31.75	2	2	2
Kokanee	*Oncorhynchus nerka*	19.01	1	8	22.93	1	6	1
Lake Chub	*Couesius plumbeus*							2
Lake Trout	*Salvelinus namaycush*	16.66	1	14	22.58	1	1	1
Largemouth Bass	*Micropterus salmoides*	31.38	1	11	34.06	1	7	1
Longnose Dace	*Rhinichthys cataractae*				28.60	2	1	2
Longnose Sucker	*Catastomus catastomus*				24.80	1	2	2
Mottled Sculpin	*Cottus bairdii*				27.85	2	1	2
Mountain Sucker	*Catostomus platyrhynchus*	21.95	2	13	29.00	2	12	1
Mountain Whitefish	*Prosopium williamsoni*							2
Northern Leatherside Chub	*Lepidomeda copei*	23.79	1	8	27.76	1	4	1
Northern Pearl Dace	*Margariscus margarita*							2
Northern Pike	*Esox lucius*				30.00	1	3	2
Orangethroat Darter	*Etheostoma spectabile*	24.41	2	17	29.98	2	14	1
Paiute Sculpin	*Cottus beldingii*							2
Plains Killifish	*Fundulus zebrinus*				38.45	2	2	2
Plains Minnow	*Hybognathus placitus*	32.94	2	4	37.12	2	3	1
Plains Topminnow	*Fundulus sciadicus*				34.20	2	1	2
Pumpkinseed Sunfish	*Lepomis gibbosus*	29.78	2	8	32.74	1	5	1
Quillback	*Carpiodes cyprinus*	26.82	2	2	33.54	2	1	1
Rainbow Trout	*Oncorhynchus mykiss*	19.35	1	24	23.77	1	20	1
Red Shiner	*Cyprinella lutrensis*				35.00	2	19	2
Redside Shiner	*Richardsonius balteatus*							2
River Carpsucker	*Carpiodes carpio*							2
Rock Bass	*Ambloplites rupestris*	30.24	2	21	34.28	1	1	1
Roundtail Chub	*Gila robusta*				34.50	2	2	2
Sand Shiner	*Notropis stramineus*				30.20	2	5	2
Sauger	*Sander canadensis*							2
Shorthead Redhorse	*Moxostoma macrolepidotum*	28.41	3	1	31.84	1	1	2
Shovelnose Sturgeon	*Scaphirhynchus platorynchus*							2
Smallmouth Bass	*Micropterus dolomieu*	28.90	1	5	33.74	2	2	1
Speckled Dace	*Rhinichthys osculus*				31.82	2	9	2
Spottail Shiner	*Notropis hudsonius*	29.21	1	5	31.94	1	4	1
Stonecat	*Noturus flavus*							2
Sturgeon Chub	*Macrhybopsis gelida*							2

Suckermouth Minnow	*Phenacobius mirabilis*							2
Tiger Muskellunge	*Esox lucius x Esox masquinongy*				30.50	1	2	2
Utah Chub	*Gila atraria*	26.36	1	3	31.86	2	1	1
Utah Sucker	*Catostomus ardens*							2
Walleye	*Sander vitreus*	25.99	1	9	31.68	1	6	1
Western Mosquitofish	*Gambusia affinis*	29.04	1	14	34.80	1	13	1
Western Silvery Minnow	*Hybognathus argyritis*							2
White Crappie	*Pomoxis annularis*	23.56	2	2	29.48	2	1	1
White Sucker	*Catostomus commersoni*	27.69	1	6	28.82	1	5	1
Yellow Perch	*Perca flavescens*	25.01	2	29	28.23	1	7	1

Table 1-4. Table indicating the MWAT and DM of all species, calculated using as many methods as possible given the available data. Methods are displayed in order of preference from left to right. For MWAT, methods in order of preference are 1) 1/3 rule using Optimum Temperature; 2) 1/3 rule using Preferred Average; 3) 1/3 rule using Avoided High; 4) Upper Optimum. For DM, methods in order of preference are 1) Median UILT/UUILT as Lethal Value; 2) CTM – Conversion Factor as Lethal Value. See **Figures 1-1** and **1-2** for more details on all methods. Dashes indicate that sufficient data were not available to calculate the MWAT or DM for a species using the indicated method. The bolded values indicate the values retained as species-specific chronic (MWAT) and acute (DM) criteria. For all species except Gizzard Shad, the retained value is calculated with the most preferable calculation method available. For Gizzard Shad, the second more preferable DM value was retained, although sufficient data were available to perform the most preferable method; this is because using the first method would have resulted in a DM criterion that was lower than the MWAT criterion, which is not possible. A relatively small sample size and widely varying study methods used in studies of Gizzard Shad thermal tolerance is likely responsible for this abnormality.

Common Name	MWAT				DM	
	1	2	3	4	1	2
Arctic Grayling	--	--	--	--	**21.00**	25.60
Bigmouth Shiner	--	--	--	--	--	**33.80**
Black Bullhead	--	--	--	--	--	**35.30**
Black Crappie	--	**26.56**	--	--	--	**32.10**
Bluegill	**31.59**	31.72	34.60	--	**33.14**	35.54
Bluehead Sucker	--	--	--	**25.00**	--	--
Brassy Minnow	--	--	--	--	--	--
Brook Stickleback	--	--	--	--	**28.60**	--
Brook Trout	**18.34**	18.34	19.68	--	**21.68**	25.28
Brown Trout	**19.32**	19.73	--	19.59	--	**24.92**
Burbot	**19.59**	17.78	--	--	--	**25.42**
Central Stoneroller	--	**27.82**	31.44	--	--	**33.84**
Channel Catfish	**32.38**	29.70	35.73	--	--	**35.76**
Common Carp	**29.84**	31.31	--	--	**33.88**	35.96
Common Shiner	--	**24.20**	32.34	--	**28.97**	29.05
Creek Chub	--	--	--	--	**28.60**	31.30
Cutthroat Trout	**18.10**	--	--	17.00	**22.31**	25.83
Emerald Shiner	**28.86**	26.88	38.27	30.00	**30.15**	32.31
Fathead Minnow	--	**28.78**	32.40	--	**31.88**	33.80
Finescale Dace	--	--	--	--	**30.00**	--
Flannelmouth Sucker	**26.22**	27.72	--	--	--	**31.15**
Flathead Catfish	--	--	--	--	--	--
Flathead Chub	--	--	--	--	--	--
Freshwater Drum	--	**30.19**	--	--	**32.02**	32.34
Gizzard Shad	--	**30.30**	--	--	28.80	**30.72**
Golden Shiner	**27.71**	--	--	--	**31.56**	33.80
Golden Trout	--	--	--	--	--	**25.50**
Goldeye	--	--	--	--	--	--
Grass Carp	**29.96**	29.66	--	--	**35.95**	35.95

Green Sunfish	--	**31.05**	34.27	--	--	**35.12**
Hornyhead Chub	--	--	--	--	--	**32.80**
Iowa Darter	--	--	--	--	--	--
Johnny Darter	--	**25.37**	--	--	--	**29.04**
Kendall Warm Springs Dace	--	--	--	--	--	**31.75**
Kokanee	**19.01**	--	--	--	**22.93**	--
Lake Chub	--	--	--	--	--	--
Lake Trout	**16.66**	16.12	--	--	**22.58**	--
Largemouth Bass	**31.38**	30.18	31.05	--	**34.06**	35.50
Longnose Dace	--	--	--	--	--	**28.60**
Longnose Sucker	--	--	--	--	--	**24.80**
Mottled Sculpin	--	--	--	--	--	**27.85**
Mountain Sucker	--	**21.95**	--	--	--	**29.00**
Mountain Whitefish	--	--	--	--	--	--
Northern Leatherside Chub	**23.79**	--	--	--	**27.76**	30.12
Northern Pearl Dace	--	--	--	--	--	--
Northern Pike	--	--	--	--	**30.00**	--
Orangethroat Darter	--	**24.41**	--	--	--	**29.98**
Paiute Sculpin	--	--	--	--	--	--
Plains Killifish	--	--	--	--	--	**38.45**
Plains Minnow	--	**32.94**	--	--	--	**37.12**
Plains Topminnow	--	--	--	--	--	**34.20**
Pumpkinseed Sunfish	--	**29.78**	--	--	**32.74**	33.72
Quillback	--	**26.82**	--	--	--	**33.54**
Rainbow Trout	**19.35**	18.78	21.20	18.20	**23.77**	25.65
Red Shiner	--	--	--	--	--	**35.00**
Redside Shiner	--	--	--	--	--	--
River Carpsucker	--	--	--	--	--	--
Rock Bass	--	**30.24**	33.99	--	**34.28**	33.64
Roundtail Chub	--	--	--	--	--	**34.50**
Sand Shiner	--	--	--	--	--	**30.20**
Sauger	--	--	--	--	--	--
Shorthead Redhorse	--	--	**28.41**	--	**31.84**	32.64
Shovelnose Sturgeon	--	--	--	--	--	--
Smallmouth Bass	**28.90**	31.51	33.92	--	--	**33.74**
Speckled Dace	--	--	--	--	--	**31.82**
Spottail Shiner	**29.21**	28.68	33.03	32.20	**31.94**	31.06
Stonecat	--	--	--	--	--	--
Sturgeon Chub	--	--	--	--	--	--
Suckermouth Minnow	--	--	--	--	--	--
Tiger Muskellunge	--	--	--	--	**30.50**	--
Utah Chub	**26.36**	--	--	30.00	--	**31.86**
Utah Sucker	--	--	--	--	--	--
Walleye	**25.99**	24.65	--	--	**31.68**	--
Western Mosquitofish	**29.04**	33.06	38.42	--	**34.80**	33.60
Western Silvery Minnow	--	--	--	--	--	--
White Crappie	--	23.56	--	--	--	29.48
White Sucker	**27.69**	25.38	--	--	**28.82**	31.34
Yellow Perch	--	**25.01**	--	--	**28.23**	31.91

Figures

Step 1. Calculate a lethal value.

Option 1. For species with available UILT and/or UUILT values, pool both sets of values and determine the median of the combined UILT/UUILT data. This median is the lethal value.

Option 2. For species with available CTM values but neither UILT nor UUILT values, determine the median CTM. Use the following equation to develop the lethal value:

$$\textit{Lethal Value} = CTM_{median} - \textit{Conversion Factor}$$

A. Default conversion factor. The default conversion factor is 0.8°C.

B. Specialized conversion factors. There are three species with specialized conversion factors: Brown Trout (*Salmo trutta*) and Brook Trout (*Salvelinus fontinalis*) each have a conversion factor of 1.3°C, and Mottled Sculpin (*Cottus bairdii*) has a conversion factor of 1.05°C [a].

Step 2. Calculate the margin of safety.

Option 1. For species with available thermal optimum data, calculate the margin of safety (MOS) as follows:

$$MOS = 1/5 * (\textit{Lethal Value} - \textit{Optimum})$$

Acceptable optimum values in order of preference are median Upper Optimum, median OptimumTemperature, median Preferred Average, and median Avoided High.

Option 2. For species with no available thermal optimum data, the margin of safety is 2°C [b].

Step 3. Calculate the acute criterion.

The acute criterion is calculated with the following equation:

$$\textit{Daily Maximum} = \textit{Lethal Value} - MOS$$

[a] EPA guidance did not allow for the use of CTM values in calculating a Lethal Value. Because many species have available CTM but not UILT/UUILT values, CWQCC introduced a conversion factor to allow for the use of converted CTM values as surrogate UILT/UUILT values. 0.8°C was established as the default by calculating the average difference between UILT/UUILT and CTM values for warm-water species with published values for both metrics. Colorado did the same type of calculations with all available data to determine whether 0.8°C was an appropriate conversion factor for cold-water species and found 1.3°C to be more appropriate for Brown Trout and Brook Trout and 1.05°C to be more appropriate for Mottled Sculpin (CWQCC 2011).

[b] EPA guidance established 2°C as the default margin of safety based upon experiments suggesting that 100% survival was typically achieved at temperatures 2°C below the UILT (Armour 1991). Because this value was derived from experiments on a small number of species, CWQCC was concerned that for some species, criteria developed with a lower MOS might be equally effective and more attainable. CWQCC determined that for species similar to those originally considered by the EPA, the 2°C MOS equates to roughly 1/5 of the distance between the UILT and the Upper Optimum. They used this information to develop the equation used here (Johnson 2006; CWQCC 2011).

Figure 1-1. Methods for calculating the daily maximum (DM) acute criterion (Brungs and Jones 1977; CWQCC 2011).

Option 1. "1/3 Rule."

Use the following equation to calculate the chronic criterion:

$$MWAT = Optimum + 1/3 * (Lethal\ Value - Optimum)$$

Acceptable Optimum values in order of preference are median Optimum Temperature, median Preferred Average, and Avoided High. If Avoided High is to be used as the optimum value for MWAT calculations, the Avoided High value should be taken from the study with an acclimation temperature closest to other median optimum metrics (Preferred Average or Optimum Temperature, in order of preference). If there are no other available optimum metrics, or if the acclimation temperature for Avoided High studies was not recorded, then the median Avoided High value should be used. The Lethal Value should be calculated according to Step 1 of the acute criterion protocol.

Option 2. "Upper Optimum Rule."

For species without sufficient data to calculate the chronic criterion using the 1/3 rule, use the following equation[a]:

$$MWAT = Upper\ Optimum_{median}$$

[a] In contrast to my preference for the 1/3 rule approach, CWQCC preferred to calculate the MWAT using Upper Optimum values, and only used the 1/3 rule when Upper Optimum values were not available (CWQCC 2011). Because only a small number of species have available Upper Optimum values, and among those species the sample size of Upper Optimum studies tends to be smaller than the sample size of studies needed to apply the 1/3 rule, I chose to prioritize the 1/3 rule but use the Upper Optimum in cases where there were not sufficient data for the 1/3 rule equation.

Figure 1-2. Methods for calculating the maximum weekly average temperature (MWAT) chronic criterion (Brungs and Jones 1977; CWQCC 2011).

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CHAPTER TWO:

Classification of species into thermal tiers and development of tier-level criteria

Introduction

The division of species into thermal tiers is a common practice in aquatic ecology as well as surface water thermal management (Hokanson et al. 1977; Magnuson et al. 1979; Sullivan et al. 2000). Species are classified into tiers of similar thermal requirements in order to simplify the development and implementation of thermal standards. Each tier is then associated with a set of regulatory criteria, and these regulatory criteria are assigned to bodies of water based upon the tier expected to be present. Most species exhibit relatively consistent thermal distribution patterns throughout their range, but the taxonomic composition and regulatory criteria of thermal tiers are expected to vary regionally in accordance with varying species assemblages and available thermal habitat.

The Wyoming Department of Environmental Quality (WDEQ) has expressed interest in developing new surface water thermal standards based upon three or more thermal tiers. The process of developing tier-based thermal standards can be split into two steps: classifying species into tiers, and assigning regulatory criteria to each tier. In this chapter, I discuss first the classification of species into thermal tiers, and second the development of tier-level regulatory criteria. There are two main considerations to take into account when developing a new thermal tier classification system for Wyoming fishes:

1. Number of thermal tiers. Early classification schemes often recognized only two thermal tiers: cold-water and warm-water species (Hokanson et al. 1977; Magnuson et al. 1979).

Because many of the first thermal standards developed by regulatory agencies were based on these early classification schemes, the WDEQ two-tier system was not unusual when it was first implemented in 1975. More recent studies of species distributions in the field, however, demonstrate that species are distributed fairly evenly across the thermal gradient rather than clustered at the warm and cold ends of the gradient (Eaton et al. 1995). As a result, researchers have increased their focus on identifying and characterizing one or more distinct cool-water species assemblages that are intermediate between cold-water and warm-water assemblages (e.g. Wehrly et al. 2003; Lyons et al 2009; Beauchene et al. 2014; Parkinson et al. 2016). Many regulatory agencies have responded to this body of research by expanding the number of thermal tiers recognized in their temperature standards (e.g. CWQCC 2011, five thermal tiers; ODEQ 2008, six thermal tiers; WQP 2012, six thermal tiers).

The variety of classification systems developed by regulatory agencies suggests that there are many potential approaches to thermal regulation. Temperature regulations must take into account not just the regional thermal regime and species assemblages, but also management goals, the availability of regulatory resources, and stakeholder interests. To be effective, thermal tiers need to achieve a balance between specificity and generality. If an agency chooses to recognize a large number of thermal tiers, each covering a narrow band of the thermal spectrum, regulations may become impractical to implement. But if the agency instead chooses to recognize a small number of broad thermal tiers, it may become difficult to assign meaningful criteria to the tiers because each will encompass a variety of species with substantially different thermal requirements. The latter scenario can produce standards that either fail to protect many species or are unattainable under natural conditions, resulting in inefficient allocation of resources intended for stream remediation (**Figure 2-1**).

WDEQ has expressed concern that the current two-tier classification system does not adequately reflect the diversity of thermal communities in Wyoming streams, creating a regulatory burden that is excessive and potentially unattainable. This concern is best illustrated with the example of Brown Trout (*Salmo trutta*). Brown Trout is classified as a cold-water species, in spite of the fact that its thermal needs are intermediate between the state's most thermally sensitive and thermally tolerant species. Its thermal criteria suggest that it can persist in streams with average temperatures that are too warm for Wyoming's other cold-water species. But because streams are assigned regulations to protect the most sensitive species in the thermal tier that is present, rather than simply the most sensitive species that is present, the decision to recognize only two thermal tiers forces Wyoming to maintain Brown Trout waters at lower temperatures than are necessary for the species. For these streams where Brown Trout is the most thermally sensitive species present, its classification as a cold-water species compromises the attainability of the standards and creates an excessive regulatory burden. The division of species into a greater number of thermal tiers could alleviate some of this burden, freeing up regulatory resources to be concentrated where they are needed most.

2. Integration of data collected in the laboratory and the field. State agencies and academic researchers have used a variety of methods to divide species into thermal tiers. These have typically relied on either rankings of species' laboratory-derived tolerances or multivariate analyses of species assemblage data collected in the field (most commonly ordination and cluster analyses) (Eaton et al. 1995; Beauchene et al. 2014; Toms and Villard 2015). Laboratory thermal testing is generally preferred over field testing because it takes place in a controlled environment and allows for testing at thermal extremes which may not exist in the field (Sullivan et al. 2000; CWQCC 2011). These thermal tolerance tests are typically conducted on individuals in ideal

living conditions (fed to excess and free of competition or predation), and they tend to produce similar results for all individuals of a species, regardless of the geographic regions from which the individuals were collected (Sullivan et al. 2000; McCullough 2010). As a result, laboratory testing is most useful for describing species' absolute thermal limits. It is less useful for understanding regional or site-specific influence on a species' thermal niche. Multivariate analyses of field data have proven more useful for understanding species' thermal distribution in context of the other variables present in a natural setting. Thermally-mediated species interactions (Fausch et al. 1994; Taniguchi et al. 1998; Carmona-Catot et al. 2013), food availability and metabolic rate at various temperatures (Sullivan et al. 2000; Larsson 2005), and the presence or absence of thermal refugia and connectivity (Peterson and Rabeni 1996; Torgersen et al. 1999; Poole et al. 2004) have the potential to influence species' thermal requirements beyond the direct effects of temperature on growth and survival. These interactions vary regionally and are difficult to measure in the lab, so field data provides an important source of information on species' thermal requirements that cannot be achieved through laboratory research.

Eaton et al. (1995) conducted one of the first comparisons between species' theoretical thermal maxima, calculated from laboratory data, and their observed thermal distributions in the field. All thirty species included in the study were most commonly observed at temperatures significantly colder than their theoretical maxima (Eaton et al. 1995). Research such as Eaton's has prompted efforts to identify distinct thermal communities in the field without relying on laboratory data. Wehrly et al. (2003) used an index of species assemblage similarity to compare several streams with different thermal regimes. They identified two thresholds between thermal communities, defined as the temperatures that corresponded to the greatest changes in species

assemblage similarity (Wehrly et al. 2003). Parkinson et al. (2016) used a similar approach to identify thresholds in Canadian streams, applying a similarity quotient of 0.50 as the defining characteristic of a thermal threshold. Beauchene et al. (2014) advanced the concept of threshold identification by implementing the program Threshold Indicator Taxa Analysis (TITAN), a variant on older indicator value analysis techniques, to identify thermal thresholds between species assemblages.

Although threshold identification has become a relatively common way to understand species' thermal distributions, it has not yet been integrated into the process of developing regulatory thermal tiers. Instead, regulatory thermal tiers are typically developed on the basis of historical studies in the literature, which utilize laboratory data to classify species. Because thermal studies conducted in the field and in the laboratory provide different types of information, however, thermal criteria should ideally incorporate both types of studies. A thermal tier development approach that integrates laboratory- and field-derived data is expected to identify species' regionally specific thermal requirements more precisely than is possible through the use of laboratory data alone.

Tier-level criteria development. The second step in the process of developing tier-based thermal standards is the development of one or more regulatory criteria for each tier. These criteria may be numeric, narrative, or both. Much like the species-specific criteria calculated in Chapter One, EPA guidance recommends that each tier be assigned a paired set of numeric criteria: one criterion to protect the tier from acute effects of altered temperature, and one criterion to protect the tier from chronic effects of altered temperature (Brungs and Jones 1977). Numeric criteria must be defined in terms of magnitude (a maximum allowable temperature), duration (the time period over which measured temperature is to be averaged when testing for

compliance with criteria), and frequency (the frequency by which the maximum allowable temperature may be exceeded without long-term deleterious impacts to the designated beneficial use). The expected magnitude, duration, and frequency characteristics of acute and chronic criteria are outlined in **Table 2-1**.

The current Wyoming temperature standards contain two criteria for each thermal tier: 1) a maximum allowable temperature, and 2) a maximum temperature increase. The maximum allowable temperature criterion is most similar to an acute criterion, because it has a relatively high magnitude and is intended to protect individuals from acute thermal effects. However, the Wyoming standards do not suggest a duration or frequency for the implementation of this criterion. The maximum temperature increase criterion is most similar to a chronic criterion, because it is intended to maintain the long-term stream temperature near an ambient condition that is presumably protective of the species that were present before the temperature was increased. This criterion's lack of a clearly defined duration and frequency, however, pose challenges for implementation. The standards do not specify the averaging period to be applied when assessing the magnitude of increase that has occurred. And if a stream's temperature is increased to an allowable degree on multiple occasions, it is possible that over time the stream could become much warmer than intended. Finally, the maximum increase criterion is only applicable to streams with a well-maintained historical thermal record; it is not meaningful for stream reaches without historical thermal monitoring.

Chapter Two has two objectives: 1) to develop a classification system for Wyoming stream fishes that accurately represents any distinct species assemblages along the thermal gradient; and 2) to assign a chronic and acute criterion to each tier.

Methods

Modeled temperature data. The Air, Water, and Aquatic Environments Program (AWAE) of the United States Forest Service Rocky Mountain Research Station has produced a series of publicly available modeled historical (1993-2011) and projected future mean August stream temperatures for much of the western United States at a 1-km resolution (Isaak et al. 2016). The modeling process was ongoing at the time this thesis was written; the majority of Wyoming streams were modeled by 2016 and are included in this thesis, but a number of streams in eastern Wyoming were not yet modeled (Isaak et al. 2016). The Belle Fourche and Cheyenne drainages are expected to be modeled by 2017, and the unmodeled portions of the North Platte drainage will be modeled at a later date (Isaak et al. 2016).

Mean August temperature was chosen as the modeled stream temperature metric for two reasons. First, managers in the Western United States have historically collected temperature data more consistently in August than in other months, so fitting the models to August data allowed AWAE to use the greatest number of stream sites for model calibration (AWAE 2016). Second, mean August temperature is highly correlated with other temperature metrics of interest (AWAE 2016). In addition to the average mean August temperature for the period from 1993 through 2011, AWAE also modeled the historical mean August temperature for each year between 1993 and 2011. Inter-annual variability was based on just two predictor variables: air temperature and stream discharge. All other predicator variables were constant among modeled years (AWAE 2016). The change in modeled mean August temperature from the coldest to warmest year at a single site ranged from 1.91°C to 2.61°C (Isaak et al. 2016).

In order to incorporate data from as many sources as possible, AWAE applied spatial statistical models that take into account the inherent connectivity of stream networks (Isaak et al.

2010). AWAE used the universal kriging algorithm (Cressie 1993) to make temperature predictions at a 1-km interval on all streams in the modeling region. The model used for these predictions was selected with a spatial Akaike information criterion (AIC) comparison (Hoeting et al. 2006) conducted on possible models fit to a preliminary set of stream sites (Isaak et al. 2010). A detailed description of the AWAE modeling protocols is available in **Table 2-2**.

Species assemblage data. I gathered statewide stream fish species assemblage data from the Wyoming Game and Fish Department (WGFD) to form a database of 1763 species assemblage survey sites. To quality for inclusion in the database, survey sites were required to meet four conditions: 1) they must have been surveyed between May and October in a year between 1989 and 2016; 2) researchers must have comprehensively surveyed all species at a site rather than targeting one or more specific species; 3) each site must be a location with documented coordinates; and 4) sites must be within the geographic range for which AWAE stream temperatures models have been completed. I paired each of the 1763 species assemblage sites with a modeled historical (1993-2011) mean August stream temperature for the 1-km stream reach in which it was located. The decision to pair each survey site with a modeled temperature rather than measured temperature data was made because only a limited number of survey sites were located near a temperature logger producing continuous temperature data. The completed database included presence/absence and count surveys for 73 out of the 78 Wyoming fish species in the Wyoming Temperature Database (WTD) (**Table 2-7**). The remaining five species were excluded from the stream temperature standards development process because they are expected to only occur in lakes and reservoirs.

Because AWAE stream temperatures models had not yet been completed for portions of eastern Wyoming in 2016, survey sites from these unmodeled regions could not be accepted into

the species assemblage database. A survey of available data from stream temperature loggers in the unmodeled drainages suggests that streams in this portion of Wyoming are generally within the thermal range observed in the rest of the state (Chandler et al. 2016). As such, I expect that the Wyoming temperature standards developed using the modeled temperatures available in 2016 will be appropriate for the unmodeled regions of Wyoming as well. Still, when the modeled temperatures for eastern Wyoming become available, it may be beneficial to incorporate any survey sites in the newly modeled drainages into the species assemblage database and repeat the analyses described in my thesis with this expanded database.

Thermal tier development. I applied a three-step process for the development of thermal tiers. I will first provide a brief outline of the thermal tier development process, and throughout the rest of this section I will describe each step in greater detail. First, I used the program Threshold Indicator Taxa Analysis (TITAN) (Baker and King 2010), the same threshold identification program applied by Beauchene et al. (2014), to identify thresholds along the thermal spectrum that separate the thermal habitats used by distinct species assemblages. A thermal threshold is defined here as a small temperature gradient over which a relatively large change in species assemblage occurs. Twenty-one of the 73 Wyoming stream fish species in the WTD occurred fewer than four times in the species assemblage database, making them ineligible for inclusion in TITAN analysis. I discuss potential causes of these species' low observation frequency as well as the methods for classifying these 21 species later in this chapter. Second, I used Indicator Value analysis (De Cáceres and Legendre 2009) to determine each species' strength of association with the distinct portions of the thermal gradient that are separated by the thresholds identified by TITAN. According to the typical terminology used for Indicator Value analysis, these distinct portions of the thermal gradient are referred to as "site-groups." As a

result of Indicator Value analysis, all 52 Wyoming stream fish species that had been included in TITAN analysis could be classified based upon their known strengths of association with one or more site-groups. Third, I used site-group associations of the 52 species included in TITAN analysis as a starting point for the development of thermal tiers. Because species' regional thermal distributions in Wyoming might differ from their theoretical thermal maxima, and because this potential discrepancy might not apply equally to all species, I compared species' field distributions with their laboratory-derived thermal tolerances and made alterations to their site-group association as necessary. I also used species' laboratory-derived thermal tolerances to classify the 21 species that were excluded from TITAN analysis into site-groups. These alterations to the initial site-groups produced by Indicator Value analysis were made through a series of reproducible steps developed to minimize subjectivity and bias. The final set of species associations, after making all necessary alterations, serve as the proposed regulatory thermal tiers. The following paragraphs will describe these three tier development steps in greater detail.

Threshold identification. I used the program Threshold Indicator Taxa Analysis (TITAN) to determine whether thermal thresholds between species assemblages could be identified. TITAN requires two inputs: 1) a species assemblage database, defined as a matrix with each row representing a species and each column representing a site; and 2) a vector containing measurements of a continuous environmental variable, where there is one measurement associated with each site in the in the species assemblage database (Baker and King 2010). After removing species with three or fewer observations (recommended by Baker and King (2015) for TITAN to perform correctly), the species assemblage database consisted of 1763 sites with presence/absence or count data for 52 species. TITAN cannot be conducted on a database containing data in multiple formats. Because 48% of the species assemblage database was

recorded in presence/absence format, and these presence/absence sites contributed substantially to the coverage of all major drainages in Wyoming (**Figure 2-2**), I decided to convert all taxa data to presence/absence format before conducting TITAN analysis so that all 1763 sites could be included in the analysis. A discussion of the relative merits of conducting TITAN analysis on presence/absence data and relative abundance data follows later in this section. The temperature gradient consisted of the modeled mean August temperature for each site.

TITAN iteratively tests along an environmental gradient for change points in the distribution of individual species, and uses synchronous response among these species to infer community-level thresholds (Baker and King 2010). To begin this process, it uses an extension of indicator species analysis (Dufrêne and Legendre 1997) to calculate species' strengths of association with each side of a binary partition at x-2 candidate change points along an environmental gradient, where x is the number of unique observations of the environmental gradient. A species' strength of association with the group of sites on either side of the partition (group i) is expressed as an Indicator Value (IndVal) score, which is a product of two characteristics: the proportion of occurrences among sites in group i relative to occurrences in all sites, and the proportion of occurrences at sites within group i (Baker and King 2010). At each candidate change point, the higher of the two IndVal scores is retained, along with the side of the partition it is associated with. TITAN then identifies and retains the candidate change point that maximizes each species' IndVal score, and also retains the IndVal score and side of the partition at the retained change point for each species. Significance of each species' IndVal score is determined by conducting IndVal analysis on 250 random permutations of the thermal gradient data to establish the mean and standard deviation of random IndVal scores for each species (Baker and King 2010).

Community-level thresholds are indicated by a synchronous response among species. TITAN standardizes all species' IndVal scores to z-scores using the mean and standard deviation obtained with permutation analysis, then sums all positive (z+) and negative (z-) standardized scores at each candidate change point. The candidate change point associated with the largest sum z+ score and the candidate change point associated with the largest sum z- score are identified as the two potential community-level thresholds. I used 500 bootstrap resamples to develop confidence limits for the two potential community-level thresholds.

Although original examples of TITAN analysis demonstrate the use of taxa measured in abundance form (rather than presence/absence) and environmental gradient data in the form of a single measured value (rather than an average or summary) (Baker and King 2010), there are many examples in the literature of TITAN being used to analyze presence/absence taxa data, summary environmental gradient data, or both (e.g. Cardoso et al. 2013; Khamis et al. 2014; Feld et al. 2014; Chariton et al. 2015). Still, I performed some additional TITAN analyses on subsets of the 1763-site species assemblage database to evaluate whether my decision to convert the portion of the database that had been in count format into presence/absence format had influenced the outcome of the analysis.

First, for the subset of the species assemblage database available in count format with available reach length measurements (315 sites), I conducted two runs of TITAN to evaluate two methods of standardizing count data. The first of these two runs analyzed count data standardized by stream reach length, and the second analyzed count data standardized by proportion of individuals present. The two TITAN runs produced very similar results (for the first, sum z- = 15.62, sum z+ = 17.91; for the second, sum z- = 15.67, sum z+ = 17.90; see the results section of Chapter Two for interpretation of these results). The second preliminary

analysis compared the results of TITAN conducted on count data standardized by proportion of individuals (913 sites) and TITAN conducted on the same database after conversion to presence/absence format. Again I observed minimal differences in the TITAN output (for the first, sum z- = 15.62, sum z+ = 19.87; for the second, sum z- = 15.62, sum z+ = 19.85; see the results section of Chapter Two for interpretation of these results). Because the change of data format from count to presence/absence appeared to have minimal effect on TITAN output, I conducted all further analyses using the results of TITAN analysis from the full 1763-site species assemblage database, converted to presence/absence format where necessary. All threshold identification analyses were conducted using the "TITAN2" package in R (Baker et al. 2015).

Indicator Value analysis. Because TITAN's output consists of two thresholds between thermally distinct species assemblages, it was possible to define three distinct groups of sites: sites with modeled mean August temperatures colder than the first threshold (referred to as the cold-water site-group), sites with temperature values between the first and second thresholds (referred to as the cool-water site-group), and sites with temperature values warmer than the second threshold (referred to as the warm-water site-group).

The 500 bootstrap resamples of the TITAN analysis made it possible to define the confidence limits surrounding the community-level thresholds identified by TITAN. I used the 5% confidence limit of the first community-level threshold as the threshold between the cold-water and cool-water site-groups, and I used the 95% confidence limit of the second community-level threshold as the threshold between the cool-water and warm-water site-groups. This choice of confidence limits, recommended by Beauchene et al. (2014), resulted in a liberal definition of the cool-water site-group. I preferred this liberal definition because it allowed for the potential

emergence of multiple unique cool-water tiers, as in the classification system suggested by Lyons et al. (2009), who identified four distinct thermal tiers.

Each site-group, based upon the results of TITAN analysis, contained a species assemblage that was more similar within the site-group than among the other site-groups. To characterize the taxonomic composition of the distinct species assemblages associated with each site-group, I applied Indicator Value analysis to determine species' strengths of association with each site-group or combination of site-groups. Because species could be associated with either a single site-group (cold-water, cool-water, warm-water) or a combination of site-groups (cold-cool, cool-warm, cold-warm, cold-cool-warm), there were seven potential associations for each species. I evaluated the strength of association between species and combinations of site-groups using the phi coefficient of association, corrected to account for the differing size of site-groups (Chytrý et al. 2002; De Cáceres and Legendre 2009).

The statistical significance of species' strengths of association was determined by conducting Indicator Value analysis on 999 random permutations. All species were classified into the site-group with which they were associated, regardless of whether that association was significant at a level of $\alpha = 0.05$, but significance values were retained. All Indicator Value analyses were conducted using the "indicspecies" package in R (De Cáceres and Legendre 2009).

Taxonomic composition of thermal tiers. Finally, I defined a series of reproducible steps to follow for the development of a set of thermal tiers based on species' site-group associations. This series of steps allowed me to integrate species' field-derived site-group associations with their laboratory-derived thermal tolerances that were compiled in Chapter One. I began with the seven potential site-group associations produced by Indicator Value analysis: cold, cold-cool,

cool, cool-warm, warm, cold-warm, and cold-cool-warm. From this point on, I referred to the groups of species associated with each site-group or site-group combination as candidate tiers. By following the series of reproducible steps, some species were moved from one candidate tier to another based upon the degree to which their observed field distributions differed from their laboratory-derived species-specific criteria as well as the field distributions of ecologically similar species. Here, I will briefly describe the purpose of each step; the steps are described in greater detail in **Table 2-3**.

First, candidate tiers containing three or fewer species were removed and any species associated with them were re-classified into the least sensitive adjacent candidate tier. This step was undertaken to avoid the development of regulations for potential species assemblages that are not actually found in Wyoming. Second, species whose laboratory-derived thermal maxima (MWAT and DM) differed substantially from their observed temperatures were reclassified into a candidate tier more closely aligned with their thermal maxima. This step was based on a recognition that species' typical thermal distributions do not perfectly correlate with their resilience to changes in their thermal habitat. As a result, species that tend to occur at the upper limits of their potential thermal range may require greater protection than those that tend to occur at the lower end of their potential thermal range. Third, laboratory-derived maxima were used to classify species that occurred at too low a frequency in the species assemblage database to be included in TITAN analysis. This step allowed me to classify species with a low occurrence frequency, species with a low probability of detection, or species that primarily occur in the unmodeled portion of Wyoming, which was excluded from my analyses. Fourth, species with insufficient data in the WTD to calculate any species-specific thermal maxima were, when deemed appropriate by regional fisheries experts, reclassified on the basis of phylogenetic or

ecological similarity to other Wyoming species. This step allowed me to extend the goal of the second step to species with no laboratory-derived thermal maxima.

The first four steps, described above, provided a mechanism for all species to be classified into a rigid number of tiers that was defined by the results of TITAN and Indicator Value analyses. The final two steps, described in this paragraph, provided a mechanism for me to optimize the number of tiers into which species were classified. In the fifth step, all candidate tiers containing four or more species were divided into two candidate sub-tiers. In the sixth and final step, sub-tiers created in step five were merged to produce a number of candidate tiers intermediate between the smallest number of candidate tiers produced by my analyses (defined in step four) and the greatest number of candidate tiers produced by my analyses (defined in step five). Steps five and six allowed me to assess whether an increase in the number of thermal tiers resulted in a greater ability to describe distinct species assemblages along the thermal gradient, or whether an increase in the number of thermal tiers instead produced multiple tiers that described the same species assemblages. The former scenario would indicate that a greater number of tiers would be beneficial for thermal regulation; the latter would indicate that a greater number of tiers would be detrimental.

Tier-level criteria development. The final step in the process of developing tier-based thermal standards is the definition of tier-level regulatory criteria in terms of magnitude, duration, and frequency. Because WDEQ has expressed interest in designing criteria to be fully protective of all species, I used the most sensitive species-specific MWAT and DM values in each tier to define the magnitude of the tier-level chronic and acute thermal criteria.

The duration of the MWAT criterion is explicit in its definition; the MWAT is an upper limit for temperatures averaged over a seven-day duration. The duration of the DM criterion is

less clearly defined. Because the exposure period in UILT testing is not standardized, the length of exposure to temperatures above the acute criterion required to cause lethality is unclear. Regulatory agencies have chosen to apply DM values with durations that range from a 24-hour averaging period to an instantaneous measurement (see IWQD 2006 for an example of an acute criterion with a 24-hour duration and NMWQCC 2013 for an example of an acute criterion based on an instantaneous measurement). The selection of an appropriate duration is influenced by a variety of factors including the degree of typical daily thermal fluctuation, the sensitivity of the species assemblage present, the confidence in the methods used in developing the criteria, and the regulatory agency's management priorities. I chose to apply a preliminary definition of two hours for the duration of the DM criterion, because this is the duration applied by the CDPHE (CWQCC 2011). In Chapter Three, I evaluate the appropriateness of this two-hour duration and make a recommendation for a DM duration in Wyoming.

Frequency, unlike magnitude and duration, is rarely explicit in the definition of a criterion. It is intended to reflect the ability of an aquatic community to recover from thermal impairment. Determining a timeline for the recovery of an aquatic community is challenging. It is influenced by many factors, including the biology and ecology of the species present; the community's typical exposure to daily, seasonal, and year-to-year thermal variation; and the characteristics of the thermal impairment. Defining a frequency for the proposed tier-level criteria is therefore outside the scope of my data analyses, but in the discussion at the end of this chapter, I provide recommendations based upon frequencies applied by other regulatory agencies.

Results

Modeled temperature data. Modeled mean August temperatures at the 1763 sites in my species assemblage database ranged from 4.4°C to 23.1°C. The distribution of sites along the thermal spectrum in the species assemblage database was relatively representative of the statewide thermal regime, though colder sites were slightly overrepresented in my database relative to their statewide frequency (**Figure 2-4**).

Species assemblage data. I accepted 850 presence/absence surveys and 913 count surveys into the stream fish species assemblage database and converted all sites to presence/absence format for a total of 1763 sites (**Figure 2-2**). The database initially contained all 73 stream fish species expected to occur in Wyoming. After removing 21 species that had three or fewer observations in the species assemblage database, as required for TITAN analysis, the database contained 52 species (Baker and King 2015). The included species varied widely in terms of frequency of observation and observed thermal range (**Figure 2-3**).

Threshold identification. The maximum sum z- and sum z+ change points identified by TITAN are listed in **Table 2-4**. Baker and King (2013) caution that TITAN is programmed to identify a maximum positive and negative change point regardless of whether a true community-level threshold exists. They offer a suite of diagnostics to assess the evidence for a community-level threshold, defined as a narrow range of environmental gradient that is associated with a relatively rapid change in species assemblage. A narrow confidence limit band for the sum z- and sum z+ change points suggests a true threshold. In contrast, a broad band of confidence limits suggests a more gradual and linear change along the thermal spectrum (Baker and King 2013). The confidence limits surrounding the community-level change points identified here are relatively narrow, suggesting the presence of a true threshold (**Table 2-4**).

Baker and King (2013) also suggest that overlap in the confidence limits of the sum z- and sum z+ change points indicates a continuous threshold range, over which species that are generally more strongly associated with the negative end of the gradient are supplanted by those that are generally more strongly associated with the positive side of the gradient. The confidence limits identified here do not overlap, suggesting the possibility of one or more unique transitional communities with species assemblages that are distinct from those on either the warm or cold end of the thermal gradient (**Table 2-4**). **Appendix B** contains additional diagnostic figures from the TITAN analysis.

Indicator Value analysis. Of the 1763 sites in the species assemblage database, 551 were classified in the cold-water site-group (< 15.5ºC), 1064 were classified in the cool-water site-group (15.5-19.9ºC), and 148 were classified in the warm-water site-group (> 19.9ºC). All 52 species in the TITAN analysis were associated with either one of these three site-groups or one of the four potential combinations of these site-groups, and 50 of these associations were significant ($p < 0.05$) (**Table 2-5**). The two non-significant species were Iowa Darter (*Etheostoma exile*) ($p = 0.083$) and Northern Leatherside Chub (*Lepidomeda copei*) ($p = 0.639$). Because there were no species associated with the cold-warm or cold-cool-warm combinations of site-groups, all species were effectively classified into just five groups: the cold-water site-group, the cold-cool site-group combination, the cool-water site-group, the cool-warm site-group combination, and the warm-water site-group (**Table 2-6**).

Thermal tiers. By integrating the five groups of species produced by Indicator Value analysis with the reproducible steps described in **Table 2-3**, I produced a system of four candidate tiers (step four), a system of seven candidate tiers (step five), and a system of five candidate tiers (step six). The seven candidate tiers produced by step five were not sufficiently

distinct to serve as regulatory thermal tiers. The third and fourth candidate thermal tiers in the seven-tier system, for example, had respective DM criteria of 27.9°C and 27.8°C, indicating that the two tiers did not contain thermally distinct species assemblages. Because the four candidate tiers produced by the fourth step and the five candidate tiers produced by the sixth step each appeared to depict thermally distinct species assemblages, the five-tier system was preferred as it allows for a greater degree of specificity in describing Wyoming streams' thermal communities. **Appendix C** is a spreadsheet that describes all changes in the number and taxonomic composition of candidate tiers at each step of the process used to convert site-groups to thermal tiers, and a concise summary of these changes is included in **Table 2-3**.

All Wyoming stream fish species were therefore classified into five regulatory thermal tiers: Tier I (Cold), Tier II (Cold-Cool), Tier III (Cool), Tier IV (Cool-Warm), and Tier V (Warm) (**Table 2-7**). Species' average occurrence frequency, abundance, and thermal distribution width varied somewhat among tiers (**Table 2-8**).

Discussion

Trends in threshold identification. The thresholds identified in Wyoming streams differ from those described elsewhere. Beauchene et al. (2014) used similar methods (TITAN and Indicator Value analysis) to define the cool-water range between warm-water and cold-water species assemblages in Connecticut as occurring between 18.5°C and 22.3°C. These values represent mean July stream temperatures, calculated from hourly temperature logger measurements (Beauchene et al. 2014). While Beauchene et al. (2014) also calculated the cool-water range in terms of mean June-August (18.29°C -21.70°C) and maximum daily mean

(22.40°C-26.30°C), the mean July temperature is likely the most analogous to the modeled mean August temperatures used in my study. The range of temperatures at sites identified as cool-water habitat in Wyoming, in terms of modeled mean August temperature, is 15.5°C through 19.9°C (**Table 2-4**). Interestingly, these cool-water ranges are similar in width (3.8°C and 4.4°C, respectively), but the Wyoming cool-water range is approximately 3°C cooler.

Parkinson et al. (2016), using a community similarity index approach, found a cool-water thermal range in British Columbia's Thompson River watershed that began at a summer MWAT of 12-13°C and ended at 19-20°C, and a range of similar width but 1-2°C colder in British Columbia's Upper Fraser River watershed. Because summarizing temperature data as MWAT produces higher values than summarizing the same data as a monthly average, it can be assumed that the cool-water range found by Parkinson et al. (2016) is on average colder than the cool-water range in Wyoming. Using a different similarity index approach, Wehrly et al. (2003) found a cool-water range in Wisconsin and Michigan that began at 18-19°C mean weekly July temperature and ended at 21-22°C. The metric of mean weekly July temperature is somewhat difficult to compare to the metrics of the other studies discussed above, but the cool-water range identified by Wehrly et al. (2003) does appear to be relatively similar to the mean July temperature cool-water range identified by Beauchene et al. (2014). These variations in cool-water range between various studies are likely due to differences in regional thermal regimes, regional species assemblages, study methodology, or a combination of the three.

These and similar efforts to identify species assemblages that are intermediate between cold- and warm-water assemblages have resulted in an increased effort to understand and characterize the cool-water thermal range. Increasingly, researchers have recognized that the cool-water range harbors a unique species assemblage, rather than simply a mixture of warm-

and cold-water species (Wehrly et al. 2003; Lyons et al. 2009). This distinct cool-water thermal range is apparent in my data; seven out of 52 species in Wyoming are exclusively associated with cool-water sites, which comprise 60% of the sites in my database (**Table 2-5**). An additional seven species have broad distribution ranges that overlap with the cool-water zone (**Table 2-5**). As such, Wyoming's cool-water habitat is clearly an important part of the state's aquatic resource and merits additional research and regulation.

Interpretation of TITAN and Indicator Value outcomes. The fact that 50 out of 52 species were significantly associated with one or more temperature site-groups serves as further evidence that the temperature thresholds identified by TITAN represent true thresholds between distinct species assemblages on the landscape. The two species with non-significant site-group associations, Iowa Darter (p = 0.083) and Northern Leatherside Chub (p = 0.639), also had the two lowest strengths of association with their site-group. These low significance and strength of association values are likely due to the fact that Iowa Darter and Northern Leatherside Chub each occurred infrequently (Iowa Darter n = 9; Northern Leatherside Chub n = 10) and exhibited a thermal range that was evenly split between two site-groups (Iowa Darter habitat, which ranged from 17.30°C-21.77°C modeled mean August temperature, is split by the 19.9°C threshold between the cool-water site-group and the warm-water site-group; Northern Leatherside Chub habitat, which ranged from 14.64°C-16.79°C modeled mean August temperature, is split by the 15.5°C threshold between the cold-water and cool-water site-groups). The lower occurrence frequency and "in-between" site-group association meant that it was impossible to classify these species decisively into any site-group or combination of site-groups. The reproducible steps developed to incorporate laboratory data into the tier development process aided in the classification of these species.

Thermal tier development. My thermal tier development approach used species' site-group associations as a starting point for regulatory tier development, ultimately integrating field-derived and laboratory-derived data to produce five distinct thermal tiers. We expect that these tiers, when assigned regulatory criteria, will allow for more nuanced thermal regulation than the two-tier system currently employed in Wyoming. Furthermore, the integration of the two types of data is expected to produce tiers that are more useful for management than tiers produced with either field data or laboratory data alone. Consider the example of Utah Sucker (*Catostomus ardens*): field-based TITAN analysis identified Utah Sucker as exclusively associated with the cold-water site-group (**Table 2-5**), but through the thermal tier development process it was classified in Tier III (Cool). This is because the Utah Sucker occupies warm-water habitats throughout its geographic range, but in Wyoming it is restricted to a small portion of the state that consists mostly of cold-water streams (Tyus et al. 1982; Baxter et al. 1995). Thermal classification of Utah Sucker based only on field observations in Wyoming would underestimate its thermal tolerance, but classification based strictly on its range-wide tolerance would overestimate its thermal tolerance in the context of available habitat within its range in Wyoming.

Additionally, the integration of two distinct sources of information on species' thermal distribution ensures that a greater proportion of species can be classified. Twenty-one out of 73 Wyoming stream fish species were not observed frequently enough to be included in TITAN analysis, and 18 out of 73 had no available MWAT or DM data. But because only seven species had neither a TITAN placement nor laboratory-derived criteria, the acceptance of both types of data enabled more species to be classified into a thermal tier.

My threshold analysis methods are a direct extension of work done by Beauchene et al. (2014) in Canadian streams. Beauchene et al. (2014) were the first to apply TITAN to the thermal classification of aquatic species, which in the past has typically been accomplished through multivariate analysis. TITAN improves upon earlier multivariate threshold identification methods through its sensitivity to species with low occurrence frequencies, which are common in our species assemblage database (Baker and King 2010). Additionally, TITAN reduces the likelihood of falsely identifying thermal thresholds by providing a set of clear diagnostics for interpreting results (Baker and King 2010).

Although Beauchene et al. (2014) implied that the identification of distinct thermal species assemblages would be useful for management and regulation, they did not investigate the ability of each species in the thermal communities they identified to withstand thermal alterations, which must be accomplished before thermal thresholds can be useful for developing regulations. If several species typically occurred together in similar thermal habitat yet had drastically different tolerances to thermal impairment, for example, then this distinct species assemblage would not be useful for thermal regulation, regardless of how distinct it was on the landscape. I interpret my TITAN results in a similar light: the thermal communities identified by TITAN utilize the available thermal habitat in similar ways, but the TITAN output does not justify the assumption that each species within a thermal community has the same resilience to changes to its thermal environment. Because an understanding of each species' resilience to thermal change is critical to thermal regulation, TITAN outputs must be integrated with information on species' thermal tolerances in order to be used for regulation. The application of the laboratory-derived thermal thresholds compiled in Chapter One is necessary for meeting this requirement.

The series of steps used to transform the thermal communities identified by TITAN into regulatory thermal tiers provided a reproducible mechanism to recognize species within each candidate thermal tier with varying degrees of sensitivity to thermal change. I defined these steps in great detail not because they have been empirically shown to be the only system for modifying field-derived thermal tiers with laboratory-derived data, but because they are one approach which may successfully meet WDEQ's policy goals. The application of these reproducible steps improved upon the candidate tiers produced through threshold identification analysis in two main ways. First, they allowed me to identify species that are observed in warmer temperatures in their natural range outside of Wyoming but are restricted to colder temperatures within the state (e.g., Utah Sucker). Unlike most species, whose temperature of observation correlates somewhat with their upper thresholds, these species with limited ranges in Wyoming have much higher upper thresholds than would be expected based upon their observed distributions. By taking their laboratory threshold values into account when classifying these species, I classified them into tiers more consistent with their upper thermal thresholds.

Second, the series of reproducible steps provided a mechanism to divide observed groupings of species into multiple thermal tiers for more precise thermal regulation. Because Wyoming does not contain a great deal of warm water, relative to other parts of the country, most warm-water species in Wyoming live in waters that are far cooler than their upper thresholds. While these species coexist in the field, they span a wide range of upper thresholds. In a scenario where many Wyoming streams were experiencing warming, it would be advisable to prioritize regulation of those streams containing the more sensitive of the warm-water species. The division of Wyoming's warm-water species into multiple tiers, based upon their laboratory-derived thresholds, makes it possible to assign regulations based on the differing sensitivity of

species present, even when that sensitivity is not reflected in distinct communities on the landscape.

Several regulatory agencies have chosen to develop thermal tiers based primarily on expert opinion. Expert opinion may produce appropriate thermal tiers in most cases, but relying on expert opinion without providing an underlying framework to ensure that it is applied in a reproducible and impartial manner risks introducing a high level of unintended bias (Sullivan et al. 2000). The purpose of clearly defining steps for thermal tier development is to ensure that when expert opinion must be applied to alter species' original site-group associations, it is done in an impartial manner. This approach is designed to give equal consideration to all species, in spite of the discrepancy in number and quality of available thermal studies among species.

Thermal criteria. The MWAT and DM values of the most thermally sensitive species in each tier were used to define the magnitude of the chronic (MWAT) and acute (DM) tier-level criteria (**Table 2-7**). CWQCC (2011) applied a different approach to calculate the magnitude of tier-level criteria, defining the magnitude of each tier-level criterion as the 95th percentile of the species-specific criteria within the tier. I propose using the lowest MWAT and DM values in each tier as the tier-level criteria because this will afford the greatest amount of protection to the species in each tier.

The duration of the MWAT criterion is, by definition, a 7-day period. In order to propose a duration for the DM criterion, we can consider durations applied by regulatory agencies in regions with similar thermal regimes. It is well known that most streams experience natural daily thermal fluctuation. The factors driving stream temperature fluctuation are complex and interrelated, but it is generally accepted that snowmelt and variation in thermal shading can play

a large role in thermal fluctuation (Caissie 2006). We would therefore expect Wyoming's streams, many of which are influenced by these characteristics, to have highly variable thermal regimes. Fish species in regions with greater thermal fluctuation have been shown to display adaptive behavior that allows them to survive daily high temperatures and recover during the cooler parts of the daily thermal cycle (Schrank et al. 2001). An ideal DM duration should be long enough so that daily high temperatures, which might briefly and occasionally exceed the magnitude of the DM criterion, do not result in a false identification of impairment. At the same time, the duration assigned to the DM criterion must allow the criterion to be sensitive to the presence of consistently elevated temperatures, which are characteristic of thermally impaired streams. In Colorado, a state with a relatively similar thermal regime to Wyoming, the Colorado Department of Public Health and the Environment (CDPHE) applies a 2-hour duration to the DM criterion (CWQCC 2011). Because of the similarity of thermal regimes in Colorado and Wyoming, as well as the similarity between thermal criteria proposed here and those implemented by CDPHE (**Figure 2-5**), I propose a 2-hour duration for the Wyoming DM criteria as well. In Chapter Three, I test the protectiveness of this 2-hour duration.

For the frequency component of both chronic and acute criteria, I am limited to a discussion of common practices among regulatory agencies; a definition of the frequency component based on data analyses is outside the scope of this thesis. We can again consider the Colorado temperature standards. CWQCC (2011) states that the MWAT and DM criteria should not be exceeded more than once every three years. The Colorado standards also note two circumstances under which a stream's criteria may be exceeded without resulting in its listing as an impaired stream: 1) when the air temperature exceeds the 90th percentile monthly maximum temperature, calculated with at least ten years of data; and 2) when the daily or monthly stream

flow falls below the acute or chronic critical low flow value (CWQCC 2011). Other regulatory agencies apply similar exemptions (e.g. ODEQ 2008), and WDEQ may want to consider them as well.

Tables

Table 2-1. Broad characterization of the different functions performed by acute and chronic criteria and the expected characteristics of each criterion's magnitude, duration, and frequency components.

	Acute Criteria	**Chronic Criteria**
Magnitude	Relatively high. Acute criteria should be slightly lower than an individual's lethal limit and are intended to prevent acute thermal shock, not to dictate optimal long-term conditions.	Relatively low. Chronic criteria should maintain thermal conditions that allow long-term population persistence.
Duration	Relatively short. Lengthy exposure to temperatures prohibited by acute criteria is not tolerable for individuals.	Relatively long. Chronic criteria should reflect the upper limits of temperatures that allow for long-term population persistence.
Frequency	As acute criteria reflect temperatures with a short duration, they may in some cases occur with greater frequency, provided that they take place in the context of natural fluctuation and are balanced by equally frequent lower temperatures.	Chronic criteria are meant to indicate desirable long-term, stable thermal conditions, and as such should be exceeded infrequently.

Table 2-2. Variables used by the Air, Water, and Aquatic Environments Program (AWAE) for creating the NorWeST stream temperature network models. Publically available model outputs include mean August temperature for streams at a 1-km resolution, for the historical period between 1993 and 2011 as well as several projected future scenarios, for streams throughout the Western United States (AWAE 2016). Table 2-2 is paraphrased from a similar table in AWAE 2016.

Predictor Variable	Description
August air temperature (°C)	Stream temperature measurements are paired with air temperature measurements from the same year. Air temperature measurements are derived from downscaled NCEP RegCM3 reanalysis (Hostetler et al. 2011).
August stream discharge (m^3/s)	Mean August stream discharge represents the basin-wide average across several USGS flow gages. Basin scale is dependent upon the availability of flow gages which met criteria for use in modeling, including availability of long-term records and minimal water abstraction or reservoirs.
Elevation (m)	Elevation, available at a 30-m resolution, is used to represent the vertical trend towards colder air temperature and colder groundwater. Data are obtained from the National Elevation Dataset (NED) associated with NHDPlusV2 (Horizon Systems Corporation, 2012; McKay et al. 2012).
Latitude (m)	Latitude, represented by sites' y-coordinates from the Albers Equal Area project, are included because of the Northern Hemisphere trend towards colder temperatures at higher latitudes. Latitude values for each site location are derived in ArcGIS (ESRI 2011).
Canopy %	In general, canopy % values are derived from the 2001 and 2011 versions of the National Land Cover Database (MRLC-NCLD 2001; Homer et al. 2007; MRLC-NCLD 2011; Homer et al. 2015). The canopy cover at sites altered by wildfire during the modeling period was adjusted based on severity of the fire (Miller et al. 2009). Canopy cover represents the average stream shading at each site.
Cumulative drainage area (km^2)	Cumulative drainage area represents stream size. It also represents a correlated characteristic, insolation, because larger streams have greater surface area. Drainage area values are derived from the NHDPlusV2 (Horizon Systems Corporation 2012; McKay et al. 2012).
Stream slope %	Slope represents flow velocity and therefore the amount of time spent in a site's localized ambient

	thermal conditions. Stream channel gradient values are derived from the NHDPlusV2 (Horizon Systems Corporation 2012; McKay et al. 2012).
Mean annual precipitation (mm)	Mean annual precipitation, averaged over the upstream catchment area, affects the amount of cooling that streams experience due to rainwater. Precipitation values are derived from the NHDPlusV2 (Horizon Systems Corporation 2012; McKay et al. 2012).
Base flow index (BFI)	The BFI represents the amount of cooling that streams experience due to groundwater input. Data are downloaded from http://ks.water.usgs.gov/pubs/abstracts/of.03-263.htm (Wolock 2003).
Glacier %	Glacier % indicates the percentage of upstream drainage considered to be glacier. Upstream glaciers are expected to have a cooling effect. Data are downloaded from http://glaciers.research.pdx.edu/Downloads (Fountain et al. 2006).
Lake %	Lake % indicates the percentage of catchment area that is open water. Upstream lakes are expected to have a warming effect. Open water data are derived from the NHDPlusV2 (Horizon Systems 2012; McKay et al. 2012).
Tailwater (categorical 0/1)	Tailwater indicates whether the site is downstream of a reservoir with hypolimnetic release. Classification was determined from observed temperature records and discussion with regional biologists.

Table 2-3. This table depicts the series of reproducible steps used to classify species into thermal tiers. The site-group combinations produced by TITAN and Indicator Value analysis were used as a basis for the classification, and laboratory-derived tolerance values were used to reclassify species and expand candidate tiers as needed. The process began with the five site-groups combinations that were associated by Indicator Value analysis with fish species (there were seven possible site-group combinations, but two [cold-warm and cold-cool-warm] were not associated with any species). These five site-group combinations are hereafter referred to as candidate tiers, and their taxonomic composition is altered at each step of the tier development process. The five candidate tiers produced by Step 6 are the final proposed regulatory tiers. This process relies heavily upon expert opinion; the purpose of applying this opinion in a stepwise, reproducible manner is to minimize bias and ensure that all species are given equal consideration in the thermal tier development process. See **Appendix C** for further detail.

TIER DEVELOPMENT STEPS		**Results of step implementation**	**Number of candidate tiers**
STEP 1: consolidation of site-groups	A. Eliminate any site-group with three or fewer species. B. Reclassify its species into the least sensitive adjacent site-group. C. Consolidated site-groups are now referred to as candidate thermal tiers.	Of the seven potential site-group combinations, two (cold-warm and cold-cool-warm) contained zero species and were eliminated. One contained two species (cool-warm) so it was removed and its species were reclassified into the warm-water site-group.	4
STEP 2: reclassification of species	A. Calculate the mean MWAT and mean DM for each candidate tier. B. Calculate the thermal distance between each pair of adjacent tiers' mean MWAT and mean DM values. C. If a species has an MWAT or DM that is 50% or more of the thermal distance between its own and another candidate tier, reclassify it into the other tier. D. If a species has an MWAT or DM that is lower than the average MWAT or DM of a tier that is two tiers lower than its own, then reclassify it into the lower tier. If both MWAT and DM are available for this species, then both qualify for this type of reclassification.	- 1 species was moved from candidate tier (CT) 1 to CT 2 - 1 species was moved from CT 2 to CT 3 - 1 species was moved from CT 3 to CT 2 - 1 species was moved from CT 3 to CT 4 - 9 species were moved from CT 4 to CT 3 - 1 species was moved from CT 4 to CT 2	4

	Step 2a. MWAT is prioritized: if a species' MWAT makes it a candidate for reclassification but its DM does not, it is moved. If a species' DM makes it a candidate for reclassification but its MWAT does not, it is not moved. **Step 2b.** There is one exception to the prioritization of MWAT: if prioritizing MWAT would cause a species to have the lowest MWAT or DM in its candidate tier, then prioritize DM.		
STEP 3: placement of species not classified by TITAN	A. Recalculate the mean MWAT and mean DM for each candidate tier. B. Classify all species not classified by TITAN into the candidate tier with the most similar MWAT and DM. **Step 3a.** MWAT is again prioritized, unless doing so would cause a species to have the lowest MWAT or DM in its candidate tier. **Step 3b.** Any species not placed by TITAN that have no species-specific criteria should be classified into a candidate tier containing species of the same genus if possible, or the most ecologically similar species if there are no species of the same genus.	- 10 species were classified into CT 3 (3 on the basis of ecological similarity) - 11 species were classified into CT 4 (4 on the basis of ecological similarity)	4
STEP 4: reclassification of some species classified by TITAN with no species-specific criteria	A. Any species that were placed by TITAN but have no species-specific criteria may be transferred into the CT of a closely related species, at expert discretion.	- 1 species was moved from CT 1 to CT 2 - 1 species was moved from CT 1 to CT 3	4
STEP 5: expansion of candidate tiers	A. Recalculate the mean MWAT and mean DM for each candidate tier. B. Divide each candidate tier containing four or more species in half to produce two candidate tiers, one containing species with MWAT and DM values below the mean, and one with MWAT and DM values above the mean. **Step 5a.** Apply the same conditions regarding prioritization of MWAT. **Step 5b.** For species with no available MWAT or DM, place them in the new	- All candidate tiers except for CT 1 were divided in two to produce seven tiers: CT 1, CT 2a, CT 2b, CT 3a, CT 3b, CT 4a, and CT 4b	7

	candidate tier containing the most ecologically similar species.		
STEP 6: consolidation of tiers	A. For all candidate tiers that were divided in Step 5, the resulting upper sub-tier is merged with the lower sub-tier of the next-warmest divided candidate tier. **Step 6a.** If the adjacent candidate tier was not divided in Step 5, the sub-tier adjacent to this undivided tier is not consolidated.	- CT 2b was merged with CT 3a - CT 3b was merged with CT 4a	5

Table 2-4. Community-level thresholds identified by TITAN. The Change Point column indicates the community-level thresholds identified by TITAN, and the 0.05, 0.10, 0.50, 0.90, and 0.95 columns represent the 5%, 10%, 50%, 90%, and 95% confidence intervals, respectively, for the recommended thresholds. Confidence intervals were developed through 500 bootstrap replications. The italicized values represent the 5% confidence interval of the first community-level threshold and the 95% confidence interval of the second community-level threshold, which were used as the thresholds between site-groups for Indicator Value analysis, following the precedent set by Beauchene et al. (2014). All values are in °C.

	Change Point	**0.05**	**0.10**	**0.50**	**0.90**	**0.95**
sum z-	15.8	*15.5*	15.6	15.8	15.9	15.9
sum z+	19.8	19.4	19.4	19.7	19.9	*19.9*

Table 2-5. Site-groups and strengths of association for the 52 species included in TITAN analysis and Indicator Value analysis.

Species	Site-group	Phi coefficient of association	Significance
Cutthroat Trout	Cold	0.505	0.001
Brook Trout	Cold	0.453	0.001
Mottled Sculpin	Cold	0.340	0.001
Utah Sucker	Cold	0.119	0.001
Paiute Sculpin	Cold	0.115	0.006
Speckled Dace	Cold-Cool	0.317	0.001
Brown Trout	Cold-Cool	0.196	0.001
Rainbow Trout	Cold-Cool	0.194	0.001
Mountain Whitefish	Cold-Cool	0.155	0.001
Mountain Sucker	Cold-Cool	0.107	0.010
Flannelmouth Sucker	Cool	0.307	0.001
Redside Shiner	Cool	0.271	0.001
Roundtail Chub	Cool	0.198	0.001
Bluehead Sucker	Cool	0.160	0.001
Utah Chub	Cool	0.139	0.002
Burbot	Cool	0.115	0.001
Northern Leatherside Chub	Cool	0.044	0.639
White Sucker	Cool-Warm	0.372	0.001
Lake Chub	Cool-Warm	0.155	0.001
Sand Shiner	Warm	0.638	0.001
Flathead Chub	Warm	0.632	0.001
River Carpsucker	Warm	0.540	0.001
Channel Catfish	Warm	0.537	0.001
Longnose Dace	Warm	0.521	0.001
Fathead Minnow	Warm	0.494	0.001
Plains Killifish	Warm	0.476	0.001
Common Carp	Warm	0.471	0.001
Stonecat	Warm	0.467	0.001
Shorthead Redhorse	Warm	0.385	0.001
Goldeye	Warm	0.363	0.001
Johnny Darter	Warm	0.341	0.001
Central Stoneroller	Warm	0.293	0.001
Common Shiner	Warm	0.291	0.001
Bigmouth Shiner	Warm	0.274	0.001
Red Shiner	Warm	0.258	0.001
Gizzard Shad	Warm	0.258	0.001

Green Sunfish	Warm	0.245	0.001
Creek Chub	Warm	0.244	0.001
Brassy Minnow	Warm	0.241	0.001
Smallmouth Bass	Warm	0.216	0.001
Yellow Perch	Warm	0.190	0.001
Plains Minnow	Warm	0.174	0.001
Hornyhead Chub	Warm	0.164	0.001
Longnose Sucker	Warm	0.161	0.001
Black Bullhead	Warm	0.146	0.001
Quillback	Warm	0.136	0.001
Sturgeon Chub	Warm	0.136	0.001
Plains Topminnow	Warm	0.127	0.002
Largemouth Bass	Warm	0.113	0.004
Brook Stickleback	Warm	0.092	0.015
Rock Bass	Warm	0.079	0.017
Iowa Darter	Warm	0.060	0.083

Table 2-6. Temperature range and number of species associated with each possible site-group or site-group combination. The site-groups are defined by the thresholds identified with TITAN analysis: the 5% confidence interval of the first community-level threshold (15.5°C) divides the cold-water site-group from the cool-water site-group; and the 95% confidence interval of the second community-level threshold (19.9°C) divides the cool-water site-group from the warm-water site-group. The species associations for each site-group combinations were derived through Indicator Value analysis and are described in greater detail in Table 2-5.

Site-group or combination	**Temperature range**	**Number of species**
Cold	< 15.5	5
Cold-Cool	< 19.9	5
Cool	15.5 – 19.8$\overline{9}$	7
Cool-Warm	≥ 15.5	2
Warm	≥ 19.9	33
Cold-Warm	< 15.5 and ≥ 19.9	0
Cold-Cool-Warm	full thermal gradient	0

Table 2-7. Taxonomic composition and regulatory criteria of proposed thermal tiers. The species with the lowest MWAT and DM value in each tier are marked with an asterisk.

Tier I (Cold)			
Common Name	**Scientific Name**	**MWAT (°C)**	**DM (°C)**
Cutthroat Trout*	*Oncorhynchus clarkii*	18.10	22.31
Brook Trout*	*Salvelinus fontinalis*	18.34	21.68
Tier I (Cold) Criteria		**≤ 18.1**	**≤ 21.7**
Tier II (Cold-Cool)			
Common Name	**Scientific Name**	**MWAT (°C)**	**DM (°C)**
Brown Trout*	*Salmo trutta*	19.32	24.92
Rainbow Trout*	*Oncorhynchus mykiss*	19.35	23.77
Burbot	*Lota lota*	19.59	25.42
Longnose Sucker	*Catostomus catostomus*		24.75
Tier II (Cold-Cool) Criteria		**≤ 19.3**	**≤ 23.8**
Tier III (Cool)			
Common Name	**Scientific Name**	**MWAT (°C)**	**DM (°C)**
Mountain Sucker*	*Catostomus platyrhynchus*	21.95	29.00
White Crappie	*Pomoxis annularis*	23.56	29.48
Northern Leatherside Chub*	*Lepidomeda copei*	23.79	27.76
Common Shiner	*Luxilus cornutus*	24.20	28.97
Orangethroat Darter	*Etheostoma spectabile*	24.41	29.98
Bluehead Sucker	*Catostomus discobolus*	25.00	
Yellow Perch	*Perca flavescens*	25.01	28.23
Johnny Darter	*Etheostoma nigrum*	25.37	29.04
White Sucker	*Catostomus commersoni*	27.69	28.82
Mottled Sculpin	*Cottus bairdi*		27.85
Longnose Dace	*Rhinichthys cataractae*		28.60
Brook Stickleback	*Culaea inconstans*		28.60
Creek Chub	*Semotilus atromaculatus*		28.60
Mountain Whitefish	*Prosopium williamsoni*		
Paiute Sculpin	*Cottus beldingii*		
Utah Sucker	*Catostomus ardens*		
Northern Pearl Dace	*Margariscus margarita*		
Tier III (Cool) Criteria		**≤ 22.0**	**≤ 27.8**
Tier IV (Cool-Warm)			
Common Name	**Scientific Name**	**MWAT (°C)**	**DM (°C)**
Walleye*	*Sander vitreus*	25.99	31.68
Flannelmouth Sucker	*Catostomus latipinnis*	26.22	31.15
Utah Chub	*Gila atraria*	26.36	31.86
Black Crappie	*Pomoxis nigromaculatus*	26.56	32.10
Quillback	*Carpiodes cyprinus*	26.82	33.54
Golden Shiner	*Notemigonus crysoleucas*	27.71	31.56
Central Stoneroller	*Campostoma anomalum*	27.82	
Shorthead Redhorse	*Moxostoma macrolepidotum*	28.41	31.84
Fathead Minnow	*Pimephales promelas*	28.78	31.88
Emerald Shiner	*Notropis atherinoides*	28.86	30.15
Smallmouth Bass	*Micropterus dolomieu*	28.90	33.74
Spottail Shiner	*Notropis hudsonius*	29.21	31.94
Grass Carp	*Ctenopharyngodon idella*	29.46	35.95

Pumpkinseed Sunfish	*Lepomis gibbosus*	29.78	32.74
Common Carp	*Cyprinus carpio*	29.84	33.88
Gizzard Shad	*Dorosoma cepedianum*	30.30	30.72
Northern Pike*	*Esox lucius*		30.00
Finescale Dace*	*Phoxinus neogaeus*		30.00
Sand Shiner	*Notropis stramineus*		30.20
Kendall Warm Springs Dace	*Rhinichthys osculus thermalis*		31.75
Speckled Dace	*Rhinichthys osculus*		31.82
Hornyhead Chub	*Nocomis biguttatus*		32.80
Brassy Minnow	*Hybognathus hankinsoni*		
Redside Shiner	*Richardsonius balteatus*		
Sauger	*Sander canadensis*		
Shovelnose Sturgeon	*Scaphirhynchus platorynchus*		
Flathead Chub	*Platygobio gracilis*		
Lake Chub	*Couesius plumbeus*		
Tier IV (Cool-Warm) Criteria		**≤ 26.0**	**≤ 30.0**
	Tier V (Warm)		
Common Name	**Scientific Name**	**MWAT (°C)**	**DM (°C)**
Western Mosquitofish*	*Gambusia affinis*	29.04	34.80
Freshwater Drum*	*Aplodinotus grunniens*	30.19	32.02
Rock Bass	*Ambloplites rupestris*	30.24	34.28
Green Sunfish	*Lepomis cyanellus*	31.05	35.12
Largemouth Bass	*Micropterus salmoides*	31.38	34.06
Bluegill	*Lepomis macrochirus*	31.59	33.14
Channel Catfish	*Ictalurus punctatus*	32.38	35.76
Plains Minnow	*Hybognathus placitus*	32.94	37.12
Bigmouth Shiner	*Notropis dorsalis*		33.80
Plains Topminnow	*Fundulus sciadicus*		34.20
Roundtail Chub	*Gila robusta*		34.50
Red Shiner	*Cyprinella lutrensis*		35.00
Black Bullhead	*Ameiurus melas*		35.30
Plains Killifish	*Fundulus zebrinus*		38.45
River Carpsucker	*Carpiodes carpio*		
Stonecat	*Noturus flavus*		
Goldeye	*Hiodon alosoides*		
Sturgeon Chub	*Macrhybopsis gelida*		
Suckermouth Minnow	*Phenacobius mirabilis*		
Flathead Catfish	*Pylodictus olivaris*		
Western Silvery Minnow	*Hybognathus argyritis*		
Iowa Darter	*Etheostoma exile*		
Tier V (Warm) Criteria		**≤ 29.0**	**≤ 32.0**
	Primarily Lentic Species (not classified)		
Common Name	**Scientific Name**	**MWAT (°C)**	**DM (°C)**
Lake Trout	*Salvelinus namaycush*	16.66	22.58
Kokanee	*Oncorhynchus nerka*	19.01	22.93
Arctic Grayling	*Thymallus arcticus*		21.00
Golden Trout	*Oncorhynchus aguabonita*		25.50
Tiger Muskellunge	*Esox lucius x Esox masquinongy*		30.50

Table 2-8. Occurrence frequency was calculated by dividing the number of sites at which a species was observed by the total 1763 sites in the species assemblage database. Mean abundance (number of individuals per site) was calculated using the 913-site subset of the species assemblage database with available count data. An N/A in the abundance column indicates that the species was observed in the 1763-site database but not the 913-site subset; a dash in any column indicates that the species was not observed in the database, although it is expected to be found in Wyoming. Low and high temperatures indicate the coldest and warmest modeled mean August temperatures of all sites where a species was observed. It may be interesting to note that the average width of thermal range at sites where a species was observed decreases from the coldest tier to the warmest; the average thermal widths (in °C) of Tier I, II, III, IV, and V are 7.53, 7.38, 6.05, 5.14, and 4.00, respectively.

Species	Occurrence Frequency	Mean Abundance	Low Temperature (°C)	High Temperature (°C)
Tier I (Cold)				
Cutthroat Trout	26.83%	6.2	12.66	19.23
Brook Trout	15.37%	31.1	11.47	19.95
Average abundance		*18.65*		
Tier II (Cold-Cool)				
Brown Trout	14.41%	23.7	11.47	21.49
Rainbow Trout	13.05%	16.6	12.36	20.54
Burbot	1.12%	2	16.3	16.85
Longnose Sucker	6.81%	13.9	12.36	23.12
Average		*14.05*		
Tier III (Cool)				
Mountain Sucker	25.58%	25.1	11.61	23.12
White Crappie	--	--	--	
Northern Leatherside Chub	0.57%	23.0	14.64	16.79
Common Shiner	1.70%	96.7	16.39	21.77
Orangethroat Darter	0.11%	47.0	21.24	21.53
Bluehead Sucker	3.29%	6.7	14.30	18.95
Yellow Perch	0.51%	20.1	18.85	21.77
Johnny Darter	2.55%	15.4	15.36	21.77
White Sucker	34.35%	44.2	12.74	22.92
Mottled Sculpin	17.41%	105.6	12.21	19.23
Longnose Dace	22.86%	64.4	12.36	23.12
Brook Stickleback	0.91%	10.9	17.04	20.98
Creek Chub	9.87%	53.6	14.30	22.42
Mountain Whitefish	5.96%	15.3	12.77	19.7

Paiute Sculpin	1.70%	N/A	--	--
Utah Sucker	1.08%	N/A	--	--
Northern Pearl Dace	--	--	--	--
Average		*38.1*		
Tier IV (Cool-Warm)				
Walleye	0.11%	3.5	17.84	21.36
Shorthead Redhorse	3.86%	31.7	15.04	23.12
Utah Chub	2.89%	9.8	15.55	19.23
Flannelmouth Sucker	9.93%	8.1	14.88	19.7
Black crappie	0.11%	1.0	21.53	21.77
Quillback	0.23%	3.5	20.16	21.77
Golden shiner	--	--	--	--
Central Stoneroller	1.65%	71.4	18.39	21.77
Fathead Minnow	22.58%	54.4	12.21	22.92
Emerald Shiner	--	--	--	--
Smallmouth Bass	1.48%	12.0	17.03	21.77
Spottail shiner	0.11%	16.0	16.28	17.13
Grass carp	--	--	--	--
Pumpkinseed sunfish	--	--	--	--
Common Carp	10.61%	58.8	15.14	23.12
Gizzard Shad	0.79%	7.1	19.95	21.77
Northern Pike	0.17%	N/A	--	--
Finescale Dace	--	--	--	--
Sand Shiner	24.39%	303.4	15.8	23.12
Kendall warm springs dace	--	--	--	--
Speckled Dace	24.39%	78.9	12.66	19.23
Hornyhead Chub	0.68%	58.9	18.47	20.54
Brassy Minnow	0.91%	13.4	16.39	22.42
Redside Shiner	17.13%	80.3	12.66	19.23
Sauger	0.11%	1.5	16.30	21.73
Shovelnose Sturgeon	--	--	--	--
Flathead Chub	8.45%	162.5	15.6	23.12
Lake Chub	7.37%	51.3	11.61	21.49
Average		*51.4*		
Tier V (Warm)				
Western mosquitofish	--	--	--	
Freshwater drum	--	--	--	
Rock Bass	0.68%	14.0	17.62	22.42
Green Sunfish	1.42%	42.3	17.03	21.77

Largemouth Bass	0.23%	2.0	19.9	21.26
Bluegill	--	--	--	--
Channel Catfish	4.82%	19.2	17.03	22.92
Plains Minnow	0.51%	15.1	17.03	22.42
Black Bullhead	0.68%	10.8	19.66	20.95
Bigmouth Shiner	2.21%	46.4	16.33	21.77
Plains Topminnow	0.34%	11.5	19.55	20.98
Roundtail Chub	3.52%	5.2	16.39	18.99
Red Shiner	1.08%	17.8	19.27	21.77
Plains Killifish	4.37%	87.7	16.54	21.36
River Carpsucker	3.69%	19.1	17.03	22.92
Stonecat	4.77%	9.3	15.04	23.12
Goldeye	2.15%	5.7	17.03	22.32
Sturgeon Chub	0.23%	20.5	20.97	21.52
Iowa Darter	0.51%	5.3	17.30	21.77
Suckermouth Minnow	--	--	--	--
Flathead Catfish	--	--	--	--
Western Silvery Minnow	--	--	--	--
Average		*21.8*		

Figures

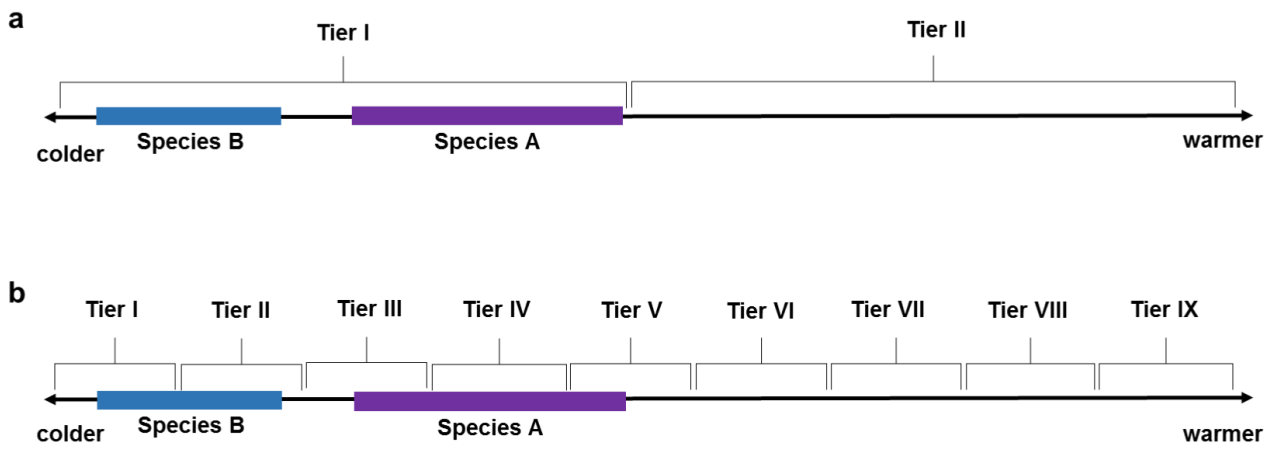

Figure 2-1. Conceptual diagram of hypothetical thermal classification systems. In each diagram, the bars represent species distributions along the available thermal spectrum. (a) A classification system with a small number of broad thermal tiers can result in unattainability and/or excessive regulatory burden. Here, Species A and Species B are both in the coldest tier. Water bodies assigned to Tier I would be required to maintain temperatures suitable for Species B, even though Species A can survive at much warmer temperatures. Waters inhabited by Species A may be unable to attain temperatures suitable for Species B under natural conditions. Setting unattainable standards for these waters may force the regulatory agency to allocate resources towards this water body for remediation, which may be more needed elsewhere. (b) A classification system with a large number of narrow thermal tiers may be difficult to implement due to the variation in species' thermal niche widths and imprecise knowledge of species assemblage in waters being regulated. Additionally, very narrow thermal tiers make it challenging to manage for species with broad thermal distributions.

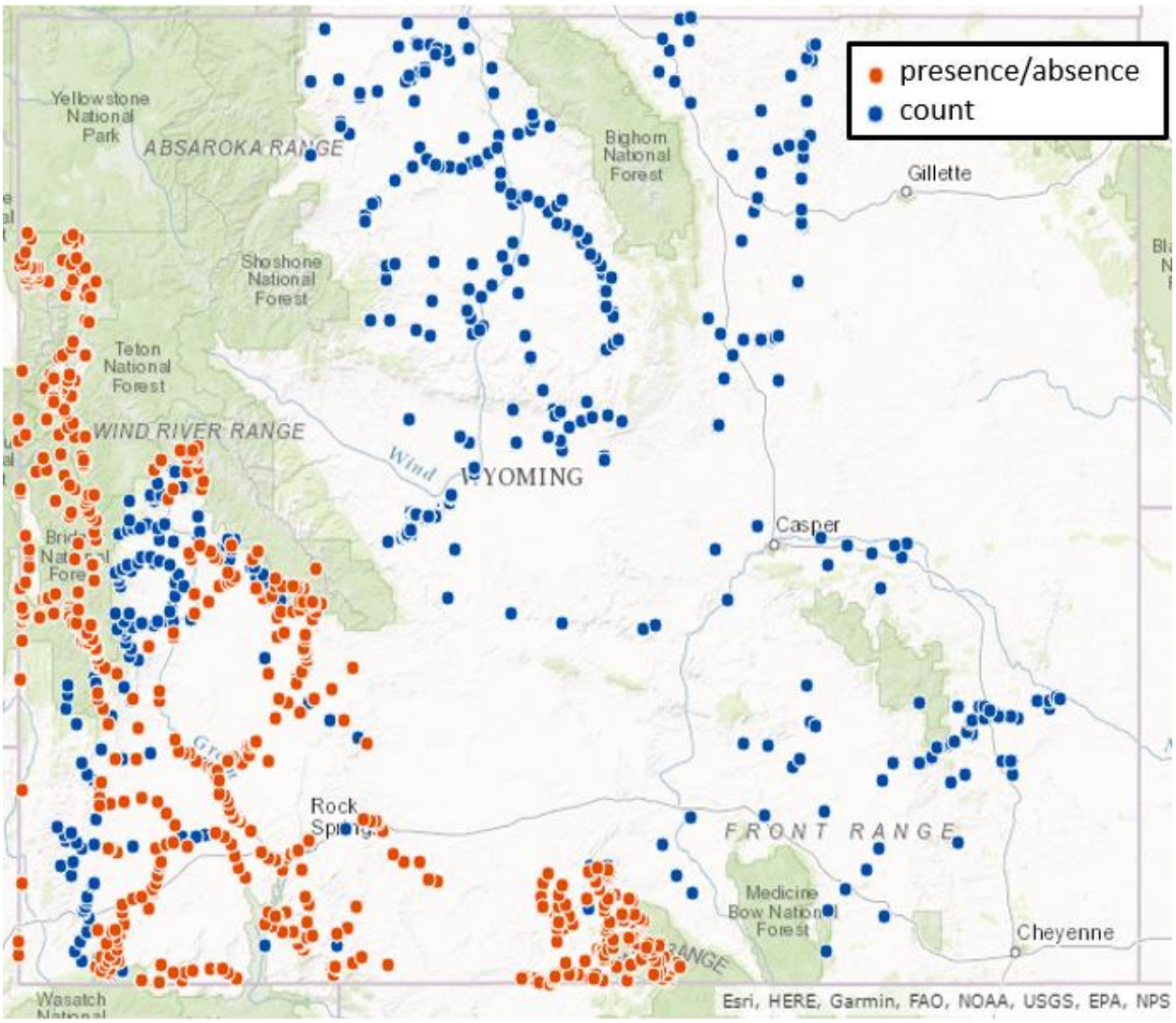

Figure 2-2. Sites included in the stream fish species assemblage database (*n* = 1763). All surveys were conducted between 1989 and 2015. Data were provided by the Wyoming Game and Fish Department (WGFD). Blue points indicate sites for which data were available in count format; orange points indicate sites for which data were only available in presence/absence format.

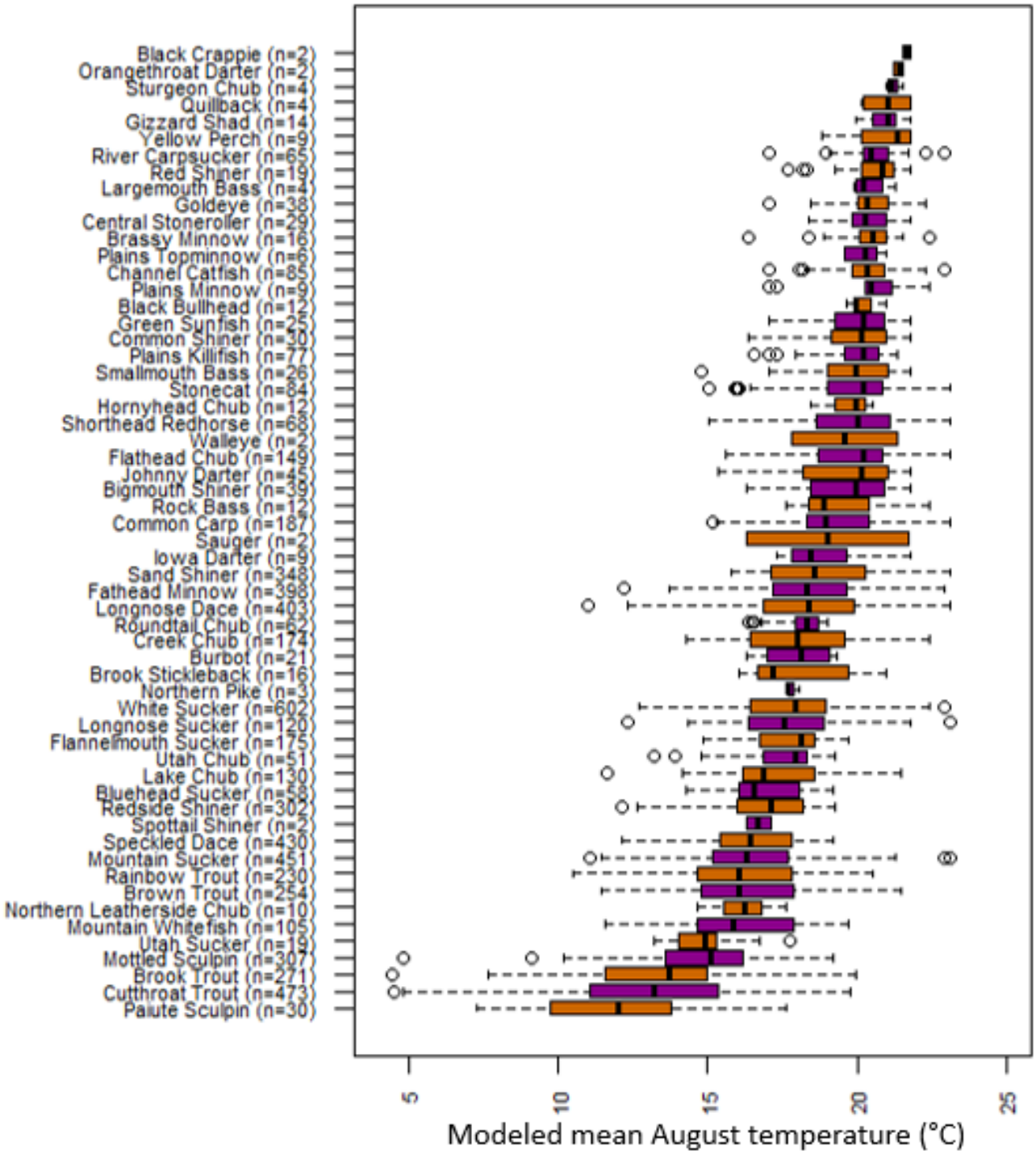

Figure 2-3. Box plots of the thermal distribution, in terms of modeled mean August temperature, for all Wyoming stream species observed at one or more sites. *n* indicates the number of sites at which species were observed. The center bar in each box indicates the mean modeled mean August temperature, the thermal range in each box indicates the range between the 25th and 75th percentiles, the whiskers indicate the 5th and 95th percentiles, and the circles represent outliers.

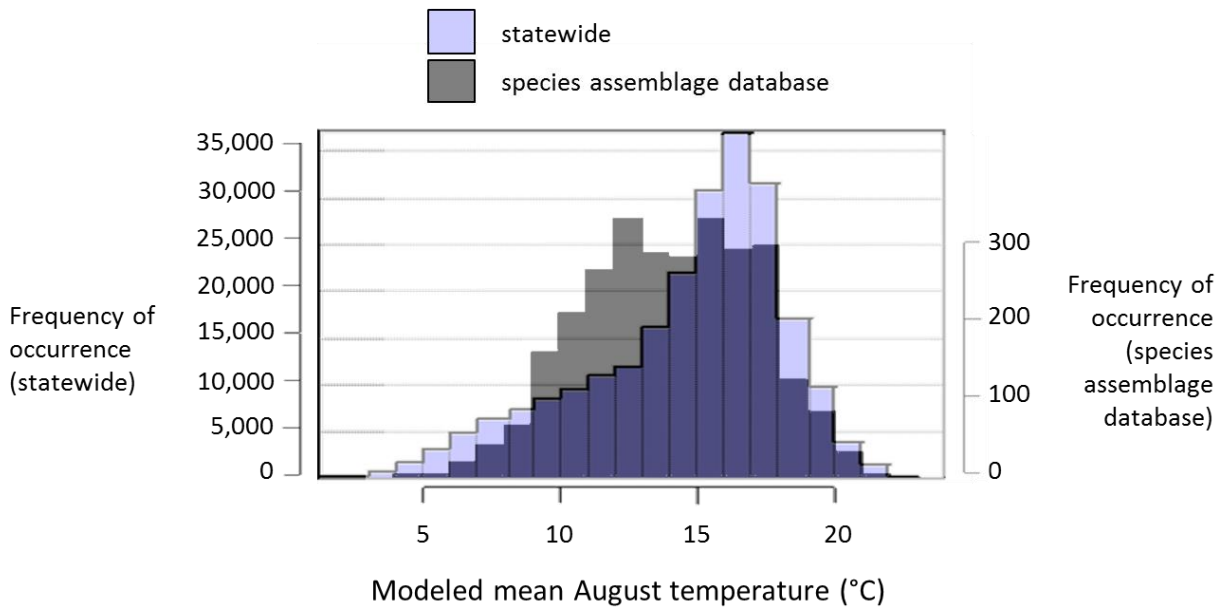

Figure 2-4. Histogram of the statewide frequency of occurrence of modeled mean August temperatures overlaid with a histogram of the frequency of occurrence of modeled mean August temperature at the 1763 sites in the species assemblage database. Both histograms represent modeled mean August temperature of streams at a 1-km resolution.

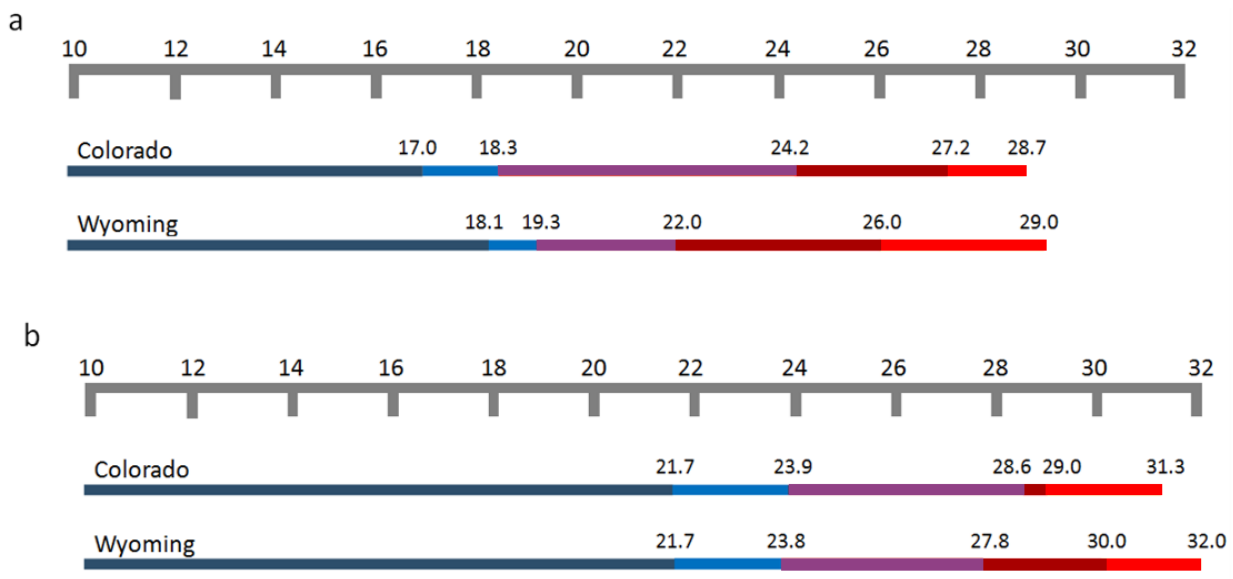

Figure 2-5. Colorado summer thermal criteria compared to proposed Wyoming criteria for (a) MWAT and (b) DM (CWQCC 2011). All temperatures are in °C.

References

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CHAPTER THREE:
Evaluation of thermal criteria

Introduction

Before thermal criteria can be implemented, it is necessary to define a protocol for assigning thermal tiers to streams based on the species observed or expected to be present. The chosen classification protocol must meet two conditions: protectiveness and attainability. A protective protocol will classify a stream into a tier whose criteria establish conditions suitable for the species that occur in the stream under natural conditions. An attainable protocol will classify a stream into a tier whose criteria are not exceeded by the stream's natural thermal regime.

Another way to conceptualize the protectiveness and attainability of a potential classification protocol is through its ability to identify thermally impaired waters, an EPA requirement of thermal regulations (USEPA OW 2009). A protective protocol avoids "false negative" identification of thermal impairment: it successfully identifies all streams that are impaired. An attainable protocol avoids "false positive" identification of thermal impairment: it does not falsely identify streams as impaired when they actually have a natural thermal regime. Accurate identification of impaired streams is important because section 303(d) of the Clean Water Act mandates that regulatory agencies complete a remediation plan, or Total Maximum Daily Load (TMDL), for every stream that is identified as impaired (33 U.S.C. § 1251; USEPA OW 2009). False identification of impairment costs regulatory agencies remediation resources that could otherwise be used to improve streams with real thermal impairment.

I identify three main approaches to classifying streams into thermal tiers:

1. Species presence/absence. Using the species presence/absence approach, streams are classified into the tier of the most sensitive species known to be present. This method does not take into account the presence of less sensitive species or the abundance of any species. Some regulatory agencies, including WDEQ, currently use this approach (WDEQ/WQD 2001; CWQCC 2011). The species presence/absence approach is expected to be highly protective of unimpaired streams because it ensures protection for the most sensitive species in the stream, even if the stream contains a higher proportion of less sensitive species. However, the species presence/absence approach may not effectively identify impaired streams; if thermally sensitive species might be present under natural conditions but are excluded under impaired conditions, the impairment would not be recognized through the presence/absence approach.

The high degree of protection afforded to thermally sensitive species by the presence/absence approach is expected to lower the attainability of this method. This is because some fish species are commonly present in low abundance outside of their expected range. These fish expand their thermal range by utilizing thermal refugia, moving in and out of stream reaches in response to daily or seasonal variation, and using nightly cool periods to recover from daily high temperatures (Schrank et al. 2001). Furthermore, agencies rarely have the means to obtain a comprehensive picture of the available thermal habitat at a given site; the more common approach is a single thermograph paired with a fish census covering several hundred meters of stream length, creating uncertainty about the temperatures fish experience. As a result, the presence of a thermally sensitive species outside of its expected thermal range does not always indicate impairment.

2. Species assemblage. Using the species assemblage classification approach, streams are classified into the most sensitive tier that comprises a pre-determined threshold percentage of all

individuals present. The species assemblage approach is expected to be protective only if all species have a relatively similar average abundance. If instead there are some generalist species that occur in greater abundance, it would be difficult for more thermally sensitive species to pass the required threshold percentage of individuals in streams where they co-occur with the generalists. As a result, these streams could be classified into a warmer tier than appropriate. And this approach, like the species presence/absence approach, is unlikely to identify streams that are already impaired. Because the species assemblage approach is less likely to classify streams into a lower thermal tier based upon the presence of only a few individuals of a thermally sensitive species, it is expected to have high attainability.

3. Predictor variable. Using the predictor variable classification approach, streams are classified into tiers based upon a variable that is correlated with expected species assemblage. The protectiveness and attainability of the predictor variable approach depend entirely on the strength of correlation between species assemblage and the chosen variable. If a suitable variable can be found, this approach is promising because it is less limited by the availability of data, especially if the predictor variable can be obtained through remote sensing or modeling.

The objective of Chapter Three is to evaluate the protectiveness and attainability of the thermal criteria identified in Chapter Two when applied to streams using each of the three classification approaches discussed above.

Methods

Evaluation database. I assembled a database of 50 sites with fish species assemblage data in count format to be used for evaluating the three stream classification approaches (**Figure 3-1**).

Each site was paired with the output of a continuously recording temperature logger located in the same stream within 1 km of the species assemblage survey site. All sites were checked to ensure that no major changes, such as tributaries entering the stream or major alterations in riparian land use, occurred between the species assemblage survey site and the temperature logger. Twenty-eight of the 50 evaluation sites were also included in the Chapter Two TITAN analysis. These 28 sites were chosen because they were the only sites in the 1763-site species assemblage database that were within the required proximity to a temperature logger and had data available in count, rather than presence/absence, format. Temperature logger data for these 28 sites were gathered from a publically available database of thermograph records from the Green, North Platte, Bighorn, and Powder-Tongue basins (Chandler et al. 2016). The thermal data from these sites are available in the form of a daily mean, daily maximum, and daily minimum temperature for each day in August. Thermal data for each of these 28 sites were summarized using August data from one year, chosen to correspond to the year in which fish survey data were collected. The remaining 22 evaluation sites were not included in any previous analyses. The species assemblage and temperature data for 14 of the 22 new sites were collected as part of ongoing graduate research at the University of Wyoming, and I collected species assemblage and temperature data for eight of the 22 new evaluation sites through field work conducted in summer 2015. All thermal data for the 22 new evaluation sites are available in the form of temperature measurements taken at 30-minute or 60-minute intervals throughout August. Species assemblage data for the 22 new sites were collected through a mixture of single-pass and multi-pass electrofishing. Each of the 50 evaluation sites were paired with a modeled mean August temperature from the AWAE stream temperature models (Isaak et al. 2016). Finally, I calculated the measured mean August temperature, MWAT, daily maximum, and daily minimum

temperature for each of the 50 sites, and I subtracted the lowest daily minimum temperature from the highest daily maximum temperature to calculate the monthly thermal range for each site.

Stream classification approaches. I used each of the three classification approaches described above to classify each site into a thermal tier. For the species presence/absence approach, I classified each site into the tier associated with its most sensitive species.

For the species assemblage approach, I classified each site into the most sensitive tier containing 10% or more of the individuals observed at the site (for example, if 1% of individuals observed at a site were in Tier I, 10% were in Tier II, and 89% of were in Tier III, the site would be classified as Tier II). If there were two adjacent tiers that did not reach the 10% threshold individually but did when added together, the site was classified into the least sensitive of the two (for example, if 5% of individuals observed at a site were in Tier I, 5% were in Tier II, and 90% were in Tier III, the site would be classified as Tier II).

For the predictor variable approach, I used each site's modeled mean August temperature as a predictor of the expected species assemblage. I used the community-level thresholds along the modeled mean August temperature gradient identified with TITAN in Chapter Two to set thresholds for thermal tier classification. Species' associations with the site-groups produced by TITAN analysis (**Table 2-5**) were used to define the stream classification thresholds. Because the cold-water site-group (<15.5°C) was associated by Indicator Value analysis with Tier I (Cold) species, I used 15.5°C as the upper threshold for classifying Tier I (Cold) streams. The cool-water site group (15.5-19.9°C) was associated by Indicator Value analysis with species in Tier II (Cold-Cool) and Tier III (Cool), so the site-group's thermal range was divided evenly

between Tier II and Tier III. This resulted in a range of 15.5°C-17.7°C for classification as a Tier II (Cold-Cool) stream and a range of 17.8°C-19.9°C for classification as a Tier III (Cool) stream.

The warm-water site-group (≥19.9°C) was associated by Indicator Value analysis with species in Tier IV (Cool-Warm) and Tier V (Warm), so I applied upper thresholds for Tier IV (Cool-Warm) and Tier V (Warm) that were both warmer than 19.9°C. I chose 24.4°C as the classification boundary between Tier IV (Cool-Warm) and Tier V (Warm) by regressing the upper classification temperature of the first three tiers against their respective MWAT criteria and using the resulting linear equation to calculate an appropriate upper classification temperature for Tier IV. As a result, the range for classification as a Tier IV (Cool-Warm) stream is 19.9°C-24.4°C, and all streams warmer than 24.4°C are classified as Tier V (Warm).

Evaluation of protectiveness. I performed two tests of protectiveness. First, I assessed the ability of each classification system to classify sites so that the thermal tier of individuals present matched the thermal tier assigned to the site. To do this, I calculated the proportion of all individuals in each tier that was observed at streams classified into each tier. I also determined how often a stream of a particular thermal classification contained species that were classified into a colder tier than the stream, because individuals of these species may be at risk of potentially harmful increases in stream temperature. This first test assesses a classification protocol's ability to protect species that have been observed at a particular site.

Second, I assessed the average allowable temperature increase for sites of each tier. To do this, I calculated the degree to which each site's observed MWAT and DM were lower than their respective tier-level criteria, for all sites where the tier-level criteria were not exceeded. Sites whose measured MWAT and DM are much lower than their MWAT and DM criteria may be

less protected. This is because protection is contingent upon the ability to accurately observe or predict species' occurrence; there is a risk that potential habitat for thermally sensitive species may be left unprotected if these species have a low probability of detection or if a predictor variable is ineffective. If there are many sites with measured temperatures that are substantially lower than their thermal criteria, it should be taken as a warning sign that these sites may contain potential habitat for thermally sensitive species that may not be fully protected. As such, this second test assesses a classification system's ability to protect species that may be present at a site but were not observed in the survey used to establish stream criteria.

Evaluation of attainability. For all sites, using each classification approach, I determined the number of times per month that the tier-level MWAT and DM criteria were exceeded as well as the magnitude of the greatest exceedance. For the 22 sites with an available hourly or 30-minute temperature record, I also calculated the duration of each DM exceedance. For all exceedances with DM duration data, I regressed duration against frequency and magnitude to assess the ability of the 2-hour DM duration selected in Chapter Two to ignore natural fluctuation (avoiding "false positive" identification) while maintaining sufficient sensitivity to detect signs of impairment (avoiding "false negative" identification).

Results

Evaluation database. The 50 evaluation sites were distributed throughout most major drainages in the state (**Figure 3-1**). The modeled mean August temperature of the 50 sites ranged from 9.3°C to 22.4°C, providing a fairly even representation of the statewide thermal range except for the coldest end of the thermal spectrum (**Figure 1-5**). Measured mean August

temperature ranged from 9.7°C to 24.2°C, MWAT ranged from 10.4°C to 26.7°C, DM ranged from 13.3°C to 32.7°C, and minimum temperature ranged from 3.4°C to 16.0°C (**Figure 3-2**). The narrowest thermal range at a single site was 2.2°C and the widest thermal range was 23.1°C; the mean thermal range per site was 13.6°C. The full evaluation database is included as **Appendix D**.

Stream classification approaches. The average site classification differed based upon the classification approach applied. Assigning each tier a numeric value based on a scale where Tier I (Cold) = 1 and Tier V (Warm) = 5, the species presence/absence approach, species abundance approach, and predictor variable approach resulted in an average tier classification of 2.22, 2.60, and 2.26, respectively (**Table 3-1**). In general the species presence/absence and species assemblage classification approaches were skewed towards the cool-water tiers, with Tier III (Cool) being the most commonly applied classification. For streams classified by the species assemblage approach, Tier III (Cool) was assigned more than twice as often as any other tier. The predictor variable approach classified a more even number of streams into each of the first four tiers, and also classified more sites as Tier I (Cold) than any other approach. None of the approaches classified any streams into Tier V (Warm).

All sites, regardless of both classification and classification approach, contained a larger proportion of Tier III (Cool) and Tier IV (Cool-Warm) individuals than individuals of other tiers (**Figure 3-3)**. This result suggests that one or more of the Tier III and Tier IV species have a high average abundance and a relatively broad thermal distribution; **Table 2-8** confirms that there are a number of species in Tier III (White Sucker, Longnose Dace, Mountain Sucker, Mottled Sculpin) and Tier IV (Fathead Minnow, Common Carp, Sand Shiner) that are above average in terms of occurrence frequency, average abundance, and thermal distribution width.

Evaluation of protectiveness. The results from the two tests of protectiveness are described below:

1) The three classification approaches differ in their ability to classify individuals into the appropriate tier (**Figure 3-4)**. All approaches were relatively protective of Tier I (Cold) fishes. The species presence/absence approach classified 100% of Tier I individuals into Tier I, affording full protection to Tier I species. For the predictor variable approach this number was 97%, while the species assemblage approach was the least protective of Tier I species at 82%. Additionally, the lack of Tier IV (Cool-Warm) and Tier V (Warm) classifications when using the presence/absence approach suggests that this approach is highly protective of species classified into these tiers; all streams containing Tier IV and Tier V species are classified as Tier III (Cool) and as a result they are assigned tier-level criteria much lower than the Tier IV and Tier V species' upper thermal tolerances. The same is true of Tier V species in the species assemblage and predictor variable approaches (**Figure 3-4**).

Another way to evaluate protectiveness is to consider the percentage of individuals at a site that belong to lower thermal tiers than the tier assigned by one of the three approaches. Such individuals would not be protected because the regulatory criteria could allow water temperatures to increase beyond the thermal tolerances of those individuals. All three approaches are protective as generally less than 1% of the individuals at sites were members of a colder thermal tier (**Table 3-2**). The worse-case scenario, which occurred when streams were classified by the predictor variable approach, was that 6.95% of the individuals in Tier IV streams were members of the Tier III thermal guild.

2) **Figure 3-5** illustrates the deviation of each site's measured MWAT and DM values from their respective criteria. Sites whose measured temperatures are substantially lower than their thermal criteria may contain suitable habitat for thermally sensitive species that have low occurrence frequency or probability of detection, and these species may not be protected by the site's criteria. The average amount by which measured MWAT and DM values are lower than their corresponding criteria is the greatest using the species assemblage approach, followed by the presence/absence approach, and it is lowest using the predictor variable approach.

Evaluation of attainability. The predictor variable approach resulted in the fewest sites where measured MWAT and DM values exceeded the respective criteria (**Table 3-3; Figure 3-5**). The magnitude and frequency of exceedances were generally highest for the species presence/absence approach. The magnitude and frequency of exceedances were slightly lower for the species assemblage approach, and lowest for the predictor variable approach. Duration of DM exceedances for all approaches displayed a strong relationship with the magnitude and frequency components of those exceedances (**Figure 3-6**).

Discussion

Evaluation database. The 50 sites in the evaluation database were selected opportunistically; it must be noted that they do not represent a random sample of Wyoming stream sites and are not distributed evenly throughout the state. While species assemblage surveys were standardized to the greatest extent possible, I did not have information on survey method, reach length, or stream width for several sites in the evaluation database (**Appendix D**). Additionally, because there is no available metric to quantify potential degradation at each site, it

is impossible to state whether the observed species assemblage represents that which would be present under natural conditions. The results presented in Chapter Three should be interpreted as an initial investigation into the viability of the thermal regulatory standard that I propose, utilizing the best available data. Further validation is recommended. To collect paired species assemblage and stream temperature data at a random sample of Wyoming stream sites would have required an effort beyond the scope of this thesis, but it would be a sensible direction for future research.

Balance between protectiveness and attainability. In general, the results of the evaluation analyses show that there is a trade-off between protectiveness and attainability. The following discussion section will demonstrate that the attributes of a classification approach that make it protective tend to do so at the expense of its attainability; the opposite statement holds true as well. Because the predictor variable approach ultimately achieves the best balance between protectiveness and attainability, I have identified it as the best classification approach.

Protectiveness. The first test of protectiveness evaluated the ability of each of the three classification approaches to accurately classify sites containing thermally sensitive species. The species presence/absence approach most accurately classified streams containing Tier I (Cold) species and became less accurate as the tiers increased along the thermal gradient. This is because the species/presence absence approach is driven by the most sensitive species present, resulting in a relatively large proportion of Tier I and Tier II (Cold-Cool) streams and a relatively small proportion of the warmer tiers. Because the presence/absence approach did not recognize any Tier IV (Cool-Warm) or Tier V (Warm) sites in the evaluation database, it classified all sites containing Tier IV and V individuals into Tier III (Cool). This afforded Tier IV and V individuals a high degree of protection but might compromise attainability at sites containing

Tier IV and Tier V species, as demonstrated by the large number of Tier III exceedances seen in plot (a) of **Figure 3-5**. This is also somewhat true of the species assemblage and predictor variable approaches, which did not recognize any Tier V sites in the evaluation database.

All three classification approaches recognize that Tier III (and to a lesser extent, Tier II and Tier IV) species tend to occur frequently, in relatively high abundance, and over a wide thermal distribution. As a result, these species tend to occur in streams of multiple classifications regardless of the approach used to classify streams (**Figure 3-3**). However, the broad distribution of generalist species has a greater effect on classifications produced by the species assemblage approach than the other two approaches; a few generalist species that occur in high abundances can make it difficult for less abundant, more sensitive species to reach the percentage of individuals required for classification (10% in my analyses) (**Table 3-2**). This results in a larger number of Tier I species occurring in Tier II streams with the species assemblage approach than with the other approaches (**Figure 3-4**). The extent to which the species assemblage classification system is driven by generalist species reduces its protectiveness of more thermally sensitive species. The predictor variable approach classifies fewer streams containing Tier I species into Tier II than the species assemblage approach, but it does result in a larger number of Tier II species in Tier III streams and Tier III species in Tier IV streams. Species that are frequently found in streams with a stream classification that is warmer than their own tier tend to be among the least sensitive species within their tier. The most common Tier II species found in streams classified by the predictor variable approach into Tier III is Longnose Sucker, and the most common Tier III species classified by the predictor variable approach into Tier IV are White Sucker and Longnose Dace, all of whom have relatively high species-specific thermal criteria compared to the other species in their own tier (**Table 2-7; Appendix D**).

The second test of protectiveness considered the degree to which sites' measured MWAT and DM values were colder than their respective criteria. A number of sites classified by the species assemblage approach into Tier III were as cold as or colder than sites classified by the same approach into Tier I (**Figure 2-4**); as a result, their measured MWAT and DM values are much lower than their respective criteria. Sites' measured MWAT and DM values are slightly closer to their criteria when classified using the species presence/absence approach, and much closer to their criteria using the predictor variable approach. When a classification system results in a large number of sites with measured values that are much colder than their criteria, it indicates that the classification system may be missing a number of sites that are cold enough to support more thermally sensitive species. It is possible that Tier I and Tier II species utilize the very cold sites classified by the species assemblage approach as Tier III occasionally, seasonally, or even regularly but were not observed when the species assemblage survey used for stream classification was conducted. It is also possible that Tier I or Tier II species inhabited these streams at one time, but have since been excluded due to habitat degradation. It is not possible to test these ideas using the 50-site evaluation database, but it is important to note that there is a high risk of the species assemblage and presence/absence approaches not being able to detect either of these scenarios. Any regulatory agency choosing to apply the presence/absence or assemblage approach should mitigate these risks by resampling species assemblage frequently and maintaining accurate historical records of assemblage.

In summary, the species presence/absence approach is the most protective method when current and historical species assemblage is well-known. But it is not realistic to expect sufficient knowledge of species assemblage to apply this method successfully: extensive field surveys for species assemblage are costly and time-consuming; individuals move in and out of habitat, which

diminishes confidence in estimates of species assemblage based on a single field survey; and even if current species assemblages could be mapped perfectly, there are limited historical data to identify streams that may already be impaired (Garcia and Cochrane 2005; Jensen and Vokoun 2013). As a result, many streams have no species assemblage data for classification. Of the sites that do have available species assemblage data, the species presence/absence approach provides no means to recognize existing impairment in those without a rigorous historical record. The above concerns apply equally to the species assemblage approach, along with the additional concern that the abundance of generalist species could compromise the protection of the most thermally sensitive species. The predictor variable approach is least susceptible to imperfect data on species assemblage, as it does not rely on historical or modern assemblage surveys for classification.

Some regulatory agencies do apply the species presence/absence method (e.g. CWQCC 2011; NMWQCC 2013). Most specify alternative methods for defining the expected species assemblage when field data are not available. For example, CDPHE accepts information on "existing temperature data" and "any other relevant factors" in lieu of species assemblage data (CWQCC 2011). The presence/absence method, with modifications where necessary to account for missing species assemblage data, does appear to provide an adequate level of protection. But if a modeled mean August temperature is able to predict species' distributions well enough to afford them sufficient thermal protection, the predictor variable method offers many advantages in terms of protectiveness. First, it is available for nearly all stream segments in the state, so it would not produce a scenario where some stream classifications are based on more reliable data than others. Second, it is not subject to the seasonal or year-to-year variation that often typifies fish assemblage data, so the odds of misclassifying a stream based upon the failure to observe an

intermittent species are greatly minimized. Finally, by providing a summary of expected stream temperature with minimal anthropogenic influence, it increases the likelihood that existing impairment will be identified.

Attainability. The species presence/absence approach resulted in the greatest number of exceedances for MWAT and DM, as well as the greatest average exceedance magnitude (**Table 3-3; Figure 3-4**). This is because the high degree of protection that the presence/absence approach affords to thermally sensitive species also compromises the attainability of the approach. The fact that the presence/absence approach classifies sites with even one individual of a Tier I (Cold) species as a Tier I stream means that the process is highly susceptible to the occasional movement of individuals out of their typical habitat as well as daily, seasonal, and year-to-year variation in species' use of habitat. Because the presence/absence approach is somewhat biased in favor of classification at the colder end of the spectrum, it produces more Tier I and Tier II (Cold-Cool) exceedances than the other classification approaches. And because many of these Tier I and Tier II streams contain a small number of thermally sensitive species but are actually dominated by a species assemblage with warmer thermal requirements, it seems likely that many of the exceedances identified by the presence/absence method could be considered "false positive" identification of exceedances (**Appendix D**).

The species assemblage approach resulted in a smaller number of exceedances than the presence/absence approach, and the majority of these exceedances are in Tier III (Cool) streams. This is because the species assemblage approach tends to be driven by generalist species and is therefore somewhat biased towards Tier III and Tier IV (Cool-Warm), which contain several generalist species. At some sites, as discussed above, this bias results in a high degree of protection for Tier IV and Tier V (Warm) species that are classified into Tier III streams. At

other sites, the bias towards generalist species results in streams with cold-water species being classified into a warmer tier due to the high average abundance of some generalist species that can thrive in relatively cold water and the lower average abundance of some cold-water species. The classification of streams with relatively cold natural thermal regimes into Tier III (and to a lesser extent Tier II and Tier IV) due to the high average abundance of generalist species also results in "false positive" identification of exceedances.

The predictor variable approach resulted in the smallest number of exceedances, as well as the highest average duration of DM exceedances, and it resulted in a greater proportion of Tier I and Tier IV exceedances than the other classification methods. All three Tier I exceedances identified using the predictor variable approach have relatively large magnitude and frequency components. The three sites at which these exceedances occur do not contain any Tier I or Tier II species (**Appendix D**), so they were classified by the other two approaches into Tier III with no exceedances. Although the evaluation database does not contain sufficient data about these three sites to suggest whether they might be impaired, they do occur in an area with high oil and natural gas development so it is possible that they historically supported a cold-water species that has since been excluded due to stream impairment (Girard 2015). The remaining exceedances identified using the predictor variable approach are relatively small in terms of magnitude, frequency, and duration. Overall, the predictor variable approach produces the most attainable stream classification system because it is least susceptible to "false positive" identification.

Duration component. The duration component of DM exceedances is closely related to the magnitude and frequency components (**Figure 3-6**). Although the relationship described here is based on a small sample size, it suggests that for sites where exceedances have an average duration component of two hours or less, the magnitude and frequency components are close to

zero. This means that these sites exceed the DM values infrequently and by a small amount. Exceedances with low magnitude that occur infrequently are likely to be due to natural diel fluctuation and day-to-day variation. A stream with chronic thermal impairment is more likely to exhibit consistently occurring exceedances. These results support the application of a 2-hour duration component for the DM criterion. **Figure 3-6** shows that a duration of even three hours can be associated with high frequency and magnitude components, so a duration of greater than two hours is not recommended for DM criteria.

Stream classification recommendation. I recommend that WDEQ apply the predictor variable stream classification approach, with modeled mean August temperature as the predictor variable, because it achieves the best balance between protection and attainability. Additionally, it is the most feasible approach to implement because modeled mean August temperature is available for nearly all stream sites in Wyoming and does not require extensive field work. Finally, it is the most objective approach. Modeled mean August temperature is not influenced by variation in species assemblage survey methods or by naturally occurring daily, seasonal, or year-to-year variation in species assemblage or thermal regime.

Tables

Table 3-1. The number of sites in the 50-site evaluation database that are classified into each tier using each of the three stream classification approaches. To calculate the average tier, I assigned each tier a number from 1 through 5, where 1 is the coldest tier and 5 is the warmest tier, and calculated the mean tier number of the 50 evaluation sites.

	Species presence/absence	**Species assemblage**	**Predictor variable**
Tier I (Cold)	11	7	18
Tier II (Cold-Cool)	17	11	11
Tier III (Cool)	22	27	11
Tier IV (Cool-Warm)	0	5	10
Tier V (Warm)	0	0	0
Average Tier	**2.22**	**2.60**	**2.26**

Table 3-2. The average percentage of individuals, by tier, in streams of each classification is shown here. Percentages to the top and right of the bolded line in each sub-table indicate individuals whose species classification is more sensitive than that of the stream in which they were observed. These individuals may not be fully protected by the criteria applied to their streams.

Species Presence/Absence Approach					
Individuals	**Tier I Streams**	**Tier II Streams**	**Tier III Streams**	**Tier IV Streams**	**Tier V Streams**
Tier I	**9.85%**	0%	0%	N/A	N/A
Tier II	1.80%	**4.64%**	0%	N/A	N/A
Tier III	77.09%	31.06%	**6.30%**	N/A	N/A
Tier IV	11.26%	60.20%	87.82%	N/A	N/A
Tier V	0%	4.11%	5.88%	N/A	N/A
Species Assemblage Approach					
Individuals	**Tier I Streams**	**Tier II Streams**	**Tier III Streams**	**Tier IV Streams**	**Tier V Streams**
Tier I	**26.14%**	0.96%	<0.01%	0%	N/A
Tier II	4.06%	**16.61%**	0.09%	0%	N/A
Tier III	69.54%	68.18%	**17.96%**	0.64%	N/A
Tier IV	0.25%	14.20%	79.34%	**90.37%**	N/A
Tier V	0%	0.04%	2.59%	8.99%	N/A
Predictor Variable Approach					
Individuals	**Tier I Streams**	**Tier II Streams**	**Tier III Streams**	**Tier IV Streams**	**Tier V Streams**
Tier I	**8.21%**	0.08%	0.09%	0%	N/A
Tier II	3.10%	**11.73%**	3.03%	0.03%	N/A
Tier III	58.0%	45.16%	**52.26%**	6.95%	N/A
Tier IV	30.69%	43.03%	42.66%	**86.90%**	N/A
Tier V	0%	0%	1.96%	6.13%	N/A

Table 3-3. All sites in the 50-site evaluation database (**Appendix D**) with measured MWAT and/or DM values that exceed their tier-level criteria are listed here. Magnitude refers to the thermal distance between the criteria and the greatest exceedance. Frequency refers to the number of days in August with an observed exceedance. Duration refers to the number of hours for which a DM exceedance was observed. Sites with an N/A in the duration column are from the group of 28 sites without hourly thermal data. Site ID refers to each site's ID number in Appendix D.

Species Presence/Absence Approach						
		MWAT		**DM**		
Thermal tier	**Site ID**	**Magnitude (°C)**	**Frequency (days)**	**Magnitude (°C)**	**Frequency (days)**	**Average duration (hours)**
Tier I (Cold)	12	0.7	12	4.41	16	N/A
Tier II (Cold-Cool)	14	--	--	1.3	3	N/A
Tier II (Cold-Cool)	17	0.1	1	4.0	13	N/A
Tier II (Cold-Cool)	44	2.9	25	2.7	18	N/A
Tier II (Cold-Cool)	28	4.9	25	5.2	20	N/A
Tier II (Cold-Cool)	29	0.7	8	0.2	1	2
Tier II (Cold-Cool)	26	1.4	11	2.7	8	2.8
Tier II (Cold-Cool)	48	0.4	4	--	--	--
Tier II (Cold-Cool)	20	3.7	12	3.9	9	N/A
Tier II (Cold-Cool)	50	0.4	5	--	--	--
Tier II (Cold-Cool)	45	1.0	6	2.2	8	3.125
Tier III (Cool)	19	1.7	2	1.0	5	N/A
Tier III (Cool)	21	4.7	23	3.3	17	N/A
Tier III (Cool)	22	2.3	4	4.0	9	N/A
Tier III (Cool)	23	1.4	3	4.9	10	N/A
Tier III (Cool)	24	--	--	1.7	7	N/A
Tier III (Cool)	25	0.9	3	0.6	4	N/A
Tier III (Cool)	11	--	--	0.9	3	N/A
Tier III (Cool)	49	0.1	1	--	--	--

Total: 19 sites		*Avg: 1.7*	*Avg: 9.1*	*Avg: 2.7*	*Avg: 9.6*	*Avg: 2.646*

Species Assemblage Approach

Thermal tier	Site ID	MWAT		DM		
		Magnitude (°C)	Frequency (days)	Magnitude (°C)	Frequency (days)	Average duration (hours)
Tier II (Cold-Cool)	12	--	--	2.3	12	N/A
Tier II (Cold-Cool)	29	0.7	8	0.2	1	2
Tier II (Cold-Cool)	45	1	6	2.2	8	3.125
Tier II (Cold-Cool)	48	0.4	4	--	--	--
Tier III (Cool)	19	1.7	2	1.0	5	N/A
Tier III (Cool)	20	1.0	3	--	--	--
Tier III (Cool)	21	4.7	23	3.3	17	N/A
Tier III (Cool)	11	--	--	0.9	3	N/A
Tier III (Cool)	26	0.2	3	--	--	--
Tier III (Cool)	28	2.2	8	1.2	3	N/A
Tier III (Cool)	49	0.1	1	--	--	--
Tier IV (Cool-Warm)	22	--	--	1.8	3	N/A
Tier IV (Cool-Warm)	23	--	--	2.7	4	N/A
Total: 13 sites		*Avg: 1.3*	*Avg: 6.4*	*Avg: 1.7*	*Avg. 6.2*	*Avg: 2.563*

Predictor Variable Approach						
Thermal tier	**Site ID**	**MWAT**		**DM**		
		Magnitude (°C)	**Frequency (days)**	**Magnitude (°C)**	**Frequency (days)**	**Average duration (hours)**
Tier I (Cold)	35	--	--	3.4	8	2.313
Tier I (Cold)	39	--	--	2.4	10	3
Tier I (Cold)	40	--	--	5.7	25	4.6
Tier II (Cold-Cool)	45	1.0	6	2.2	8	3.125
Tier II (Cold-Cool)	14	--	--	1.3	1	N/A
Tier II (Cold-Cool)	29	0.7	8	0.2	1	2
Tier II (Cold-Cool)	50	0.5	5	--	--	--
Tier III (Cool)	11	--	--	0.9	3	N/A
Tier IV (Cool-Warm)	21	0.7	6	1.1	5	N/A
Tier IV (Cool-Warm)	22	--	--	1.8	3	N/A
Tier IV (Cool-Warm)	23	--	--	2.7	4	N/A
Total: 11 sites		*Avg: 0.7*	*Avg: 2.3*	*Avg: 2.2*	*Avg: 7.2*	*Avg: 3.001*

Figures

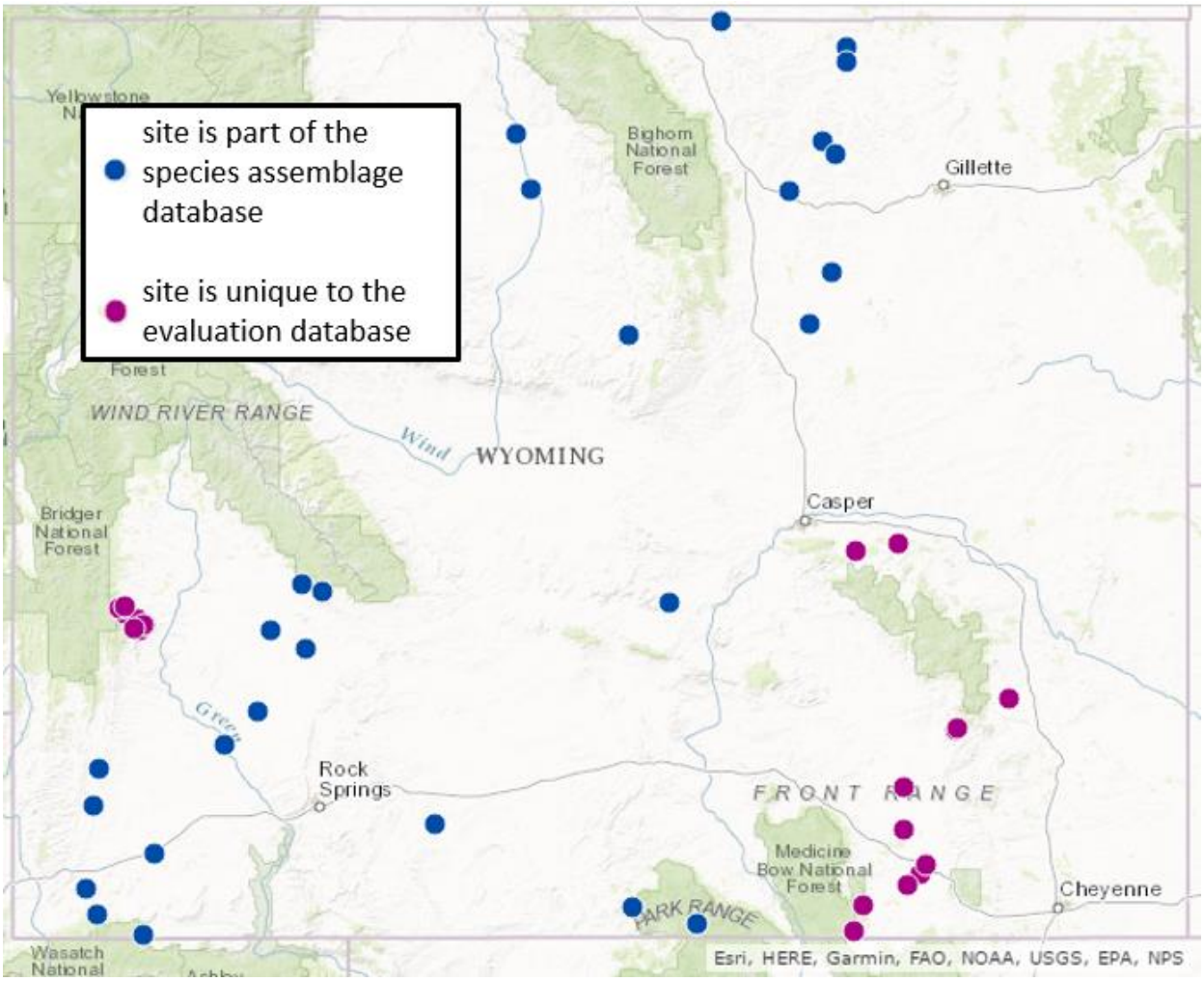


Figure 3-1. Locations of the 50 sites in the evaluation database. Blue sites are also included in the 1763-site species assemblage database and purple sites are unique to the evaluation database. The species assemblage and temperature data for the sites unique to the evaluation database were gathered by University of Wyoming graduate students. Further information of the 50 sites is found in **Appendix D**.

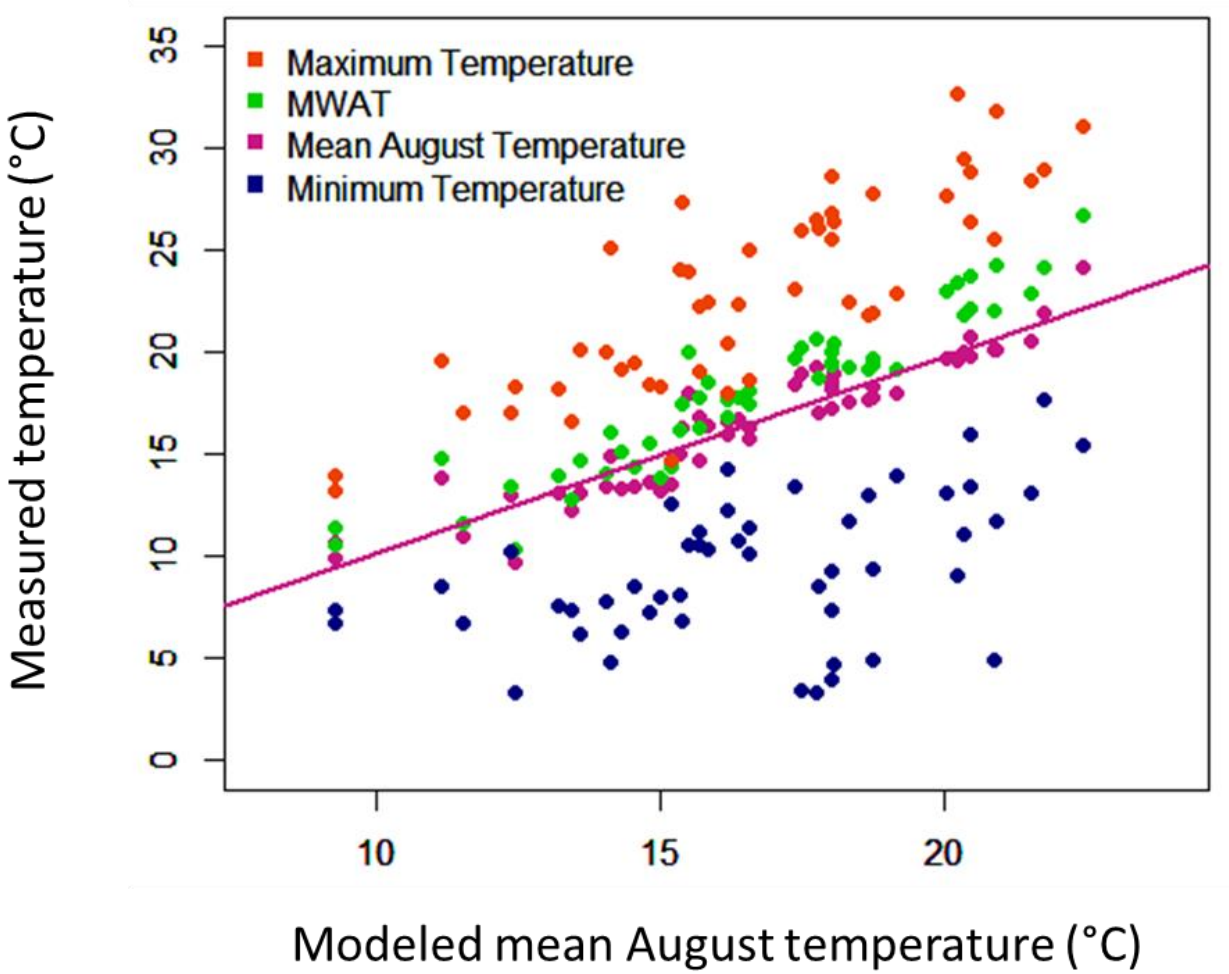


Figure 3-2. Four measured temperature metrics (maximum temperature, MWAT, mean August temperature, and minimum temperature) for each of the 50 sites in the evaluation database are plotted against the site's modeled mean August temperature. All temperature metrics were calculated using temperature measured throughout the month of August. The pink line represents the linear relationship between measured and modeled mean August temperature ($y = 0.416 + 0.969*x$; adjusted $R^2 = 0.8871$; $p < 2.2*e^{-16}$). The standard error for the intercept is 0.832 ($p = 0.619$) and the standard error for the slope is 0.049 ($p < 2.2*e^{-16}$).

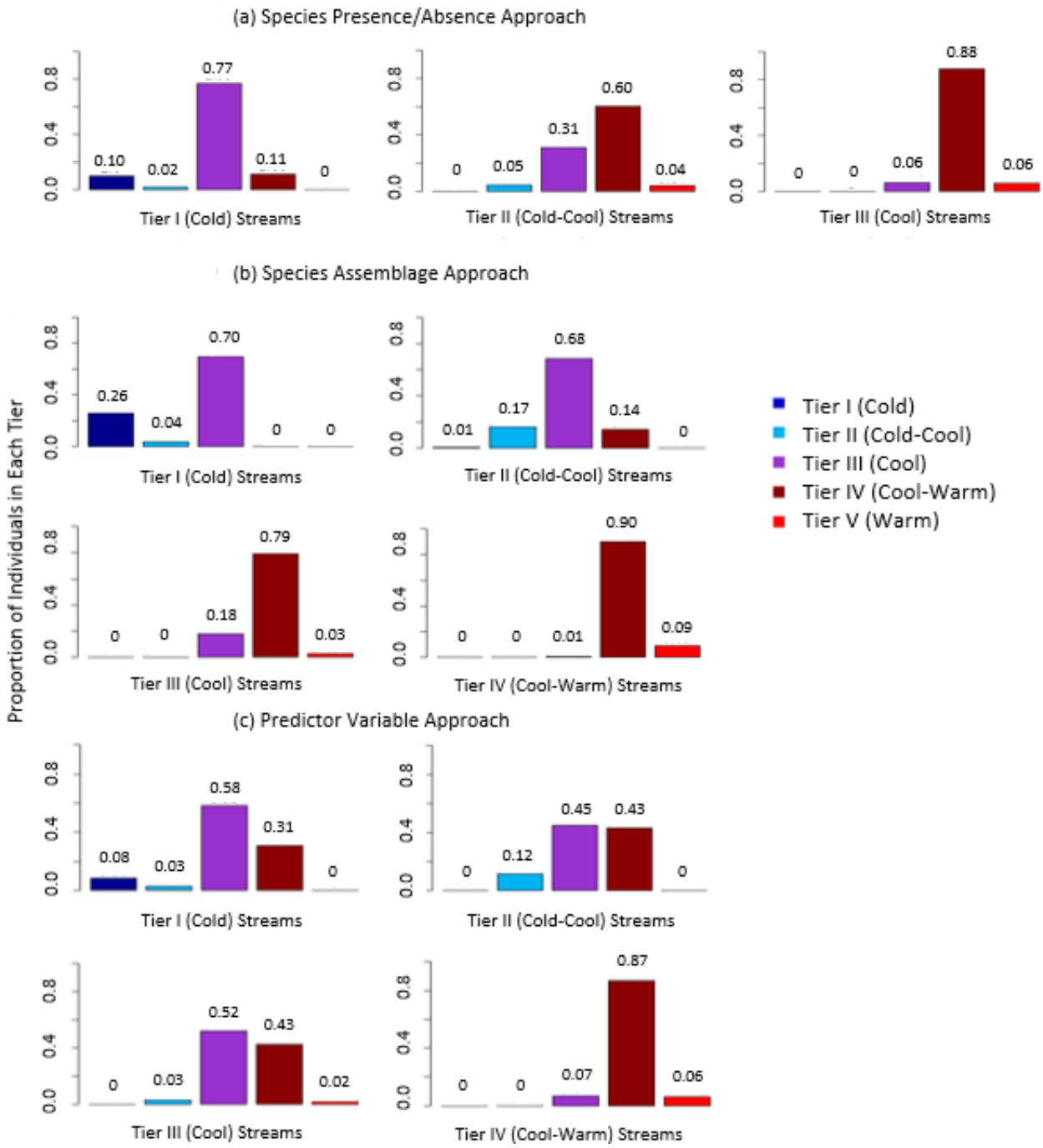


Figure 3-3. Each of the sub-plots within plots (a), (b), and (c) represents the distribution of individuals within streams as they are classified by (a) the species presence/absence classification approach, (b) the species assemblage classification approach, and (c) the predictor variable classification approach. For example, using the species presence/absence approach shown in plot (a), streams classified into Tier I (Cold) contain 10% Tier I species, 2% Tier II species, 77% Tier III species, and 11% Tier IV species.

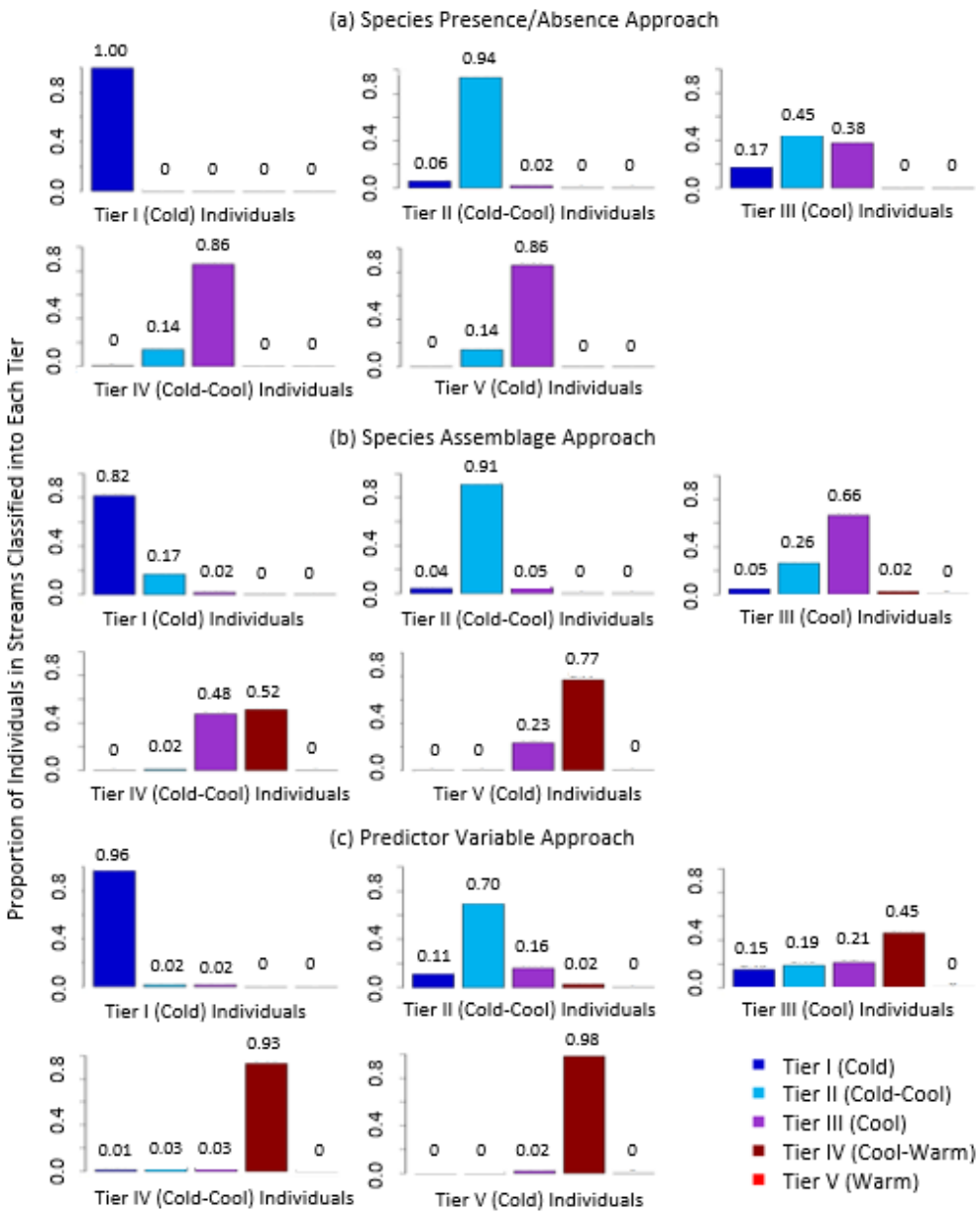
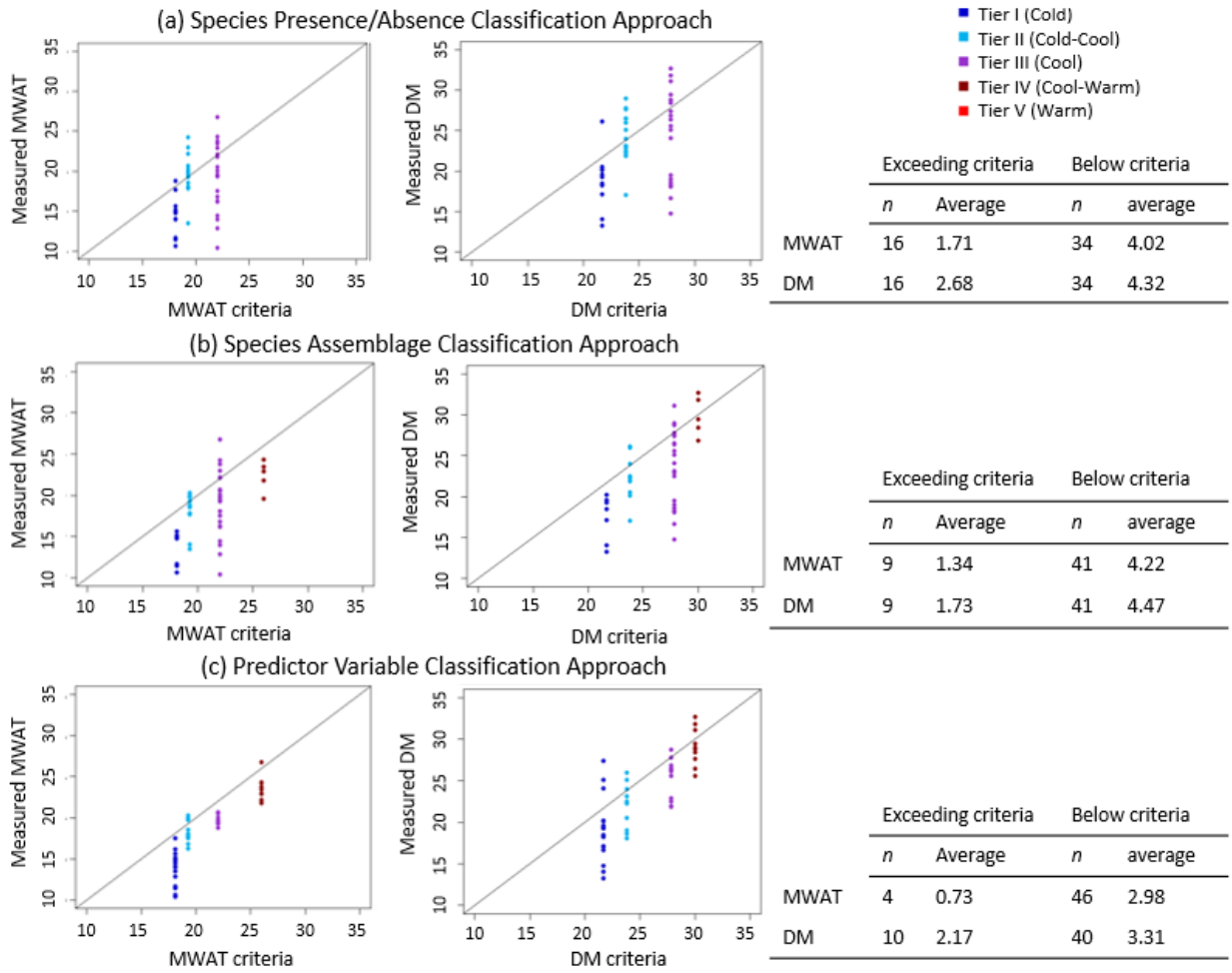


Figure 3-4. The distribution of individuals from each tier in streams of different classifications is illustrated here. Each of the five sub-plots within plots (a), (b), and (c) represents all the individuals of one thermal tier, and each bar represents the classification of the streams at which those individuals are found. The values of the proportions in each sub-plot should add to 1.00. Any instance of proportions not adding to 1.00 is due to the rounding of proportions to two decimal places. For example, using the species presence/absence approach shown in plot (a), individuals in Tier I (Cold) are depicted in the upper left sub-plot, and 100% of individuals in this tier were in streams classified into Tier I. Individuals in Tier II (Cold-Cool) are depicted in the upper center sub-plot; 6% of these individuals were in streams classified into Tier I, 94% were in streams classified into Tier II, and 2% were in streams classified into Tier III.



	Exceeding criteria		Below criteria	
	n	Average	*n*	average
MWAT	16	1.71	34	4.02
DM	16	2.68	34	4.32

	Exceeding criteria		Below criteria	
	n	Average	*n*	average
MWAT	9	1.34	41	4.22
DM	9	1.73	41	4.47

	Exceeding criteria		Below criteria	
	n	Average	*n*	average
MWAT	4	0.73	46	2.98
DM	10	2.17	40	3.31

Figure 3-5. Measured temperature values at the 50 evaluation sites, summarized as MWAT and DM, are plotted against their respective thermal criteria. Points on the 1:1 line would represent sites whose measured values exactly match their criteria. Points below the line represent sites whose measured values are colder than their criteria, and points above the line represent sites whose measured values exceed their criteria. (a) Upper plots illustrate deviation from criteria when sites are classified with the species presence/absence approach; (b) middle plots illustrate deviation from criteria when sites are classified by the species assemblage classification approach, using a 10% threshold; and (c) lower plots illustrate deviation from criteria when sites are classified by the predictor variable classification approach, using modeled mean August temperature as the predictor variable. The table associated with each set of plots indicates the number of sites exceeding and below the criteria (*n*) and the average deviation above and below the criteria.

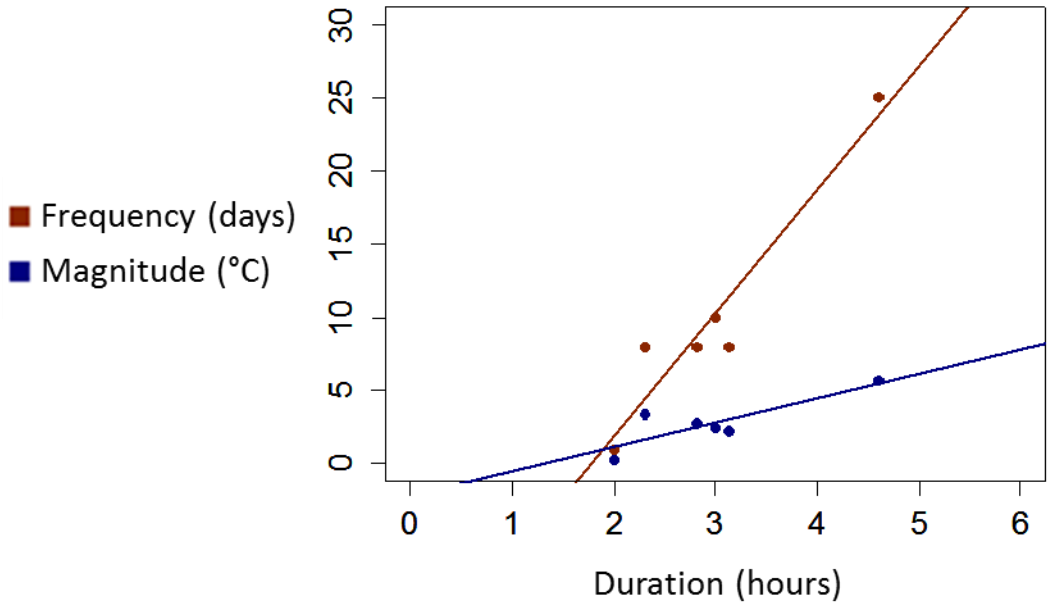


Figure 3-6. Duration regressed against frequency (y = -15.163 + 8.458*x; adjusted R^2 = 0.8969; *p* = .002624) and magnitude (y = -2.169 + 1.659*x; adjusted R^2 = 0.9456, *p* = 3.229*e^{-5}) for the six DM exceedances with available duration data.

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CONCLUSION

Summary of proposed temperature standards. The proposed surface water temperature standards for Wyoming streams consist of five thermal tiers, each with a chronic and acute criterion, and are applied on the basis of streams' modeled mean August temperatures (**Table C-1**). The acute criterion is expressed as a daily maximum (DM) temperature, averaged over a duration of two hours. The chronic criterion is expressed as a maximum weekly mean temperature (MWAT), calculated on a rolling 7-day basis. I propose these standards because of their ability to protect Wyoming fish species from harmful increases in stream temperature and their attainability under Wyoming's natural thermal regime, as demonstrated in Chapter Three.

There are currently no regulatory agencies in the United States that base their stream classification entirely on stream temperature models. Agencies use a variety of data sources for stream classification, including observed species assemblage, measured temperature data, proximity to sites with known species assemblages, and predictor variables that are included in the AWAE models such as elevation and discharge (ODEQ 2008; CWQCC 2011; WQP 2012). Rather than using only one of the above approaches, most agencies accept two or more types of evidence for expected species assemblage in order to compensate for the lack of a comprehensive classification method that can be applied to all streams. The recently developed AWAE stream temperature models made available a predictor variable that could be applied to all streams statewide, allowing all streams in the state to be classified according to the same protocols. And by minimizing the potential disjointedness that might arise from classifying streams according to different protocols, the predictor variable method increases the likelihood that thermal regulation will preserve a natural thermal regime. The TITAN threshold analysis

and subsequent Indicator Value analysis conducted in Chapter Two found that 98.1% of the 52 fish species included in TITAN analysis were significantly associated with one or more distinct portions of the modeled mean August temperature gradient, suggesting that modeled temperature is an appropriate predictor variable for expected species assemblage.

The integration of species' laboratory-derived thermal tolerance with field-derived thermal distributions resulted in a reproducible method for classifying species into thermal tiers. Like most approaches to thermal tier development, the method presented in Chapter Two utilizes expert opinion. However, it is unique in that it consists of well-defined steps to ensure that all species are given equal consideration, and that species with regionally distinct thermal requirements are recognized. This difference between range-wide and localized thermal distribution is an important concept in surface water thermal regulation. Species that might be considered cold-water species in a universal sense, such as Brown Trout (*Salmo trutta*) and Rainbow Trout (*Oncorhynchus mykiss*), are classified in Wyoming, a state with a relatively cold thermal regime, into the Cold-Cool tier. This type of regionally appropriate regulation can only be developed by integrating field-derived data on species' local thermal distributions into the development process. At the same time, field-derived data are not sufficient for the development of thermal tiers; it is equally critical to consider species' theoretical thermal maxima in order to predict their response to thermal impairment. Because my proposed thermal standards integrate both types of data, they may be able to effectively protect Wyoming's thermally diverse aquatic communities.

The standards I propose are expected to provide a high level of protectiveness and attainability in the majority of circumstances, but there are some considerations for thermal regulation under more specialized circumstances that are outside the scope of this thesis. Below,

I briefly address the following considerations: winter thermal requirements; spawning and reproduction; the lower limit of species' thermal tolerances; and the thermal regime of lakes and reservoirs.

Winter thermal requirements, spawning, and reproduction. Winter thermal requirements and thermal requirements for spawning and reproduction can be discussed together, because reproduction is typically fishes' most thermally sensitive winter behavior. During the development of the Colorado temperature standards, the available data on species' requirements for spawning and reproduction were not sufficient to develop objective thermal criteria for reproduction (CWQCC 2011). Instead, a winter standard for cold-water species was based on two values published by the EPA: a value of 9°C, based on the optimum spawning temperature for Brook Trout (*Salvelinus fontinalis*) and Rainbow Trout, was applied as the chronic upper winter criterion, and a value of 13°C, based on the maximum temperature for incubation and hatching of salmonid embryos, was set as the acute upper winter criterion (CWQCC 2011). Because 9°C and 13°C were approximately 50% of the summer chronic and acute criteria for the CWQCC Coldwater Tier I and Coldwater Tier II, CWQCC (2011) assigned each warm-water tier acute and chronic criteria that equaled 50% of its summer criteria. CWQCC applies the cold-water winter criteria from October through May and the warm-water winter criteria from December through May, with a shoulder-season transition period between the two seasons (CWQCC 2011). The application of seasonal standards is based on typical time of spawning (CWQCC 2011). The Washington Department of Ecology takes a similar approach, identifying streams that provide key spawning habitat and assigning them site-specific winter criteria (WQP 2012). Other regulatory agencies have developed different approaches. For example, regulatory agencies in Michigan, Wisconsin, and Ohio apply a different upper thermal limit for each month

(MDEQ 2006; WDNR 2008; OEPA 2015); the Connecticut Department of Environmental Protection applies slightly more stringent standards to certain water bodies in the winter in an effort to maintain a natural thermal regime (CDEP 2011); and the Idaho Department of Environmental Quality classifies some water bodies as seasonally, rather than permanently, cold-water in order to maintain certain streams at temperatures appropriate for spawning (IWQD 2006). Still other regulatory agencies do not recognize any seasonal temperature standards.

Lower thermal tolerance limits. Thermal regulation is generally discussed in terms of protecting species from increases in stream temperature, because thermal impairment due to surface water warming is more common than surface water cooling. Still, thermal impairment occasionally results in the lowering of stream temperatures. This mainly occurs when dams with hypolimnetic release decrease water temperatures downstream of the dam (Olden and Naiman 2010). Because only a small amount of data exists on species' lower thermal tolerances, this type of thermal impairment is not typically addressed by numeric criteria in regulatory standards. Many regulatory agencies do attempt to regulate stream temperature cooling by establishing a narrative criterion requiring the preservation of a natural thermal regime (e.g. ODEQ 2008; CWQCC 2011; WQP 2012). Because thermal impairment due to surface water cooling is not a common problem in Wyoming, I follow the precedent of not proposing numeric lower thermal criteria. I do recommend the implementation of a narrative criterion, applied to all surface waters, requiring the preservation of a natural thermal regime.

Lakes and reservoirs. Because of the distinct thermal regime of lakes and reservoirs, regulatory agencies often apply different regulations to lakes and reservoirs than they do to streams. Lakes and reservoirs are generally at a lower risk of thermal impairment than streams, so their regulations tend to be less nuanced. The Colorado Department of Public Health and

Environment (CDPHE) has one of the most rigorous regulation protocols for lakes and reservoirs: they developed distinct cold-water and warm-water tiers of species expected to be found in lakes and used the species-specific criteria in each lake tier to produce cold-water and warm-water tier-level criteria for lakes (CWQCC 2011). The DM is defined in lakes as a 2-hour maximum temperature, and the MWAT is defined as the maximum of at least three measurements taken throughout the growing season in the mixed layer of a stratified lake. Other agencies have approached the regulation of lake temperature by setting numeric standards based on expected ambient temperatures for either the mixed zone or the hypolimnetic zone and setting limitations on the proportion of the lake that can be part of a thermal effluent mixing zone (WDNR 2008; OEPA 2015).

Site-specific regulation. Many of the specialized thermal considerations described above could also be managed through the application of site-specific standards. The majority of regulatory agencies allow for the development of site-specific standards when either 1) none of the possible thermal classifications are appropriate for the body of water under consideration due to an unusual species assemblage or hydrologic regime, or 2) the criteria of the applied classification are unattainable under natural conditions (e.g. ODEQ 2008; CWQCC 2011). Agencies generally need to obtain a large amount of evidence in support of site-specific standards and often need to obtain EPA approval before implementing site-specific standards, so it is advisable that agencies classify water bodies according to the statewide standards if possible before resorting to site-specific standards (ODEQ 2008; CWQCC 2011). Still, site-specific standards can sometimes be the only option for the regulation of water bodies with unique thermal requirements. The Wyoming Temperature Database (WTD) developed in Chapter One provides a valuable resource for the development of site-specific standards. If the species

assemblage for the site in question can be surveyed, the species-specific criteria can be used to develop tier-level criteria that are tailored to a unique species assemblage. The AWAE stream temperature models might also be used to develop site-specific standards for sites that are particularly vulnerable to climate change. In addition to the historical modeled mean August temperatures used in this thesis, AWAE has produced modeled projected future scenarios for streams at a 1-km resolution (AWAE 2016). These future scenarios may be useful for assessing projected changes in attainability of criteria and developing site-specific standards where necessary.

In summary, the temperature standards proposed here are developed using the available data on thermal thresholds and distributions of Wyoming stream fish species. The standards are expected to be attainable under Wyoming's natural thermal regime and to provide protection for all Wyoming stream fishes. The data used to calculate species' thermal thresholds as well as the thermal tier development and stream classification methods are all well-documented and provide a foundation for revisions, should more thermal data become available in the future.

Tables

Table C-1. Proposed surface water thermal standards for Wyoming streams. DM temperatures are to be averaged over a 2-hour duration. The modeled temperature range for stream classification is based on August mean water temperature from the AWAE database (AWAE 2016).

Thermal tier	Modeled temperature range for stream classification (°C)	Chronic (MWAT) criterion (°C)	Acute (DM) criterion (°C)
Tier I: Cold	< 15.5	18.1	21.7
Tier II: Cold-Cool	15.6-17.7	19.3	23.8
Tier III: Cool	17.8-19.9	22.0	27.8
Tier IV: Cool-Warm	20.0-24.4	26.0	30.0
Tier V: Warm	> 24.4	29.0	32.0

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Common Name	Scientific Name	Life stage	Replicates/Sample Size	Acclimation Temperature	Avoid high	Avoid low	Pref high	Pref ave	Pref low	Lower Optimum	Optimum	Upper Optimum	UILT	UUILT	CTM	Rate of Increase (CTM)	Other Notes	Complete Reference	Lab (y/n)
Arctic Grayling	Thymallus arcticus	adult	20	8.4											26.6	0.4 C/min	1	Lohr et al. 1996	1
Arctic Grayling	Thymallus arcticus	adult	18	16.0											28.4	0.4 C/min	2	Lohr et al. 1996	1
Arctic Grayling	Thymallus arcticus	adult	17	20.0											29.4	0.4 C/min	3	Lohr et al. 1996	1
Arctic Grayling	Thymallus arcticus	adult	N=50 (n=10)	8.4									23			0.4 C/min		Lohr et al. 1996	1
Arctic Grayling	Thymallus arcticus	adult	N=50 (n=10)	16.0									23			0.4 C/min		Lohr et al. 1996	1
Arctic Grayling	Thymallus arcticus	adult	N=50 (n=10)	20.0									25			0.4 C/min		Lohr et al. 1996	1
				minimum									23.00		26.60				
				median									**23.00**		**28.40**				
				maximum									25.00		29.40				
				(n)									3		3				

	Estimates of Factors		**Calculation of Metrics**	**Notes on Calculation Methods**
			DM2MOS 2	
	Median CTM's	28.40	DM1MOS **2**	MOS method 2: default = 2
2	Median CTM's-conversion	27.60	DM 2 25.60	
1	Median UILT/UUILT	**23.00**	**DM 1 21.00**	DM method 1: median UILT/UUILT - MOS
1	Optimum Temperature for 1/3 Rule	no data	MWAT 1 no data	Cannot calculate MWAT; no optimal data
2	Pref Ave for 1/3 Rule	no data	MWAT 2 no data	
3	Avoided High for 1/3 Rule	no data	MWAT 3 no data	
4	Upper Optimum	no data	MWAT 4 no data	

Notes: data not used
- 1= acclimation too low- below 7
- 2= acclimation too high- above 23 or higher than min CTM
- 3= lifestage = embryo/larvae
- 4= field study

[1]CTM reported is median of fish tested. Mean was 26.4 C.
[2]CTM reported is median of fish tested. Mean was 28.5 C.
[3]CTM reported is median of fish tested. Mean was 29.3 C.

Common Name	Scientific Name	Life stage	Replicates/Sample Size	Acclimation Temperature	Avoid high	Avoid low	Pref high	Pref ave	Pref low	Lower Optimum	Optimum	Upper Optimum	UILT	UUILT	CTM	Rate of Increase (CTM)	Other Notes	Complete Reference	Lab (y/n)
Bigmouth Shiner	Notropis dorsalis		9	26											36.6	2 C/hr		Smale and Rabeni 1995	1
				minimum											36.60				
				median											**36.60**				
				maximum											36.60				
				(n)											1				

	Estimates of Factors		**Calculation of Metrics**		**Notes on Calculation Methods**
			DM MOS	**2**	MOS method 2: default = 2
	Median CTM's	36.60			
2	Median CTM's-conversion	35.80	**DM 2**	**33.80**	DM method 2: converted CTM - MOS
1	Median UILT/UUILT	no data	DM 1	no data	
1	Optimum Temperature for 1/3 Rule	no data	MWAT 1	no data	Cannot calculate MWAT; no OT data
2	Pref Ave for 1/3 Rule	no data	MWAT 2	no data	
3	Avoided High for 1/3 Rule	no data	MWAT 3	no data	
4	Upper Optimum	no data	MWAT 4	no data	

Notes: data not used
1= acclimation too low- below 15
2= acclimation too high- above 30 or higher than min CTM
3= lifestage = embryo/larvae
4= field study

Common Name	Scientific Name	Life stage	Replicates/Sample Size	Acclimation Temperature	Avoid high	Avoid low	Pref high	Pref ave	Pref low	Lower Optimum	Optimum	Upper Optimum	UILT	UUILT	CTM	Rate of Increase (CTM)	Other Notes	Complete Reference	Lab (y/n)
Black Bullhead	Ameiurus melas		N=50/n=1	11									35					Black 1953	1
Black Bullhead	Ameiurus melas		7	26											38.1	2 C/hr		Smale and Rabeni 1995	1
				minimum											38.10				
				median											**38.10**				
				maximum											38.10				
				(n)											1				

	Estimates of Factors		**Calculation of Metrics**	**Notes on Calculation Methods**
			DM MOS 2	MOS method 2: default = 2
	Median CTM's	38.10		
2	Median CTM's-conversion	37.30	**DM 2 35.30**	DM method 2: converted CTM - MOS
1	Median UILT/UUILT	no data	DM 1 no data	
1	Optimum Temperature for 1/3 Rule	no data	MWAT 1 no data	Cannot calculate MWAT; no optimal data
2	Pref Ave for 1/3 Rule	no data	MWAT 2 no data	
3	Avoided High for 1/3 Rule	no data	MWAT 3 no data	
4	Upper Optimum	no data	MWAT 4 no data	

Notes: data not used
1= acclimation too low- below 15
2= acclimation too high- above 30 or higher than min CTM
3= lifestage = embryo/larvae
4= field study

Common Name	Scientific Name	Life stage	Replicates/Sample Size	Acclimation Temperature	Avoid high	Avoid low	Pref high	Pref ave	Pref low	Lower Optimum	Optimum	Upper Optimum	UILT	UUILT	CTM	Rate of Increase (CTM)	Other Notes	Complete Reference	Lab (y/n)
Black Crappie	Pomoxis nigromaculatus	adult	N=6	not reported				24										Reynolds and Casterlin 1977	1
Black Crappie	Pomoxis nigromaculatus	adult		23.8				21.7							34.9		1	Reutter and Herdendorf 1976	1
				minimum				21.70							34.90				
				median				**22.85**							**34.90**				
				maximum				24.00							34.90				
				(n)				2							1				

	Estimates of Factors		**Calculation of Metrics**		**Notes on Calculation Methods**
			DM MOS	2	MOS method 2: default = 2
	Median CTM's	34.90			
2	Median CTM's-conversion	34.10	**DM 2**	**32.10**	DM method 2: converted CTM - MOS
1	Median UILT/UUILT	no data	DM 1	no data	
1	Optimum Temperature for 1/3 Rule	no data	MWAT 1	no data	
2	Pref Ave for 1/3 Rule	22.85	**MWAT 2**	**26.5625**	MWAT method 2: 1/3 rule with preferred average
3	Avoided High for 1/3 Rule	no data	MWAT 3	no data	
4	Upper Optimum	no data	MWAT 4	no data	

Notes: data not used
1= acclimation too low- below 15
2= acclimation too high- above 30 or higher than min CTM
3= lifestage = embryo/larvae
4= field study

[1] Observations for the Preferred Average were done in the summer.

1	Common Name	Scientific Name	Life stage	Replicates/Sample Size	Acclimation Temperature	Avoid high	Avoid low	Pref high	Pref ave	Pref low	Lower Optimum	Optimum	Upper Optimum	UILT	UUILT	CTM	Rate of Increase (CTM)	Other Notes	Complete Reference	Lab (y/n)
2	Bluegill	Lepomis macrochirus	adult	10/treatment	1	27.6								23.3				1	Peterson and Schutsky 1976	1
3	Bluegill	Lepomis macrochirus	juvenile	2/n=8(N=16)	6				18.7									2	Cherry et al. 1975	1
4	Bluegill	Lepomis macrochirus	juvenile	4/n=2(N=8)	6	22	5											2	Cherry et al. 1975	1
5	Bluegill	Lepomis macrochirus	juvenile	2/n=8(N=16)	9				19.6									2	Cherry et al. 1975	1
6	Bluegill	Lepomis macrochirus	juvenile	4/n=2(N=8)	9	23	7											2	Cherry et al. 1975	1
7	Bluegill	Lepomis macrochirus	juvenile	2/N=5	10									30				3	Hathaway 1928	1
8	Bluegill	Lepomis macrochirus	juvenile	3/N=15	10									30.6				3	Hathaway 1928	1
9	Bluegill	Lepomis macrochirus		84	10											33.59	1 C/min		Lutterschmidt and Hutchison 1997	1
10	Bluegill	Lepomis macrochirus		84	10											30.38	1 C/min		Lutterschmidt and Hutchison 1997	1
11	Bluegill	Lepomis macrochirus	juvenile	2/n=8(N=16)	12				23.9									2	Cherry et al. 1975	1
12	Bluegill	Lepomis macrochirus	juvenile	4/n=2(N=8)	12	25	12											2	Cherry et al. 1975	1
13	Bluegill	Lepomis macrochirus	adult	10/treatment	13	30.3			24.6					29.3				1	Peterson and Schutsky 1976	1
14	Bluegill	Lepomis macrochirus	adult	N=234, 4 trials	13			26.2	21.5	17.3								4	Kelsch 1996	1
15	Bluegill	Lepomis macrochirus	adult	n=12	13							23.5						5	Kelsch 1996	1
16	Bluegill	Lepomis macrochirus		10	32											38.5	1 C/min	6	Murphy et al. 1976	1
17	Bluegill	Lepomis macrochirus	juvenile	11	35											41.9	1 C/min	7	Holland et al. 1974	1
18	Bluegill	Lepomis macrochirus	juvenile	11	35											40.4	1 C/min	8	Holland et al. 1974	1
19	Bluegill	Lepomis macrochirus	juvenile	6	35											42.4	1 C/min	7	Holland et al. 1974	1
20	Bluegill	Lepomis macrochirus	juvenile	6	35											40.9	1 C/min	8	Holland et al. 1974	1
21	Bluegill	Lepomis macrochirus	juvenile	6	35											40.9	1 C/min	8	Holland et al. 1974	1
22	Bluegill	Lepomis macrochirus	juvenile	31	35											42.8	1 C/min	7	Holland et al. 1974	1
23	Bluegill	Lepomis macrochirus	juvenile	31	35											41.4	1 C/min	8	Holland et al. 1974	1
24	Bluegill	Lepomis macrochirus	juvenile	6	35											42.4	1 C/min	7	Holland et al. 1974	1
25	Bluegill	Lepomis macrochirus	see notes	see notes														9	Yoder and Gammon 1976	0
26	Bluegill	Lepomis macrochirus	see notes	see notes														10	Yoder and Gammon 1976	0
27	Bluegill	Lepomis macrochirus	juvenile	2/n=8(N=16)	15				25.9									2	Cherry et al. 1975	1
28	Bluegill	Lepomis macrochirus	juvenile	4/n=2(N=8)	15	26	14											2	Cherry et al. 1975	1
29	Bluegill	Lepomis macrochirus		9	16											31.5	1 C/min	6	Murphy et al. 1976	1
30	Bluegill	Lepomis macrochirus		8	16											31.4	1 C/min	6	Murphy et al. 1976	1
31	Bluegill	Lepomis macrochirus	juvenile	2/n=8(N=16)	18				29.2									2	Cherry et al. 1975	1
32	Bluegill	Lepomis macrochirus	juvenile	4/n=2(N=8)	18	31	17											2	Cherry et al. 1975	1
33	Bluegill	Lepomis macrochirus	adult	5	20											37.3	1 C/min	11	Dent and Lutterschmidt 2003	1
34	Bluegill	Lepomis macrochirus	juvenile	2/n=8(N=16)	21				30.1									2	Cherry et al. 1975	1
35	Bluegill	Lepomis macrochirus	juvenile	4/n=2(N=8)	21	33	20											2	Cherry et al. 1975	1
36	Bluegill	Lepomis macrochirus		N=18 (n=8)	21.5									31.5				12	Hickman and Dewey 1973	1
37	Bluegill	Lepomis macrochirus	juvenile a	N=19	22			32.8	32.3	26.7								13	Reynolds and Casterlin 1976	1
38	Bluegill	Lepomis macrochirus	juvenile	3/N=15	22.5									34				3	Hathaway 1928	1
39	Bluegill	Lepomis macrochirus	juvenile	2/n=8(N=16)	24				31.2									2	Cherry et al. 1975	1
40	Bluegill	Lepomis macrochirus	juvenile	4/n=2(N=8)	24	33	23											2	Cherry et al. 1975	1
41	Bluegill	Lepomis macrochirus		10	24											37.5	1 C/min	6	Murphy et al. 1976	1
42	Bluegill	Lepomis macrochirus		10	24											35.6	1 C/min	6	Murphy et al. 1976	1
43	Bluegill	Lepomis macrochirus	juvenile a	N=10	25	33.4	30.2		31.8									14	Beitinger 1976	1
44	Bluegill	Lepomis macrochirus	juvenile a	N=9	25	33.7	30.3		32									15	Beitinger 1976	1
45	Bluegill	Lepomis macrochirus	juvenile a	N=7	25	33.6	29.9		31.8									16	Beitinger 1976	1
46	Bluegill	Lepomis macrochirus	juvenile a	N=40	25				30									14	Stunts and Magnuson 1976	1
47	Bluegill	Lepomis macrochirus	juvenile a	3/n=4	25											35.8	0.3 C/min	17	Carveth et al. 2006	1
48	Bluegill	Lepomis macrochirus	juvenile a	3/n=4	25											37.3	0.3 C/min	17	Carveth et al. 2006	1
49	Bluegill	Lepomis macrochirus	adult	N=238, 4 trials	25			29.8	28.1	26.1								4	Kelsch 1996	1
50	Bluegill	Lepomis macrochirus	adult	n=12	25							28.5						5	Kelsch 1996	1
51	Bluegill	Lepomis macrochirus	juvenile	25	25											36.7	1 C/min	8	Holland et al. 1974	1
52	Bluegill	Lepomis macrochirus	juvenile	13	25											37.3	1 C/min	7	Holland et al. 1974	1
53	Bluegill	Lepomis macrochirus	juvenile	13	25											36.8	1 C/min	8	Holland et al. 1974	1
54	Bluegill	Lepomis macrochirus	juvenile	25	25											37.6	1 C/min	7	Holland et al. 1974	1
55	Bluegill	Lepomis macrochirus	juvenile	15	25											37	1 C/min	7	Holland et al. 1974	1

1	Common Name	Scientific Name	Life stage	Replicates/Sample Size	Acclimation Temperature	Avoid high	Avoid low	Pref high	Pref ave	Pref low	Lower Optimum	Optimum	Upper Optimum	UILT	UUILT	CTM	Rate of Increase (CTM)	Other Notes	Complete Reference	Lab (y/n)
56	Bluegill	Lepomis macrochirus	juvenile	36	25											39.1	1 C/min	7	Holland et al. 1974	1
57	Bluegill	Lepomis macrochirus	juvenile	36	25											37	1 C/min	8	Holland et al. 1974	1
58	Bluegill	Lepomis macrochirus	juvenile	15	25											36.3	1 C/min	8	Holland et al. 1974	1
59	Bluegill	Lepomis macrochirus		8	26											37.9	2 C/hr		Smale and Rabeni 1995	1
60	Bluegill	Lepomis macrochirus	adult	10/treatment	27	33.5			30.7					35.8				Acclim. P	Peterson and Schutsky 1976	1
61	Bluegill	Lepomis macrochirus	juvenile	2/n=8(N=16)	27				31.4									2	Cherry et al. 1975	1
62	Bluegill	Lepomis macrochirus	juvenile	4/n=2(N=8)	27	34	24											2	Cherry et al. 1975	1
63	Bluegill	Lepomis macrochirus	juvenile	2/N=9	30									34.3				3	Hathaway 1928	1
64	Bluegill	Lepomis macrochirus	juvenile	2/N=11	30									35.6				3	Hathaway 1928	1
65	Bluegill	Lepomis macrochirus	juvenile a	3/n=4	30											38.7	0.3 C/min	17	Carveth et al. 2006	1
66	Bluegill	Lepomis macrochirus	juvenile a	3/n=4	30											39.6	0.3 C/min	17	Carveth et al. 2006	1
67	Bluegill	Lepomis macrochirus	juvenile	2/n=8(N=16)	30				31.7									2	Cherry et al. 1975	1
68	Bluegill	Lepomis macrochirus	juvenile	4/n=2(N=8)	30	35	26											2	Cherry et al. 1975	1
69	Bluegill	Lepomis macrochirus	adult	n=248, 4 trials	30			31.4	30.4	26.6								4	Kelsch 1996	1
70	Bluegill	Lepomis macrochirus	adult	n=12	30							31.5						5	Kelsch 1996	1
71	Bluegill	Lepomis macrochirus	juvenile	16	30											39.4	1 C/min	7	Holland et al. 1974	1
72	Bluegill	Lepomis macrochirus	juvenile	16	30											38.8	1 C/min	8	Holland et al. 1974	1
73	Bluegill	Lepomis macrochirus	juvenile	18	30											38	1 C/min	8	Holland et al. 1974	1
74	Bluegill	Lepomis macrochirus	juvenile	26	30											39	1 C/min	7	Holland et al. 1974	1
75	Bluegill	Lepomis macrochirus	juvenile	18	30											39.1	1 C/min	7	Holland et al. 1974	1
76	Bluegill	Lepomis macrochirus	adult	9	30											41.2	1 C/min	11	Dent and Lutterschmidt 2003	1
77	Bluegill	Lepomis macrochirus	juvenile	36	30											40.9	1 C/min	7	Holland et al. 1974	1
78	Bluegill	Lepomis macrochirus	juvenile	36	30											39.6	1 C/min	8	Holland et al. 1974	1
79	Bluegill	Lepomis macrochirus	juvenile	26	30											37.4	1 C/min	8	Holland et al. 1974	1
80	Bluegill	Lepomis macrochirus		10	32											41.4	1 C/min	6	Murphy et al. 1976	1
81	Bluegill	Lepomis macrochirus	juvenile a	N=20 (n=5)								31						18	Beitinger and Magnuson 1979	1
82	Bluegill	Lepomis macrochirus	juvenile	105								30						19	Lemke 1977	1
83	Bluegill	Lepomis macrochirus			15									30.7					Brett 1956	1
84	Bluegill	Lepomis macrochirus			20									31.5					Brett 1956	1
85	Bluegill	Lepomis macrochirus			30									33.8					Brett 1956	1
86	Bluegill	Lepomis macrochirus	adult		22.8				27.4							38.3		20	Reutter and Herdendorf 1976	1
87	Bluegill	Lepomis macrochirus	yoy	300-400										28.5				21	Cvancara et al. 1976	1
88	Bluegill	Lepomis macrochirus	juvenile		25	33.1	29.3												Beitinger 1974	1
91					**minimum**	26.00	14.00	29.80	25.90	26.10		28.50		28.50		31.40				
92					**median**	**33.40**	**25.00**	**31.40**	**30.70**	**26.60**		**30.50**		**33.80**		**37.60**				
93					**maximum**	35.00	30.30	32.80	32.30	26.70		31.50		35.80		41.40				
94					**(n)**	11	10	3	15	3		4		9		29				

	Estimates of Factors		**Calculation of Metrics**	
			DM2MOS	1.26
	Median CTM's	37.60	DM1MOS	**0.66**
2	Median CTM's-conversion	36.80	DM 2	35.54
1	Median UILT/UUILT	33.80	**DM 1**	**33.14**
1	Optimum Temperature for 1/3 Rule	30.50	**MWAT 1**	**31.589**
2	Pref Ave for 1/3 Rule	30.70	MWAT 2	31.723
3	Avoided High for 1/3 Rule	35.00	MWAT 3	34.604
4	Upper Optimum	no data	MWAT 4	no data

Notes on Calculation Methods

MOS method 1: 20% rule using median UILT/UUILT and Optimum Temperature

DM method 1: median UILT/UUILT - MOS

MWAT method 1: 1/3 rule with Optimum Temperature

35 was chosen as Avoided High because the acclimation temperature (30) was closest to the other known temperature optimum metrics.

Notes: data not used

1= acclimation too low- below 15

2= acclimation too high- above 30 or higher than min CTM

3= lifestage = embryo/larvae

4= field study

[1] Acclimation period not reported, but assume 1C/day to final acclimation temperature from pond temperature at capture based on citation of Brett 1952 methods. Treatment temperatures were not specified. Ultimate Upper Lethal temp reported is not a UUILT.
[2] It is assumed that fish tested were adults. Fish were fasted for 2.5-3 days before testing.
[3] Test is an early predecessor of UILT. Study tested tolerances up to only 24 hours. Four minute, 15 minute, 1 hour, and 4 hour tolerances were also reported. Author used the weighted average for the lethal temperature.
[4] Minimum and maximum treatments indicate the normal upper and lower temperatures in the gradient tank. The lower preferred temperature indicates the first quartile of observations; the preferred temperature indicates the median; and upper preferred temperature indicates the third quartile. Sample size is 12 fish.
[5] Optimum was measured for performance as the median of the temperature range where modal maximum critical swimming speed was recorded.
[6] Tests were done in winter with normal temperatures for the latitude. The study compared thermal tolerances of fish from two ponds in a close-loop cooling system for nuclear.
[7] Study was conducted on fish from a private pond. The lethal endpoint CTM was referred to as DP in paper, which is different from the Loss of Equilibrium lethal endpoint typically associated with CTM.
[8] Study was conducted on fish from a private pond. CTM was calculated by subtracting reported differences between CTM and DP from reported DP.
[9] Fish were captured in the summer. Sample size was not given, but sampling design and other plots suggest it is high for most species. Winter data were also provided but not included in database.
[10] Fish were captured in the fall. Sample size was not given, but sampling design and other plots suggest it is high for most species. Winter data were also provided but not included in database.
[11] Only results from groups where $n > 4$ are included in database.
[12] Fish were caught and tested in March and April. UILT (lethal temperature) was estimated over 24 hours from data presented in Table 1 of references.
[13] Study tested daytime preference. Acclimation temperature here is median of the range reported (20-24°C); sample size refers to number of fish, each of which had several measurements taken over time.
[14] Temperature was controlled by the movement of fish between compartments. The rate of increase was 3.0°C/hour and the rate of decrease was 3.0°C/hour in response to fish movements between compartments.
[15] Temperature was controlled by the movement of fish between compartments. The rate of increase was 3.0°C/hour and the rate of decrease was 1.5°C/hour in response to fish movements between compartments.
[16] Temperature was controlled by the movement of fish between compartments. The rate of increase was 1.5°C/hour and the rate of decrease was 3.0°C/hour in response to fish movements between compartments.
[17] Fish were 80-116 mm in length. Listed replicates and sample size indicate the minimum for all species tested.
[18] Fish age and size were not reported. Optima is judged as the temperature of higher growth over 10 days with ad-libitum feed, although authors report growth rates could not be statistically distinguished (probably due to small sample size).
[19] Nine temperature treatment levels were tested (11-12 fish/treatment), one month duration, specific growth was measured under conditions of ad lib feeding. Optimum was determined as the temperature level with maximum specific growth over the study period.
[20] Preferred average was measured in the winter.
[21] Summer.

1	Common Name	Scientific Name	Life stage	Replicates/Sample Size	Acclimation Temperature	Avoid high	Avoid low	Pref high	Pref ave	Pref low	Lower Optimum	Optimum	Upper Optimum	UILT	UUILT	CTM	Rate of Increase (CTM)	Spawning info	Other Notes	Complete Reference	Lab (y/n)
2	Bluehead Sucker	Catostomus discobolus	larvae								8		26						1	Lamarra 2007	1
3	Bluehead Sucker	Catostomus discobolus										20.5							2	Lamarra 2007	1
4	Bluehead Sucker	Catostomus discobolus	adult								8	20	25						3	Lamarra 2007	1
5	Bluehead Sucker	Catostomus discobolus									8.1								4	Lamarra 2007	1
6																					
7																					
8					**minimum**						8.00	20.00	25.00								
9					**median**						**8.05**	**20.00**	**25.00**								
10					**maximum**						8.10	20.00	25.00								
11					**(n)**						2	1	1								
12																					
13																					
14					**Estimates of Factors**						**Calculation of Metrics**			**Notes on Calculation Methods**							
15											DM MOS	**2**		MOS method 2: default = 2							
16					Median CTM's				no data												
17				2	Median CTM's-conversion				no data		DM 2	no data		Cannot calculate DM; no lethal data							
18				1	Median UILT/UUILT				no data		DM 1	no data									
19				1	Optimum Temperature for 1/3 Rule				20.00		MWAT 1	no data									
20				2	Pref Ave for 1/3 Rule				no data		MWAT 2	no data									
21				3	Avoided High for 1/3 Rule				no data		MWAT 3	no data									
22				4	Upper Optimum				25.00		**MWAT 4**	**25.00**		MWAT method 4: Upper Optimum							
23																					
24				Notes:	data not used																
25					1= acclimation too low- below 15																
26					2= acclimation too high- above 30 or higher than min CTM																
27					3= lifestage = embryo/larvae																
28					4= field study																

[1] 8-26°C is the temperature range for larval growth.

[2] Optimal hatching temperature.

[3] 8-25°C is the optimum temperature range and 20°C is the optimal temperature.

[4] Estimated temperature below which growth rate is 0.

1	Common Name	Scientific Name	Life stage	Replicates/Sample Size	Acclimation Temperature	Avoid high	Avoid low	Pref high	Pref ave	Pref low	Lower Optimum	Optimum	Upper Optimum	UILT	UUILT	CTM	Rate of Increase (CTM)	Spawning Info	Other Notes	Complete Reference	Lab (y/n)
2	Brassy Minnow	Hybognathus hankinsoni	embryo															12.8	1	Scott and Crossman 1973	1
3																					
4																					
5																					
6																					
7																					
8					**minimum**																
9					**median**																
10					**maximum**																
11					**(n)**																
12																					
13					**Estimates of Factors**						**Calculation of Metrics**			**Notes on Calculation Methods**							
14											DM MOS		**2**	MOS method 2: default = 2							
15					Median CTM's				no data												
16				2	Median CTM's-conversion				no data		DM 2	no data		Cannot calculate DM; no lethal data							
17				1	Median UILT/UUILT				no data		DM 1	no data									
18				1	Optimum Temperature for 1/3 Rule				0.00		MWAT 1	no data		Cannot calculate MWAT; no optimal data							
19				2	Pref Ave for 1/3 Rule				no data		MWAT 2	no data									
20				3	Avoided High for 1/3 Rule				no data		MWAT 3	no data									
21				4	Upper Optimum				0.00		MWAT 4	no data									
22																					
23				Notes: data not used																	
24					1= acclimation too low- below 15																
25					2= acclimation too high- above 30 or higher than min CTM																
26					3= lifestage = embryo/larvae																
27					4= field study																

[1] 12.8°C is the 24-hour maximum temperature for successful embryo survival.

	Common Name	Scientific Name	Life stage	Replicates/Sample Size	Acclimation Temperature	Avoid high	Avoid low	Pref high	Pref ave	Pref low	Lower Optimum	Optimum	Upper Optimum	UILT	UUILT	CTM	Rate of Increase (CTM)	Other Notes	Complete Reference	Lab (y/n)
1																				
2	Brook Stickleback	Culaea inconstans	juvenile	(N=27 in 4 groups)	25.5									30.6				1	Brett 1944	1
3																				
4																				
5					**minimum**									30.60						
6					**median**									**30.60**						
7					**maximum**									30.60						
8					**(n)**									1						
9																				
10																				
11					**Estimates of Factors**						**Calculation of Metrics**			**Notes on Calculation Methods**						
12											DM MOS	**2**		MOS method 2: default = 2						
13					Median CTM's				no data											
14					2 Median CTM's-conversion				no data		DM 2	no data								
15					1 Median UILT/UUILT				30.60		**DM 1**	**28.60**		DM method 1: UILT/UUILT - MOS						
16					1 Optimum Temperature for 1/3 Rule				no data		MWAT 1	no data		Cannot calculate MWAT; no optimal data						
17					2 Pref Ave for 1/3 Rule				no data		MWAT 2	no data								
18					3 Avoided High for 1/3 Rule				no data		MWAT 3	no data								
19					4 Upper Optimum				no data		MWAT 4	no data								
20																				
21				Notes: data not used																
22					1= acclimation too low- below 15															
23					2= acclimation too high- above 30 or higher than min CTM															
24					3= lifestage = embryo/larvae															
25					4= field study															
26																				

[1] No lab acclimation; acclimation temperature indicates the median of the range reported during the collection period (Aug 7) for Lake Opeongo (25-26°C).

1	Scientific Name	Life stage	Replicates/Sample Size	Acclimation Temperature	Avoid high	Avoid low	Pref high	Pref ave	Pref low	Lower Optimum	Optimum	Upper Optimum	UILT	UUILT	CTM	Rate of Increase (CTM)	Other Notes	Complete Reference	Lab (y/n)
2	Salvelinus fontinalis	juvenile	82/N=5	see notes													1	Sullivan and Fischer 1953	1
3	Salvelinus fontinalis	juvenile	2/n=8(N=16)	6				11.2									2	Cherry et al. 1975	1
4	Salvelinus fontinalis	juvenile	4/n=2(N=8)	6	14	5											2	Cherry et al. 1975	1
5	Salvelinus fontinalis	juvenile	N=13-17	4				10									3	Fisher and Elson 1950	1
6	Salvelinus fontinalis	juvenile	see notes	3									23.4				4	Fry et al. 1946	1
7	Salvelinus fontinalis	fry	n=13 (see notes)	2.5									20.4				5	McCormick et al. 1972	1
8	Salvelinus fontinalis	juvenile	see notes	see notes									25.3	25.3			6	Fry et al. 1946	1
9	Salvelinus fontinalis	juvenile	(N=21 in 3 groups)	25.5									26.1				7	Brett 1944	1
10	Salvelinus fontinalis	juvenile	2/n=8(N=16)	24				19									2	Cherry et al. 1975	1
11	Salvelinus fontinalis	juvenile	4/n=2(N=8)	24	25	18											2	Cherry et al. 1975	1
12	Salvelinus fontinalis	embryos	(see notes)	stream ambient and 8 C in tank							6						8	Hokanson et al. 1973	1
13	Salvelinus fontinalis	embryo	(see notes)								7.4						9	Marten 1992	1
14	Salvelinus fontinalis	adult	17														10	Baird and Krueger 2003	0
15	Salvelinus fontinalis	fry	N=360 (among 6 groups)	see notes							15.4						11	McCormick et al. 1972	1
16	Salvelinus fontinalis	juvenile	2/n=8(N=16)	21				18.3									2	Cherry et al. 1975	1
17	Salvelinus fontinalis	juvenile	4/n=2(N=8)	21	23	16											2	Cherry et al. 1975	1
18	Salvelinus fontinalis	juvenile	see notes	20									25.3				4	Fry et al. 1946	1
19	Salvelinus fontinalis	juvenile	3/n=5	20											29.76	0.2 C/min	12	Lee and Rinne 1980	1
20	Salvelinus fontinalis	juvenile	5 replicates/n=5-6/rep	20				16									13	Javaid and Anderson 1967b	1
21	Salvelinus fontinalis	juvenile	5 replicates/n=5-6/rep	20				18									14	Javaid and Anderson 1967b	1
22	Salvelinus fontinalis	juvenile	2/n=8(N=16)	18				18									2	Cherry et al. 1975	1
23	Salvelinus fontinalis	juvenile	4/n=2(N=8)	18	20	14											2	Cherry et al. 1975	1
24	Salvelinus fontinalis	adult	N=16	18				18.04									15	Muller 1977	1
25	Salvelinus fontinalis	fry	n=20 (see notes)	15									24.3				16	McCormick et al. 1972	1
26	Salvelinus fontinalis	juvenile	2/n=8(N=16)	15				15.2									2	Cherry et al. 1975	1
27	Salvelinus fontinalis	juvenile	4/n=2(N=8)	15	18	12											2	Cherry et al. 1975	1
28	Salvelinus fontinalis	juvenile	30	15											28.4	4 C/day	17	Galbreath et al. 2004	1
29	Salvelinus fontinalis	juvenile	28	15											28.6	8 C/day	17	Galbreath et al. 2004	1
30	Salvelinus fontinalis	juvenile	26	15											28	2 C/day	17	Galbreath et al. 2004	1
31	Salvelinus fontinalis	juvenile	30	15											28.8	24 C/day	17	Galbreath et al. 2004	1
32	Salvelinus fontinalis	juvenile	24	15											28.9	24 C/day	17	Galbreath et al. 2004	1
33	Salvelinus fontinalis	juvenile	N=35 (among 7 tests)	13			18.5	15.3	11								18	Peterson 1973	1
34	Salvelinus fontinalis	fry	6 replicates/n=5	12.7				8.7									19	Peterson et al. 1979	1
35	Salvelinus fontinalis	juvenile	6 replicates/n=5	12.1				17.5									19	Peterson et al. 1979	1
35	Salvelinus fontinalis	juvenile	6 replicates/n=5	12.1				17.5									19	Peterson et al. 1979	1
36	Salvelinus fontinalis	fry	n=20 (see notes)	12									22.5				20	McCormick et al. 1972	1
37	Salvelinus fontinalis	fry	n=20 (see notes)	12									20.2				16	McCormick et al. 1972	1
38	Salvelinus fontinalis	fry	n=20 (see notes)	12									24.8				16	McCormick et al. 1972	1
39	Salvelinus fontinalis	juvenile	2/n=8(N=16)	12				13.7									2	Cherry et al. 1975	1
40	Salvelinus fontinalis	juvenile	4/n=2(N=8)	12	16	9											2	Cherry et al. 1975	1
41	Salvelinus fontinalis	juvenile	see notes	11									24.5				4	Fry et al. 1946	1
42	Salvelinus fontinalis	fry	6 replicates/n=5	10.6				11.5									19	Peterson et al. 1979	1
43	Salvelinus fontinalis	adult	n=21	10											29	0.2 C/min		De Staso and Rahel 1994	1
44	Salvelinus fontinalis	juvenile	3/n=5	10											28.74	0.2 C/min	12	Lee and Rinne 1980	1
45	Salvelinus fontinalis	adult	N=18	10				16.81									15	Muller 1977	1
46	Salvelinus fontinalis	fry	n=15 (see notes)	9.5									20.4				16	McCormick et al. 1972	1
47	Salvelinus fontinalis	fry	n=10-20 (see notes)	9.5									23.7				16	McCormick et al. 1972	1
48	Salvelinus fontinalis	juvenile a	N=50 /n=10	9							16						21	Hokanson et al. 1973	1
49	Salvelinus fontinalis	juvenile	2/n=8(N=16)	9				11.3									2	Cherry et al. 1975	1
50	Salvelinus fontinalis	juvenile	4/n=2(N=8)	9	15	7											2	Cherry et al. 1975	1
51	Salvelinus fontinalis	fry	n=10 (see notes)	7.5									22.2				16	McCormick et al. 1972	1
52	Salvelinus fontinalis	fry	n=15 (see notes)	7									19.4				16	McCormick et al. 1972	1
53	Salvelinus fontinalis	fry juveni	3 replicates								16						22	Dwyer and Kramer 1975	1
54	Salvelinus fontinalis	juvenile	n=27	12-17 C											28.03	2 C/day	23	Galbreath et al. 2006	1
55	Salvelinus fontinalis	juvenile	n=44	12-17 C											28.06	2 C/day	24	Galbreath et al. 2006	1
56	Salvelinus fontinalis	juvenile	n=39	12-17 C											27.96	2 C/day	25	Galbreath et al. 2006	1
57	Salvelinus fontinalis	juvenile	n=43	12-17 C											27.56	2 C/day	26	Galbreath et al. 2006	1
58	Salvelinus fontinalis	juvenile	n=41	12-17 C											27.64	2 C/day	27	Galbreath et al. 2006	1

60					minimum	15.00	7.00	18.50	8.70	11.00		15.40		19.40		27.56		
61					**median**	**18.00**	**12.00**	**18.50**	**16.00**	**11.00**		**16.00**		**23.10**		**28.40**		
62					maximum	23.00	16.00	18.50	18.30	11.00		16.00		25.30		29.76		
63					(n)	5	5	1	13	1		3		10		13		
64																		
65																		
66					**Estimates of Factors**						**Calculation of Metrics**			**Notes on Calculation Methods**				
67											DM2MOS	2.32						
68					Median CTM's				28.40		DM1MOS	**1.42**		MOS method 1: 20% rule with UILT/UUILT and Optimum Temperature				
69				2	Median CTM's-conversion				27.60		DM 2	25.28						
70				1	Median UILT/UUILT				23.10		**DM 1**	**21.68**		DM method 1: UILT/UUILT - MOS				
71				1	Optimum Temperature for 1/3 Rule				16.00		**MWAT 1**	**18.343**		MWAT method 1: 1/3 rule with Optimum Temperature				
72				2	Pref Ave for 1/3 Rule				16.00		MWAT 2	18.343						
73				3	Avoided High for 1/3 Rule				18.00		MWAT 3	19.683		18 was chosen as Avoided High because the acclimation temperature (15) was closest				
74				4	Upper Optimum				no data		MWAT 4	no data		to the other known temperature optimum metrics				
75																		
76			Notes: data not used															
77					1= acclimation too low- below 7													
78					2= acclimation too high- above 23 or higher than min CTM													
79					3= lifestage = embryo/larvae													
80					4= field study													

[1] For acclimation, fish were maintained in tap water that varied seasonally between 2°C and 8°C. Sample size indicates number of fish; many observations taken for each fish and pooled. 82 replicates were performed over four years, at invertvals from November through March.

[2] Fish are assumed to be adults tested; fish were fasted 2.5-3 days before being tested.

[3] Authors noted no evidence that preference differed between first and second half of test period; fish were fasted for 24 hours before being tested.

[4] Total number of fish was 240 (summed from figure 1), but the number of these used here is unknown; acclimation procedure not specified, but based on reference to Brett 1944 the acclimation would be 1°C/day until the final acclimation temperature was reached.

[5] Number of different temperature exposures was not specified.

[6] Fish from 24°C and 25°C acclimation were pooled due to small sample size. Sample size and acclimation procedure not specified, but based on reference to Brett 1944 the acclimation would be 1°C/day until the final acclimation temperature was reached.

[7] No lab acclimation; the acclimation temperature is the median of the range reported during the collection period (Jun 20) for Lake Opeongo (25-26°C).

[8] Optimum corresponds to lowest incubation temp used, but survival rates are very high and likely would not improve much at still lower temps, so 6°C may be a reasonable approximation of optimum incubation temperature. Three replicates were performed and n = 100 for each replicate and treatment.

[9] A curve was fit to hatch data from various temperatures and used to predict maximum eying/optimum incubation temperature. Survival did not differ between groups after eyeing. There were three tanks of each temperature, and in each tank n = 175.

[10] Testing was conducted in June through September. Observations were recorded when main river flow temperature was < 20°C; the preferred temperature reported is slightly higher than the typical optimum growth range reported elsewhere for brook trout.

[11] Acclimation/tempering of fry consisted of a 3°C/hour rate of change to the final treatment temps. A 2-3°C gap may have affected the precision and accuracy of estimated optima, but the value is generally consistent with other data from literature.

[12] Also studied modified CTM (not included) based on gradual rise in diurnally fluctuating temperature regime.
[13] Fish were fasted. The thermal preference was measured daily (repeated measures) over 15 days and preferences were similar throughout fasting period, so a combined average is estimated (to nearest half degree) from figure 1 and reported here.
[14] Fish were fed. The thermal preference was measured daily (repeated measures) over 15 days and preferences were similar throughout fasting period, so a combined average is estimated (to nearest half degree) from figure 1 and reported here.
[15] Preference reported is the mean; data were reported only for fish at homogeneous acclimation, rather than heterogeneous, which is a process where head and tail ends of fish are acclimated to quite different temperatures in a way that is not duplicated in nature.
[16] Number of different temperature exposures not specified.
[17] PisgahXEdray strains.
[18] Origin of fish not stated, but hatchery origin is likely.
[19] Fish were hatched in the laboratory. The acclimation period is presumed to be long; fish were brought to acclimation temperatures at rate of 2°C/month after incubation at 7-8°C.
[20] Alevin. Number of different temperature exposures was not specified.
[21] Sample size was not specified; growth optimum was determined by maximum weight increase.
[22] Owhi strain was used. Wide gaps in temperature treatment decrease precision, but 16°C optimum is an approximation with reasonable consistency to other reported optima for brook trout.
[23] From brook trout #1 test in paper - diploid fish only.
[24] From brook trout #1 test in paper - diploid fish that received thermal shock as eggs to induce triploidy, but which did not become triploid.
[25] From brook trout #2a test in paper - diploid fish only.
[26] From brook trout #2b test in paper - diploid fish only.
[27] From brook trout #3 test in paper - diploid fish only.

1	Common Name	Scientific Name	Life stage	Replicates/Sample Size	Acclimation Temperature	Avoid high	Avoid low	Pref high	Pref ave	Pref low	Lower Optimum	Optimum	Upper Optimum	UILT	UUILT	CTM	Rate of Increase (CTM)	Other Notes	Complete Reference	Lab (y/n)
2	Brown Trout	Salmo trutta	larvae	n=10 per	5-6									22.5				1	Bishai 1960	1
3	Brown Trout	Salmo trutta	larvae	n=10 per	5-6									22				2	Bishai 1960	1
4	Brown Trout	Salmo trutta	adult	N=6	0-5 C range			13.7	12.2	10.3								3	Reynolds and Casterlin 1979a	1
5	Brown Trout	Salmo trutta	larvae	n=10 per	10									23				1	Bishai 1960	1
6	Brown Trout	Salmo trutta	larvae	n=10 per	10									23				1	Bishai 1960	1
7	Brown Trout	Salmo trutta	larvae	n=10 per	10									23				2	Bishai 1960	1
8	Brown Trout	Salmo trutta	larvae	n=10 per	10									23				2	Bishai 1960	1
9	Brown Trout	Salmo trutta	juvenile	N=30/n=30/tank								12						4	Swift 1961	1
10	Brown Trout	Salmo trutta	juvenile	3/n=5	10											28.96	0.2 C/min	5	Lee and Rinne 1980	1
11	Brown Trout	Salmo trutta	fry	15	10.9											28.6	0.3 C/min	6	Carline and Machung 2001	1
12	Brown Trout	Salmo trutta	fry	15	10.9											28.2	0.3 C/min	7	Carline and Machung 2001	1
13	Brown Trout	Salmo trutta	fry	15	10.9											28.5	0.3 C/min	8	Carline and Machung 2001	1
14	Brown Trout	Salmo trutta	fry	15	10.9											28.7	0.3 C/min	9	Carline and Machung 2001	1
15	Brown Trout	Salmo trutta	fry	15	10.9											28.1	0.3 C/min	7	Carline and Machung 2001	1
16	Brown Trout	Salmo trutta	fry	15	10.9											28.3	0.3 C/min	10	Carline and Machung 2001	1
17	Brown Trout	Salmo trutta	fry	15	10.9											28.2	0.3 C/min	11	Carline and Machung 2001	1
18	Brown Trout	Salmo trutta	fry	15	10.9											28.4	0.3 C/min	12	Carline and Machung 2001	1
19	Brown Trout	Salmo trutta	juvenile adult	10	15											24.75	0.0104 C/hr	13	Elliott and Elliott 1995	1
20	Brown Trout	Salmo trutta	juvenile adult	10	15											24.95	0.0208 C/hr	13	Elliott and Elliott 1995	1
21	Brown Trout	Salmo trutta	juvenile adult	10	15											25.3	0.05 C/hr	13	Elliott and Elliott 1995	1
22	Brown Trout	Salmo trutta	juvenile adult	10	15											26	0.1 C/hr	13	Elliott and Elliott 1995	1
23	Brown Trout	Salmo trutta	juvenile adult	10	15											28.55	0.5 C/hr	13	Elliott and Elliott 1995	1
24	Brown Trout	Salmo trutta	juvenile adult	10	15											29.65	1.0 C/hr	13	Elliott and Elliott 1995	1
25	Brown Trout	Salmo trutta	juvenile adult	10	15											29.9	2.0 C/hr	13	Elliott and Elliott 1995	1
26	Brown Trout	Salmo trutta	juvenile adult	10	15											29.9	6.0 C/hr	13	Elliott and Elliott 1995	1
27	Brown Trout	Salmo trutta	juvenile adult	10	15											30	18.0 C/hr	13	Elliott and Elliott 1995	1
28	Brown Trout	Salmo trutta	juvenile	30	15											29.2	24 C/day	14	Galbreath et al. 2004	1
29	Brown Trout	Salmo trutta	juvenile	30	15											29.2	8 C/day	15	Galbreath et al. 2004	1
30	Brown Trout	Salmo trutta	juvenile	29	15											29.3	4 C/day	15	Galbreath et al. 2004	1
31	Brown Trout	Salmo trutta	juvenile	30	15											29.2	24 C/day	16	Galbreath et al. 2004	1
32	Brown Trout	Salmo trutta	juvenile	30	15											29	2 C/day	15	Galbreath et al. 2004	1
33	Brown Trout	Salmo trutta	adults	10	20											24.85	0.0104 C/hr	13	Elliott and Elliott 1995	1
34	Brown Trout	Salmo trutta	adults	10	20											25	0.0208 C/hr	13	Elliott and Elliott 1995	1
35	Brown Trout	Salmo trutta	adults	10	20											25.25	0.05 C/hr	13	Elliott and Elliott 1995	1
36	Brown Trout	Salmo trutta	adults	10	20											25.65	0.1 C/hr	13	Elliott and Elliott 1995	1
37	Brown Trout	Salmo trutta	adults	10	20											28.45	0.5 C/hr	13	Elliott and Elliott 1995	1
38	Brown Trout	Salmo trutta	adults	10	20											29.5	1.0 C/hr	13	Elliott and Elliott 1995	1
39	Brown Trout	Salmo trutta	adults	10	20											29.95	2.0 C/hr	13	Elliott and Elliott 1995	1
40	Brown Trout	Salmo trutta	adults	10	20											30	6.0 C/hr	13	Elliott and Elliott 1995	1
41	Brown Trout	Salmo trutta	adults	10	20											29.95	18.0 C/hr	13	Elliott and Elliott 1995	1
42	Brown Trout	Salmo trutta	juvenile	3/n=5	20											29.85	0.2 C/min	5	Lee and Rinne 1980	1
43	Brown Trout	Salmo trutta	juvenile	N=10	9-11 C				16										Larsson 2005	1
44	Brown Trout	Salmo trutta	juvenile adult	N=210; N=252								13.9						17	Elliott and Hurley 1999	1
45	Brown Trout	Salmo trutta	juvenile	N=480 (n=40 per temp)							13.78	16.87	19.59					18	Ojanguren et al. 2001	1
46																				
47					**minimum**				16.00		13.78	13.90	19.59			24.75				
48					**median**				**16.00**		**13.78**	**15.39**	**19.59**			**28.60**				
49					**maximum**				16.00		13.78	16.87	19.59			30.00				
50					**(n)**				1		1	2	1			33				

53		Estimates of Factors		Calculation of Metrics		Notes on Calculation Methods
54				DM2MOS	2.383	MOS method 1: 20% rule with converted CTM and Optimum Temperature
55		Median CTM's	28.60	DM1MOS	no data	
56	2	Median CTM's-conversion	27.30	DM 2	24.92	DM method 2: Converted CTM - MOS
57	1	Median UILT/UUILT	no data	DM 1	no data	
58	1	Optimum Temperature for 1/3 Rule	15.39	MWAT 1	19.317	MWAT method 1: 1/3 rule with Optimum Temperature
59	2	Pref Ave for 1/3 Rule	16.00	MWAT 2	19.729	
60	3	Avoided High for 1/3 Rule	no data	MWAT 3	no data	18 was chosen as Avoided High because the acclimation temperature (15) was closest to
61	4	Upper Optimum	19.59	MWAT 4	19.59	the other known temperature optimum metrics
62		** Special CTM conversion factor = 1.3				
63	Notes:	data not used				
64		1= acclimation too low- below 7				
65		2= acclimation too high- above 23 or higher than min CTM				
66		3= lifestage = embryo/larvae				
67		4= field study				
68		5= other				

[1] Fish were stream resident stock. Larvae were reared at acclimation temperature.

[2] Fish were anadromous. Larvae were reared at acclimation temperature.

[3] Fish were not fed during period of captivity for study. Acclimation is too low winter temps, so preferenda may be lower than reasonable for setting summer maximum temp standards.

[4] Optimum temperature for growth. Only three temperature levels used in study (8°C, 12°C, 16°C), so accuracy of reported optima may be poor.

[5] Also studied modified CTM (not included) based on gradual rise in diurnally fluctuating temperature regime.

[6] Fish are from Reynoldsdale hatchery and have been exposed to electrofishing. Hatchery vs. wild strain comparison results are not included in database due to small sample size (n = 3 per group).

[7] Fish are from Huntsdale hatchery and have been exposed to electrofishing. Hatchery vs. wild strain comparison results are not included in database due to small sample size (n = 3 per group).

[8] Fish are from Reynoldsdale hatchery and have not been exposed to electrofishing. Hatchery vs. wild strain comparison results are not included in database due to small sample size (n = 3 per group).

[9] Fish are from Big Spring hatchery and have been exposed to electrofishing. Hatchery vs. wild strain comparison results are not included in database due to small sample size (n = 3 per group).

[10] Fish are from Big Spring hatchery and have not been exposed to electrofishing. Hatchery vs. wild strain comparison results are not included in database due to small sample size (n = 3 per group).

[11] Fish are from Benner Spring hatchery and have been exposed to electrofishing. Hatchery vs. wild strain comparison results are not included in database due to small sample size (n = 3 per group).

[12] Fish are from Benner Spring hatchery and have not been exposed to electrofishing. Hatchery vs. wild strain comparison results are not included in database due to small sample size (n = 3 per group).

[13] Experiment appears to be repeated-measures, based on use of ANOVAR (repeated-measured analysis of variance). Repeated measures of CTM to Loss of Equilibrium in 10 fish at 9 acclimation temperatures.

[14] Pisgah X Walhalla strains; trial 2 at this rate of temperature change.

[15] Pisgah X Walhalla strains.

[16] Pisgah X Walhalla strains; trial 1 at this rate of temperature change.
[17] High zero-growth temperature was also reported for each size classes studied (Table 2 of reference). This study is a re-analysis of data reported in two Elliott 1975 papers (original results are not included in database).
[18] Lower and upper thermal optima indicate the range encompassing 90% of maximum growth threshold temperatures.

1	Common Name	Scientific Name	Life stage	Replicates/Sample Size	Acclimation Temperature	Avoid high	Avoid low	Pref high	Pref ave	Pref low	Lower Optimum	Optimum	Upper Optimum	UILT	UUILT	CTM	Rate of Increase (CTM)	Spawning Optimum	Egg Dev. Optimum	Other Notes	Complete Reference	Lab (y/n)
2	Burbot	Lota lota	small	42	ave.				11.4												Hofmann and Fischer 2002	1
3	Burbot	Lota lota	large	40	ave.				14.2												Hofmann and Fischer 2002	1
4	Burbot	Lota lota	small	42	5.2											27.1	2 deg/h				Hofmann and Fischer 2002	1
5	Burbot	Lota lota	small	42	9.9											27.8	2 deg/h				Hofmann and Fischer 2002	1
6	Burbot	Lota lota	small	42	14.9											30.2	2 deg/h				Hofmann and Fischer 2002	1
7	Burbot	Lota lota	small	42	19.6											31.5	2 deg/h				Hofmann and Fischer 2002	1
8	Burbot	Lota lota	large	40	5.2											26.8	2 deg/h				Hofmann and Fischer 2002	1
9	Burbot	Lota lota	large	40	9.9											27.5	2 deg/h				Hofmann and Fischer 2002	1
10	Burbot	Lota lota	large	40	14.9											29.6	2 deg/h				Hofmann and Fischer 2002	1
11	Burbot	Lota lota	large	40	19.6											31.7	2 deg/h				Hofmann and Fischer 2002	1
12	Burbot	Lota lota	juvenile	10	16.7							16								growth optimum	Hofmann and Fischer 2003	1
13	Burbot	Lota lota	juvenile	2500	12							15								growth optimum	Wolnicki et al. 2001	1
14																						
15					**minimum**				11.40			15.00				26.80						
16					**median**				**12.80**			**15.50**				**28.70**						
17					**maximum**				14.20			16.00				31.70						
18					**(n)**				2			2				8						
19																						

20	**Estimates of Factors**		**Calculation of Metrics**		**Notes on Calculation Methods**
21			DM2MOS	**2.48**	MOS method 1: 20% rule with converted CTM and Optimum Temperature
22	Median CTM's	28.70	DM1MOS	no data	
23	2 Median CTM's-conversion	27.90	**DM 2**	**25.42**	DM method 2: Converted CTM - MOS
24	1 Median UILT/UUILT	no data	DM 1	no data	
25	1 Optimum Temperature for 1/3 Rule	15.50	**MWAT 1**	**19.592**	MWAT method 1: 1/3 rule with Optimum Temperature
26	2 Pref Ave for 1/3 Rule	12.80	MWAT 2	17.783	
27	3 Avoided High for 1/3 Rule	no data	MWAT 3	no data	
28	4 Upper Optimum	no data	MWAT 4	no data	
29					

30	Notes: data not used
31	1= acclimation too low- below 7
32	2= acclimation too high- above 23 or higher than min CTM
33	3= lifestage = embryo/larvae
34	4= field study

1	Common Name	Scientific Name	Life stage	Replicates/Sample Size	Acclimation Temperature	Avoid high	Avoid low	Pref high	Pref ave	Pref low	Lower Optimum	Optimum	Upper Optimum	UILT	UUILT	CTM	Rate of Increase (CTM)	Other Notes	Complete Reference	Lab (y/n)
2	Central Stoneroller	Campostoma anomalum	juvenile adult	2/n=8(N=16)	6				13.4									1	Cherry et al. 1975	1
3	Central Stoneroller	Campostoma anomalum	juvenile adult	4/n=2(N=8)	6	18	6											1	Cherry et al. 1975	1
4	Central Stoneroller	Campostoma anomalum	juvenile adult	2/n=8(N=16)	9				15.2									1	Cherry et al. 1975	1
5	Central Stoneroller	Campostoma anomalum	juvenile adult	4/n=2(N=8)	9	19	7											1	Cherry et al. 1975	1
6	Central Stoneroller	Campostoma anomalum		18	10											31.75	1 C/min		Lutterschmidt and Hutchison 1997	1
7	Central Stoneroller	Campostoma anomalum		18	10											29.82	1 C/min		Lutterschmidt and Hutchison 1997	1
8	Central Stoneroller	Campostoma anomalum	juvenile adult	2/n=8(N=16)	12				20.7									1	Cherry et al. 1975	1
9	Central Stoneroller	Campostoma anomalum	juvenile adult	4/n=2(N=8)	12	23	10											1	Cherry et al. 1975	1
10	Central Stoneroller	Campostoma anomalum	45-57 mm TL	6												37.7	0.5-0.8 C/	2	Mundahl 1990	1
11	Central Stoneroller	Campostoma anomalum	juvenile adult	2/n=8(N=16)	15				21.5									1	Cherry et al. 1975	1
12	Central Stoneroller	Campostoma anomalum	juvenile adult	4/n=2(N=8)	15	22	13											1	Cherry et al. 1975	1
13	Central Stoneroller	Campostoma anomalum	juvenile adult	2/n=8(N=16)	18				22.3									1	Cherry et al. 1975	1
14	Central Stoneroller	Campostoma anomalum	juvenile adult	4/n=2(N=8)	18	25	17											1	Cherry et al. 1975	1
15	Central Stoneroller	Campostoma anomalum	juvenile adult	2/n=8(N=16)	21				23.6									1	Cherry et al. 1975	1
16	Central Stoneroller	Campostoma anomalum	juvenile adult	4/n=2(N=8)	21	30	18											1	Cherry et al. 1975	1
17	Central Stoneroller	Campostoma anomalum	juvenile adult	2/n=8(N=16)	24				25.3									1	Cherry et al. 1975	1
18	Central Stoneroller	Campostoma anomalum	juvenile adult	4/n=2(N=8)	24	29	21											1	Cherry et al. 1975	1
19	Central Stoneroller	Campostoma anomalum		13	26											37.2	2 C/hr		Smale and Rabeni 1995	1
20	Central Stoneroller	Campostoma anomalum	juvenile adult	2/n=8(N=16)	27				28.6									1	Cherry et al. 1975	1
21	Central Stoneroller	Campostoma anomalum	juvenile adult	4/n=2(N=8)	27	33	24											1	Cherry et al. 1975	1
22																				
23					**minimum**	22	13		21.5							37.2				
24					**median**	**29**	**18**		**23.6**							**37.2**				
25					**maximum**	33	24		28.6							37.2				
26					**(n)**	5	5		5							1				

	Estimates of Factors		**Calculation of Metrics**	**Notes on Calculation Methods**
			DM2MOS **2.56**	MOS method 1: 20% rule with converted CTM and Preferred Average
	Median CTM's	37.20	DM1MOS no data	
2	Median CTM's-conversion	36.40	**DM 2 33.84**	DM method 2: Converted CTM - MOS
1	Median UILT/UUILT	no data	DM 1 no data	
1	Optimum Temperature for 1/3 Rule	no data	MWAT 1 no data	
2	Pref Ave for 1/3 Rule	23.60	**MWAT 2 27.824**	MWAT method 2: 1/3 rule with Preferred Average
3	Avoided High for 1/3 Rule	29.00	MWAT 3 31.442	29 was chosen as Avoided High because the acclimation temperature
4	Upper Optimum	no data	MWAT 4 no data	(24) was closest to the other known temperature optimum metrics

Notes: data not used
1= acclimation too low- below 15
2= acclimation too high- above 30 or higher than min CTM
3= lifestage = embryo/larvae
4= field study

[1] Fish were assumed to be adults; fish were fasted 2.5-3 days before tests.

[2] Nonstandard acclimation process: natural conditions were measured in pool during low water with disconnected pools, with temperatures ranging from 32.5°C in submerged rock cavities to 39.5°C in full sun.

1	Common Name	Scientific Name	Life stage	Replicates/Sample Size	Acclimation Temperature	Avoid high	Avoid low	Pref high	Pref ave	Pref low	Lower Optimum	Optimum	Upper Optimum	UILT	UUILT	CTM	Rate of Increase (CTM)	Other Notes	Complete Reference	Lab (y/n)
2	Channel Catfish	Ictalurus punctatus	juvenile	2/n=8(N=16)	6				18.9									1	Cherry et al. 1975	1
3	Channel Catfish	Ictalurus punctatus	juvenile	4/n=2(N=8)	6	25	4											1	Cherry et al. 1975	1
4	Channel Catfish	Ictalurus punctatus	juvenile	2/n=8(N=16)	9				20.4									1	Cherry et al. 1975	1
5	Channel Catfish	Ictalurus punctatus	juvenile	4/n=2(N=8)	9	26	7											1	Cherry et al. 1975	1
6	Channel Catfish	Ictalurus punctatus	juvenile	n=9	10											31.1	0.15 C/mi	2	Bennet et al. 1998	1
7	Channel Catfish	Ictalurus punctatus		20	10											33.31	1 C/min		Lutterschmidt and Hutchison 1997	1
8	Channel Catfish	Ictalurus punctatus		20	10											31.32	1 C/min		Lutterschmidt and Hutchison 1997	1
9	Channel Catfish	Ictalurus punctatus	juvenile	2/n=8(N=16)	12				19.9									1	Cherry et al. 1975	1
10	Channel Catfish	Ictalurus punctatus	fry	12	12											34.5	1 C/min	3	Cheetham et al. 1976	1
11	Channel Catfish	Ictalurus punctatus	fry	12	12											36	1 C/min	4	Cheetham et al. 1976	1
12	Channel Catfish	Ictalurus punctatus	fry	6	12				16.5									5	Cheetham et al. 1976	1
13	Channel Catfish	Ictalurus punctatus	juvenile	4/n=2(N=8)	12	29	13											1	Cherry et al. 1975	1
14	Channel Catfish	Ictalurus punctatus	fry	12	32											41	1 C/min	3	Cheetham et al. 1976	1
15	Channel Catfish	Ictalurus punctatus	fry	12	32											42.5	1 C/min	4	Cheetham et al. 1976	1
16	Channel Catfish	Ictalurus punctatus	fry	6	32				29.5									5	Cheetham et al. 1976	1
17	Channel Catfish	Ictalurus punctatus	juvenile	n=8	35											42.3	0.15 C/mi	2	Bennet et al. 1998	1
18	Channel Catfish	Ictalurus punctatus	see notes	see notes														6	Yoder and Gammon 1976	0
19	Channel Catfish	Ictalurus punctatus	see notes	see notes														7	Yoder and Gammon 1976	0
20	Channel Catfish	Ictalurus punctatus	juvenile	2/n=8(N=16)	15				21.7									1	Cherry et al. 1975	1
21	Channel Catfish	Ictalurus punctatus	juvenile	4/n=2(N=8)	15	30	14											1	Cherry et al. 1975	1
22	Channel Catfish	Ictalurus punctatus	fry	12	16											34.5	1 C/min	3	Cheetham et al. 1976	1
23	Channel Catfish	Ictalurus punctatus	fry	12	16											36.5	1 C/min	4	Cheetham et al. 1976	1
24	Channel Catfish	Ictalurus punctatus	fry	6	16				21									5	Cheetham et al. 1976	1
25	Channel Catfish	Ictalurus punctatus	juvenile	2/n=8(N=16)	18				22.9									1	Cherry et al. 1975	1
26	Channel Catfish	Ictalurus punctatus	juvenile	4/n=2(N=8)	18	30	16											1	Cherry et al. 1975	1
27	Channel Catfish	Ictalurus punctatus	juvenile	20	20											38	0.3 C/min	8	Watenpaugh et al. 1985	1
28	Channel Catfish	Ictalurus punctatus	juvenile	n=9	20											35.9	0.15 C/mi	2	Bennet et al. 1998	1
29	Channel Catfish	Ictalurus punctatus	fry	12	20											35.5	1 C/min	1	Cheetham et al. 1976	1
30	Channel Catfish	Ictalurus punctatus	fry	12	20											37	1 C/min	2	Cheetham et al. 1976	1
31	Channel Catfish	Ictalurus punctatus	fry	6	20				21									3	Cheetham et al. 1976	1
32	Channel Catfish	Ictalurus punctatus	juvenile	2/n=8(N=16)	21				26.1									1	Cherry et al. 1975	1
33	Channel Catfish	Ictalurus punctatus	juvenile	4/n=2(N=8)	21	32	19											1	Cherry et al. 1975	1
34	Channel Catfish	Ictalurus punctatus	juvenile	2/n=8(N=16)	24				29.4									1	Cherry et al. 1975	1
35	Channel Catfish	Ictalurus punctatus	fry	12	24											38.5	1 C/min	3	Cheetham et al. 1976	1
36	Channel Catfish	Ictalurus punctatus	fry	12	24											37.5	1 C/min	2	Cheetham et al. 1976	1
37	Channel Catfish	Ictalurus punctatus	fry	6	24				27.5									5	Cheetham et al. 1976	1
38	Channel Catfish	Ictalurus punctatus	juvenile	4/n=2(N=8)	24	33	23											1	Cherry et al. 1975	1
39	Channel Catfish	Ictalurus punctatus	juvenile	2/n=8(N=16)	27				29.5									1	Cherry et al. 1975	1
40	Channel Catfish	Ictalurus punctatus	juvenile	4/n=2(N=8)	27	34	23											1	Cherry et al. 1975	1
41	Channel Catfish	Ictalurus punctatus	fry	12	28											39.5	1 C/min	3	Cheetham et al. 1976	1
42	Channel Catfish	Ictalurus punctatus	fry	12	28											40.5	1 C/min	4	Cheetham et al. 1976	1
43	Channel Catfish	Ictalurus punctatus	fry	6	28				26									5	Cheetham et al. 1976	1
44	Channel Catfish	Ictalurus punctatus	juvenile	2/n=8(N=16)	30				30.5									1	Cherry et al. 1975	1
45	Channel Catfish	Ictalurus punctatus	juvenile	n=9	30											40.1	0.15 C/mi	2	Bennet et al. 1998	1
46	Channel Catfish	Ictalurus punctatus	juvenile	4/n=2(N=8)	30	35	23											1	Cherry et al. 1975	1
47	Channel Catfish	Ictalurus punctatus	juvenile	N=600(n=20)								30						9	Andrews and Stickney 1972	1
48	Channel Catfish	Ictalurus punctatus	juvenile	n=11	20											36.4	0.3 C/min		Currie et al. 2004	1
49	Channel Catfish	Ictalurus punctatus	juvenile	n=11	25											38.7	0.3 C/min		Currie et al. 2004	1
50	Channel Catfish	Ictalurus punctatus	juvenile	n=11	30											40.3	0.3 C/min		Currie et al. 2004	1
51	Channel Catfish	Ictalurus punctatus	juvenile	n=11	20-30 (diel cycling)											39	0.3 C/min		Currie et al. 2004	1
52	Channel Catfish	Ictalurus punctatus	adult		22.7				25.2							38		10	Reutter and Herdendorf 1976	1

minimum	30.00	14.00	21.00	30.00	34.50
median	**32.50**	**21.00**	**26.00**	**30.00**	**38.00**
maximum	35.00	23.00	30.50	30.00	40.50
(n)	6	6	11	1	16

Estimates of Factors		**Calculation of Metrics**		**Notes on Calculation Methods**
		DM2MOS	**1.44**	MOS method 1: 20% rule with converted CTM and Optimum Temperature
Median CTM's	38.00	DM1MOS	no data	
2 Median CTM's-conversion	37.20	**DM 2**	**35.76**	DM method 2: Converted CTM - MOS
1 Median UILT/UUILT	no data	DM 1	no data	
1 Optimum Temperature for 1/3 Rule	30.00	**MWAT 1**	**32.376**	MWAT method 1: 1/3 rule with Optimum Temperature
2 Pref Ave for 1/3 Rule	26.00	MWAT 2	29.696	
3 Avoided High for 1/3 Rule	35.00	MWAT 3	35.726	35 was chosen as Avoided High because the acclimation temperature (30) was closest to the other known temperature optimum metrics
4 Upper Optimum	no data	MWAT 4	no data	

Notes: data not used
1= acclimation too low- below 15
2= acclimation too high- above 30 or higher than min CTM
3= lifestage = embryo/larvae
4= field study

[1] Fish were assumed to be adults; fish were fasted 2.5-3 days before tests.
[2] Fish were fasted one day before being tested; CTM was estimated using the regression equation in the Figure 1 caption. Other CTM values were reported in paper but not used due to thermal shock pre-treatments used before the CTM testing.
[3] CTM value was estimated from Figure 1 to the nearest 0.5°C.
[4] CTM value (to the Death Point) was estimated from Figure 1 to the nearest 0.5°C.
[5] Preferences were estimated from Figure 1 to the nearest 0.5°C.
[6] Data are from summer captures. Sample sizes are not given, but sampling design and other plots suggest they are high for most species. Winter data are also provided but not included in database.
[7] Data are from fall captures. Sample sizes are not given, but sampling design and other plots suggest they are high for most species. Winter data are also provided but not included in database.
[8] Fish were a control group in a study of Nitrite exposure on CTM.
[9] Acclimation process was not described. The precision of optimum determination was poor due to 4°C temperature gap between temperature treatment levels, but result agrees with other studies. Optimum was judged by maximum growth rate.
[10] Preferred average refers to summer.

1	Common name	Scientific name	Life stage	Replicates/Sample Size	Acclimation Temperature	Avoid high	Avoid low	Pref high	Pref ave	Pref low	Lower Optimum	Optimum	Upper Optimum	UILT	UUILT	CTM	Rate of Increase (CTM)	Other Notes	Complete Reference	Lab (y/n)
2	Common Carp	Cyprinus carpio	fry	N=6 per trial	10				17									1	Pitt et al. 1956	1
3	Common Carp	Cyprinus carpio		N=110/n=10	11									35.7					Black 1953	1
4	Common Carp	Cyprinus carpio	fry	N=6 per trial	35				32									2	Pitt et al. 1956	1
5	Common Carp	Cyprinus carpio	see notes	see notes														3	Yoder and Gammon 1976	0
6	Common Carp	Cyprinus carpio	see notes	see notes														4	Yoder and Gammon 1976	0
7	Common Carp	Cyprinus carpio	fry	N=6 per trial	15				25									5	Pitt et al. 1956	1
8	Common Carp	Cyprinus carpio	fry	N=6 per trial	20				27									6	Pitt et al. 1956	1
9	Common Carp	Cyprinus carpio	fry	N=6 per trial	25				31									7	Pitt et al. 1956	1
10	Common Carp	Cyprinus carpio	fry	N=6 per trial	30				31									8	Pitt et al. 1956	1
11	Common Carp	Cyprinus carpio	adult	N=6	not reported				29										Reynolds and Casterlin 1977	1
12	Common Carp	Cyprinus carpio	juvenile	30					27									9	Goolish and Adelman 1984	1
13	Common Carp	Cyprinus carpio			20									32.5				10	Black 1953	1
14	Common Carp	Cyprinus carpio			26									35.7				10	Black 1953	1
15	Common Carp	Cyprinus carpio													38.5			11	Meuwis and Heuts 1957	1
16	Common Carp	Cyprinus carpio													35.5			12	Meuwis and Heuts 1957	1
17	Common Carp	Cyprinus carpio	adult		23.3				29.7							39		13	Reutter and Herdendorf 1976	1
18	Common Carp	Cyprinus carpio										27							Meuwis and Heuts 1957	1
19	Common Carp	Cyprinus carpio							29.4									13	Reutter and Herdendorf 1976	1
20																				
21					**minimum**				25.00			27.00		32.50	35.50	39.00				
22					**median**				29.20			**27.00**		**34.10**	**37.00**	**39.00**				
23					**maximum**				31.00			27.00		35.70	38.50	39.00				
24					**(n)**				8			1		2	2	1				
25																				
26																				
27					**Estimates of Factors**						**Calculation of Metrics**			**Notes on Calculation Methods**						
28											DM2MOS	2.24								
29					Median CTM's				39.00		DM1MOS	**1.72**		MOS method 1: 20% rule with median UILT/UUILT and Optimum Temperature						
30					2 Median CTM's-conversion				38.20		DM 2	35.96								
31					1 Median UILT/UUILT				35.60		**DM 1**	**33.88**		DM method 1: Median UILT/UUILT - MOS						
32					1 Optimum Temperature for 1/3 Rule				27.00		**MWAT 1**	**29.838**		MWAT method 1: 1/3 rule with Optimum Temperature						
33					2 Pref Ave for 1/3 Rule				29.20		MWAT 2	31.312								
34					3 Avoided High for 1/3 Rule				no data		MWAT 3	no data								
35					4 Upper Optimum				no data		MWAT 4	no data								
36																				
37				Notes: data not used																
38					1= acclimation too low- below 15															
39					2= acclimation too high- above 30 or higher than min CTM															
40					3= lifestage = embryo/larvae															
41					4= field study															

[1] 360 total observations were made. Fish were tempered at a rate of 1°C/day, then held at the final acclimation temperature for 1-2 days before testing.
[2] 240 total observations were made. Fish were tempered at a rate of 1°C/day, then held at the final acclimation temperature for 1-2 days before testing.
[3] Data are from fall captures. Sample sizes are not given, but sampling design and other plots suggest they are high for most species. Winter data are also provided but not included in database.
[4] Data are from summer captures. Sample sizes are not given, but sampling design and other plots suggest they are high for most species. Winter data are also provided but not included in database.
[5] 480 total observations were made. Fish were tempered at a rate of 1°C/day, then held at the final acclimation temperature for 1-2 days before testing.
[6] 359 total observations were made. Fish were tempered at a rate of 1°C/day, then held at the final acclimation temperature for 1-2 days before testing.
[7] 358 total observations were made. Fish were tempered at a rate of 1°C/day, then held at the final acclimation temperature for 1-2 days before testing.
[8] 336 total observations were made. Fish were tempered at a rate of 1°C/day, then held at the final acclimation temperature for 1-2 days before testing.
[9] The optimum is the median of the upper two temperature treatments, which produced similar growth at all ration levels, and it corresponds to the temperature of maximum estimated growth and activity.
[10] Mean of reported values.
[11] Small fish; mean of reported values.
[12] Large fish; mean of reported values.
[13] Preferred average in the summer.

1	Common name	Scientific name	Life stage	Replicates/Sample Size	Acclimation Temperature	Avoid high	Avoid low	Pref high	Pref ave	Pref low	Lower Optimum	Optimum	Upper Optimum	UILT	UUILT	CTM	Rate of Increase (CTM)	Other Notes	Complete Reference	Lab (y/n)
2	Common Shiner	Notropis cornutus	juvenile adult	5	5									26.7					Hart 1947	1
3	Common Shiner	Notropis cornutus	juenile adult	N=8	6	12			11									1	Barila et al. 1982	1
4	Common Shiner	Notropis cornutus	adult	17	8				11									2	Domanik and Zar 1978	1
5	Common Shiner	Notropis cornutus	adult	15	8				12									2	Domanik and Zar 1978	1
6	Common Shiner	Notropis cornutus	juvenile	16	8				11.4									2	Domanik and Zar 1978	1
7	Common Shiner	Notropis cornutus	juvenile adult	5	10									28.6					Hart 1947	1
8	Common Shiner	Notropis cornutus	juenile adult	N=8	12	24			13									1	Barila et al. 1982	1
9	Common Shiner	Notropis cornutus	juenile adult	N=8	33	36			24									1	Barila et al. 1982	1
10	Common Shiner	Notropis cornutus	adult	10	15											30.6	1 C/min	3	Kowalski et al. 1978	1
11	Common Shiner	Notropis cornutus	adult	8	15											31.9	1 C/min		Schubauer et al. 1980	1
12	Common Shiner	Notropis cornutus	adult	16	15											31.9	1 C/min	4	Kowalski et al. 1978	1
13	Common Shiner	Notropis cornutus	juvenile adult	5	15									30.3					Hart 1947	1
14	Common Shiner	Notropis cornutus	adult	15	17				20.2									2	Domanik and Zar 1978	1
15	Common Shiner	Notropis cornutus	adult	20	17				20.9									2	Domanik and Zar 1978	1
16	Common Shiner	Notropis cornutus	juvenile	15	17				20.8									2	Domanik and Zar 1978	1
17	Common Shiner	Notropis cornutus	juenile adult	N=8	18				18									1	Barila et al. 1982	1
18	Common Shiner	Notropis cornutus	juvenile adult	5	20									31					Hart 1947	1
19	Common Shiner	Notropis cornutus	juenile adult	N=8	24	33			23									1	Barila et al. 1982	1
20	Common Shiner	Notropis cornutus	juvenile adult	5	25									31	31				Hart 1947	1
21	Common Shiner	Notropis cornutus	juvenile	(N=24 in 4 groups)	25.5									32				5	Brett 1944	1
22	Common Shiner	Notropis cornutus		18	26											35.7	2 C/hr		Smale and Rabeni 1995	1
23	Common Shiner	Notropis cornutus	juenile adult	N=8	30	33			24									1	Barila et al. 1982	1
24																				
25					**minimum**	33.00			18.00					30.30	31.00	30.60				
26					**median**	**33.00**			**20.85**					**31.00**	**31.00**	**31.90**				
27					**maximum**	33.00			24.00					32.00	31.00	35.70				
28					**(n)**	2			6					4	1	4				

30		**Estimates of Factors**		**Calculation of Metrics**		**Notes on Calculation Methods**
31				DM2MOS	2.05	
32		Median CTM's	31.90	DM1MOS	**2.03**	MOS method 1: 20% rule with median UILT/UUILT and Preferred Average
33	2	Median CTM's-conversion	31.10	DM 2	29.05	
34	1	Median UILT/UUILT	31.00	**DM 1**	**28.97**	DM method 1: Median UILT/UUILT - MOS
35	1	Optimum Temperature for 1/3 Rule	no data	MWAT 1	no data	
36	2	Pref Ave for 1/3 Rule	20.85	**MWAT 2**	**24.1995**	MWAT method 2: 1/3 rule with Preferred Average
37	3	Avoided High for 1/3 Rule	33.00	MWAT 3	32.34	33 was chosen as Avoided High because the acclimation temperature (24) was
38	4	Upper Optimum	no data	MWAT 4	no data	closest to the other known temperature optimum metrics

39	
40	Notes: data not used
41	1= acclimation too low- below 15
42	2= acclimation too high- above 30 or higher than min CTM
43	3= lifestage = embryo/larvae
44	4= field study

[1] Preference is estimated to nearest 1°C from the midpoint of eight points at each temperature on Figure 1. Avoidance temperatures reported should be regarded with skepticism, as the sample is small, and the test is designed to assess preference, not avoidance.

[2] Values are reported for the untreated control group of 2-year-old fish only, obtained from Figure 2.

[3] Fish were collected and tested in winter.

[4] Fish were collected and tested in spring.

[5] No lab acclimation; the acclimation temperature is the median of the range reported during the collection period (Jul 29) for Lake Opeongo (25-26°C

1	Common Name	Scientific Name	Life stage	Replicates/Sample Size	Acclimation Temperature	Avoid high	Avoid low	Pref high	Pref ave	Pref low	Lower Optimum	Optimum	Upper Optimum	UILT	UUILT	CTM	Rate of Increase (CTM)	Other Notes	Complete Reference	Lab (y/n)
2	creek chub	Semotilus atromaculatus	adult	27														1	Taniguchi et al. 1998	0
3	creek chub	Semotilus atromaculatus	juvenile a	5	5									24.7					Hart 1947	1
4	creek chub	Semotilus atromaculatus	juvenile a	5	10									27.3					Hart 1947	1
5	creek chub	Semotilus atromaculatus	juvenile	(N=30 in 3 groups)	10									28.2				2	Brett 1944	1
6	creek chub	Semotilus atromaculatus	juvenile	(N=40 in 4 groups)	14									30				2	Brett 1944	1
7	creek chub	Semotilus atromaculatus	juvenile	(N=28 in 4 groups)	14.5									30.3				2	Brett 1944	1
8	creek chub	Semotilus atromaculatus	juvenile a	5	15									29.3					Hart 1947	1
9	creek chub	Semotilus atromaculatus	juvenile	(N=34 in 4 groups)	15									29.9				2	Brett 1944	1
10	creek chub	Semotilus atromaculatus	juvenile	(N=45 in 4 groups)	17									30.6				2	Brett 1944	1
11	creek chub	Semotilus atromaculatus	juvenile	(N=25 in 4 groups)	17.5									31				2	Brett 1944	1
12	creek chub	Semotilus atromaculatus	juvenile a	5	20									30.3					Hart 1947	1
13	creek chub	Semotilus atromaculatus	juvenile	(N=40 in 4 groups)	20									32				2	Brett 1944	1
14	creek chub	Semotilus atromaculatus	juvenile	(N=40 in 4 groups)	21									31.8				2	Brett 1944	1
15	creek chub	Semotilus atromaculatus	juvenile	(N=29 in 3 groups)	22									32.6				2	Brett 1944	1
16	creek chub	Semotilus atromaculatus	juvenile a	5	25										30.3				Hart 1947	1
17	creek chub	Semotilus atromaculatus		9	26											35.7	2 C/hr		Smale and Rabeni 1995	1
18	creek chub	Semotilus atromaculatus		N=24	see notes											32.5	4 C/hr.	3	McFarland et al. 1976	1
19																				
20					**minimum**									29.30	30.30	32.50				
21					**median**									**30.80**	**30.30**	**34.10**				
22					**maximum**									32.60	30.30	35.70				
23					**(n)**									8	1	2				
25																				
26					**Estimates of Factors**						**Calculation of Metrics**			**Notes on Calculation Methods**						
27											DM2MOS	2								
28					Median CTM's				34.10		DM1MOS	**2**		MOS method 2: default = 2						
29					2 Median CTM's-conversion				33.30		DM 2	31.30								
30					1 Median UILT/UUILT				30.60		**DM 1**	**28.60**		DM method 1: Median UILT/UUILT - MOS						
31					1 Optimum Temperature for 1/3 Rule				no data		MWAT 1	no data		Cannot calculate MWAT; no optimal data						
32					2 Pref Ave for 1/3 Rule				no data		MWAT 2	no data								
33					3 Avoided High for 1/3 Rule				no data		MWAT 3	no data								
34					4 Upper Optimum				no data		MWAT 4	no data								
35																				
36				Notes: data not used																
37					1= acclimation too low- below 15															
38					2= acclimation too high- above 30 or higher than min CTM															
39					3= lifestage = embryo/larvae															
40					4= field study															

[1] Value is reported for the occupied temperature in the field is the modal maximum daily temperature where fish were observed.

[2] No lab acclimation; acclimation temperature is estimated from Figure 4 as equal to the approximate average lake temperature at the time of fish collection (May 12).

[3] Fish were tested soon after capture at ambient stream temps.

1	Common Name	Scientific Name	Life stage	Replicates/Sample Size	Acclimation Temperature	Avoid high	Avoid low	Pref high	Pref ave	Pref low	Lower Optimum	Optimum	Upper Optimum	UILT	UUILT	CTM	Rate of Increase (CTM)	Other Notes	Complete Reference	Lab (y/n)
2	Cutthroat Trout	Oncorhynchus clarkii	juvenile	2/N=60(n=10)	see notes									26				1	Golden 1978	1
3	Cutthroat Trout	Oncorhynchus clarkii	adults	87 sites (presence/absence)														2	Dunham et al. 2003	0
4	Cutthroat Trout	Oncorhynchus clarkii	adult	n=33	10											28	0.2 C/min		De Staso and Rahel 1994	1
5	Cutthroat Trout	Oncorhynchus clarkii	juvenile	2/n=5	10											27.9	0.125 C/n	3	Golden 1978	1
6	Cutthroat Trout	Oncorhynchus clarkii	juvenile	2/n=5	10											28.2	0.125 C/n	4	Golden 1978	1
7	Cutthroat Trout	Oncorhynchus clarkii	juvenile	2/n=5	10											27.5	0.125 C/n	5	Golden 1978	1
8	Cutthroat Trout	Oncorhynchus clarkii	juvenile	2/n=5	10											28.1	0.125 C/n	6	Golden 1978	1
9	Cutthroat Trout	Oncorhynchus clarkii		N=140 (n=20)	13									25.5			4 C/day	7	Dickerson and Vinyard 1999	1
10	Cutthroat Trout	Oncorhynchus clarkii	juvenile	N=10	13.6											27.9	0.2 C/min	8	Wagner et al. 2001	1
11	Cutthroat Trout	Oncorhynchus clarkii	juvenile	N=10	13.6											28.6	0.2 C/min	8	Wagner et al. 2001	1
12	Cutthroat Trout	Oncorhynchus clarkii	juvenile	N=10	13.6											28.3	0.2 C/min	8	Wagner et al. 2001	1
13	Cutthroat Trout	Oncorhynchus clarkii	juvenile	N=10	13.6											28.7	0.2 C/min	8	Wagner et al. 2001	1
14	Cutthroat Trout	Oncorhynchus clarkii	juvenile	N=10	13.6											28.2	0.2 C/min	9	Wagner et al. 2001	1
15	Cutthroat Trout	Oncorhynchus clarkii	juvenile	N=10	13.6											28.6	0.2 C/min	9	Wagner et al. 2001	1
16	Cutthroat Trout	Oncorhynchus clarkii	juvenile	N=10	13.6											28.1	0.2 C/min	10	Wagner et al. 2001	1
17	Cutthroat Trout	Oncorhynchus clarkii	juvenile	N=10	13.6											28.6	0.2 C/min	10	Wagner et al. 2001	1
18	Cutthroat Trout	Oncorhynchus clarkii	juvenile	2/n=5	15											28.9	0.125 C/n	11	Golden 1978	1
19	Cutthroat Trout	Oncorhynchus clarkii	juvenile	2/n=5	15											29.3	0.125 C/n	4	Golden 1978	1
20	Cutthroat Trout	Oncorhynchus clarkii	juvenile	2/n=5	15											28.5	0.125 C/n	12	Golden 1978	1
21	Cutthroat Trout	Oncorhynchus clarkii	juvenile	2/n=5	15											29.2	0.125 C/n	6	Golden 1978	1
22	Cutthroat Trout	Oncorhynchus clarkii	juvenile	N=10	18											29.7	0.2 C/min	8	Wagner et al. 2001	1
23	Cutthroat Trout	Oncorhynchus clarkii	juvenile	N=10	18											30	0.2 C/min	8	Wagner et al. 2001	1
24	Cutthroat Trout	Oncorhynchus clarkii	juvenile	N=10	18											29.5	0.2 C/min	8	Wagner et al. 2001	1
25	Cutthroat Trout	Oncorhynchus clarkii	juvenile	N=10	18											29.7	0.2 C/min	8	Wagner et al. 2001	1
26	Cutthroat Trout	Oncorhynchus clarkii	juvenile	N=10	18											29.4	0.2 C/min	9	Wagner et al. 2001	1
27	Cutthroat Trout	Oncorhynchus clarkii	juvenile	N=10	18											29.6	0.2 C/min	9	Wagner et al. 2001	1
28	Cutthroat Trout	Oncorhynchus clarkii	juvenile	N=10	18											29.5	0.2 C/min	10	Wagner et al. 2001	1
29	Cutthroat Trout	Oncorhynchus clarkii	juvenile	N=10	18											29.7	0.2 C/min	10	Wagner et al. 2001	1
30	Cutthroat Trout	Oncorhynchus clarkii	adult	9/n=6-10	18									24.2			1-2 C/min	13	Johnstone and Rahel 2003	1
31	Cutthroat Trout	Oncorhynchus clarkii	juvenile	2/n=5	20											29.9	0.125 C/n	11	Golden 1978	1
32	Cutthroat Trout	Oncorhynchus clarkii	juvenile	2/n=5	20											30.4	0.125 C/n	4	Golden 1978	1
33	Cutthroat Trout	Oncorhynchus clarkii	juvenile	2/n=5	20											29.5	0.125 C/n	12	Golden 1978	1
34	Cutthroat Trout	Oncorhynchus clarkii	juvenile	2/n=5	20											30.2	0.125 C/n	6	Golden 1978	1
35	Cutthroat Trout	Oncorhynchus clarkii	juvenile	2/n=5	23											30.5	0.125 C/n	11	Golden 1978	1
36	Cutthroat Trout	Oncorhynchus clarkii	juvenile	2/n=5	23											31	0.125 C/n	4	Golden 1978	1
37	Cutthroat Trout	Oncorhynchus clarkii	juvenile	2/n=5	23											30.1	0.125 C/n	11	Golden 1978	1
38	Cutthroat Trout	Oncorhynchus clarkii	juvenile	2/n=5	23											30.8	0.125 C/n	6	Golden 1978	1
39	Cutthroat Trout	Oncorhynchus clarkii	juvenile	2/N=60(n=10)	23									25.5				14	Golden 1978	1
40	Cutthroat Trout	Oncorhynchus clarkii	juvenile	N=140 (n=10-20 per treatment)	20 fish@12.5C, 30@13.6C, 40@									23.9				8	Wagner et al. 2001	1
41	Cutthroat Trout	Oncorhynchus clarkii	juvenile	N=140 (n=10-20 per treatment)	20 fish@12.5C, 30@13.6C, 40@									24.3				8	Wagner et al. 2001	1
42	Cutthroat Trout	Oncorhynchus clarkii	juvenile	N=140 (n=10-20 per treatment)	20 fish@12.5C, 30@13.6C, 40@									23.5				9	Wagner et al. 2001	1
43	Cutthroat Trout	Oncorhynchus clarkii	juvenile	N=140 (n=10-20 per treatment)	20 fish@12.5C, 30@13.6C, 40@									24				10	Wagner et al. 2001	1
44	Cutthroat Trout	Oncorhynchus clarkii	juvenile	3/ n=50 per tank											19.6			15	Bear 2005	1
45	Cutthroat Trout	Oncorhynchus clarkii	juvenile								10.3	13.6	17					16	Bear 2005	1
46	Cutthroat Trout	Oncorhynchus clarkii	juvenile	3/ n=50 per tank											24.1			15	Bear 2005	1
47	Cutthroat Trout	Oncorhynchus clarkii	juvenile	N=110/n=22(avg)								15						17	Dwyer and Kramer 1975	1
48	Cutthroat Trout	Oncorhynchus clarkii	juvenile	4 replicates/n=80/treatment								16.4						18	Brandt 2009	1
49	Cutthroat Trout	Oncorhynchus clarkii	juvenile	5 replicates/n=80/treatment								15.3						18	Brandt 2009	1
50																				
51					**minimum**						10.30	13.60	17.00	23.50	19.60	27.50				
52					**median**						**10.30**	**15.15**	**17.00**	**24.20**	**21.85**	**29.30**				
53					**maximum**						10.30	16.40	17.00	25.50	24.10	31.00				
54					**(n)**						1	4	1	7	2	33				

57			Estimates of Factors		Calculation of Metrics		Notes on Calculation Methods
58					DM2MOS	2.67	
59			Median CTM's	29.30	DM1MOS	**1.79**	MOS method 1: 20% rule with median UILT/UUILT and Optimum Temperature
60		2	Median CTM's-conversion	28.50	DM 2	25.83	
61		1	Median UILT/UUILT	24.10	**DM 1**	**22.31**	DM method 1: Median UILT/UUILT - MOS
62		1	Optimum Temperature for 1/3 Rule	15.15	**MWAT 1**	**18.1035**	MWAT method 1: 1/3 rule with Optimum Temperature
63		2	Pref Ave for 1/3 Rule	no data	MWAT 2	no data	
64		3	Avoided High for 1/3 Rule	no data	MWAT 3	no data	
65		4	Upper Optimum	17.00	MWAT 4	17.00	
66							
67	Notes: data not used						
68			1= acclimation too low- below 7				
69			2= acclimation too high- above 23 or higher than min CTM				
70			3= lifestage = embryo/larvae				
71			4= field study				

[1] Coastal cutthroat subspecies; acclimated to diel cycle (13-25°C).

[2] Lahontan subspecies; warm-adapted desert strain. Maximum occupied indicates the maximum daily temperature at the warmest site where trout were observed in the field. Trout were observed at the coldest daily maximum stream temperatures included in the study, so a minimum cannot be established.

[3] Coastal cutthroat subspecies. Constant increasing acclimation: three weeks at 10°C in the laboratory. CTM was calculated at acclimation temperatures from reported regression equations.

[4] Coastal cutthroat subspecies. Constant decreasing acclimation of 1.85°C per week from 23°C to 10°C in steps of approximately 2.5°C. CTM was calculated at acclimation temperatures from reported regression equations.

[5] Coastal cutthroat subspecies. Variable increasing acclimation: three weeks at 10°C with diel fluctuations in the laboratory. CTM was calculated at acclimation temperatures from reported regression equations.

[6] Coastal cutthroat subspecies. Variable decreasing acclimation of 1.85°C per week from 23°C to 10°C in steps of approximately 2.5°C. CTM was calculated at acclimation temperatures from reported regression equations.

[7] UILT reported in the database is the median of the likely range of temperatures encompassing 50% response over 7-days (25-26°C).

[8] Bonneville subspecies.

[9] Snake River subspecies.

[10] Yellowstone subspecies.

[11] Coastal cutthroat subspecies. Constant increasing acclimation of 1.85°C per week from 10°C to 15°C in steps of approximately 2.5°C. CTM was calculated at acclimation temperatures from reported regression equations.

[12] Coastal cutthroat subspecies. Variable increasing acclimation of 1.85°C per week from 10°C to 15°C in steps of approximately 2.5°C. CTM was calculated at acclimation temperatures from reported regression equations.

[13] Bonneville subspecies. Gradual temperature increase was used to avoid the shock of standard UILT testing. The paper also contains test of tolerance to a cycling temperature regime that exceeds UILT.

[14] Coastal cutthroat subspecies. Constant 23°C acclimation.

[15] Nonstandard UUILT method: some disease occurred and was treated, which is a common occurrence in warm treatments of longer lab studies, where disease rates can increase with thermal stress.

[16] Optimum range was based on the lack of significant different from the 95% confidence interval of the regression line at the optimum.

[17] Wide gap between temperature treatments may have resulted in low precision and accuracy in estimating optima.

[18] Colorado River subspecies. Fish were fed Skettering/Bio-Vita Fry feed (higher energy content, fat, and protein). 10°C treatment was terminated at 175 days.

1	Common name	Scientific name	Life stage	Replicates/Sample Size	Acclimation Temperature	Avoid high	Avoid low	Pref high	Pref ave	Pref low	Lower Optimum	Optimum	Upper Optimum	UILT	UUILT	CTM	Rate of Increase (CTM)	Spawning Info	Other Notes	Complete Reference	Lab (y/n)
2	Emerald Shiner	Notropis atherinoides			5									23.2						Brett 1956	1
3	Emerald Shiner	Notropis atherinoides			10									26.7						Brett 1956	1
4	Emerald Shiner	Notropis atherinoides			15									28.9						Brett 1956	1
5	Emerald Shiner	Notropis atherinoides			20									30.7						Brett 1956	1
6	Emerald Shiner	Notropis atherinoides			25									30.7						Brett 1956	1
7	Emerald Shiner	Notropis atherinoides	yoy											35.2						McCormick and Kleiner 1976	1
8	Emerald Shiner	Notropis atherinoides	yoy						22-23										1	Reutter and Herdendorf 1976	1
9	Emerald Shiner	Notropis atherinoides	adult						22-24										1	Reutter and Herdendorf 1976	1
10	Emerald Shiner	Notropis atherinoides	adult		7.8				8.3							28.6			2	Reutter and Herdendorf 1976	1
11	Emerald Shiner	Notropis atherinoides	yoy									27							3	McCormick and Kleiner 1976	1
12	Emerald Shiner	Notropis atherinoides							27.8 / 25.1										4	McCormick and Kleiner 1976	1
13	Emerald Shiner	Notropis atherinoides														34.3				Ellis 1984	1
14	Emerald Shiner	Notropis atherinoides												35.2						Ellis 1984	1
15	Emerald Shiner	Notropis atherinoides			5									23						Carlander 1969	1
16	Emerald Shiner	Notropis atherinoides			10									27						Carlander 1969	1
17	Emerald Shiner	Notropis atherinoides			15									28.9						Carlander 1969	1
18	Emerald Shiner	Notropis atherinoides			20									31						Carlander 1969	1
19	Emerald Shiner	Notropis atherinoides													30.7					Carlander 1969	1
20	Emerald Shiner	Notropis atherinoides												27-28						Brown 1974	1
21	Emerald Shiner	Notropis atherinoides	yoy											35.2		34.3				Talmage 1978	1
22	Emerald Shiner	Notropis atherinoides			20-25									32.6						Talmage 1978	1
23	Emerald Shiner	Notropis atherinoides				>31.1														Brown 1974	1
24	Emerald Shiner	Notropis atherinoides				42	6													Ellis 1984	1
25	Emerald Shiner	Notropis atherinoides							25											Brown 1974	1
26	Emerald Shiner	Notropis atherinoides							25										1	EPA 1974	1
27	Emerald Shiner	Notropis atherinoides							27										2	EPA 1974	1
28	Emerald Shiner	Notropis atherinoides										26.45							3	McCormick and Kleiner 1976	1
29	Emerald Shiner	Notropis atherinoides	yoy								21								5	Carlander 1969	1
30	Emerald Shiner	Notropis atherinoides	juvenile									29							6	Brown 1974	1
31	Emerald Shiner	Notropis atherinoides											30						7	EPA 1974	1
32	Emerald Shiner	Notropis atherinoides											31						8	EPA 1974	1
33	Emerald Shiner	Notropis atherinoides	yoy								<19	28.9	29						9	Talmage 1978	1
34	Emerald Shiner	Notropis atherinoides																24	10	Scott and Crossman 1973	1
35	Emerald Shiner	Notropis atherinoides																20-27	11	Brown 1974	1
36	Emerald Shiner	Notropis atherinoides																23.9	12	Brown 1974	1
37	Emerald Shiner	Notropis atherinoides																23	13	EPA 1974	1
38	Emerald Shiner	Notropis atherinoides																27	14	EPA 1974	1
39	Emerald Shiner	Notropis atherinoides	adult	10	25											37.6	1C/min		15	Beitinger et al. 2000	1
40	Emerald Shiner	Notropis atherinoides		8	10											34.1	1C/min		15	Beitinger et al. 2000	1
41	Emerald Shiner	Notropis atherinoides		8	10											30.1	1C/min		15	Beitinger et al. 2000	1
42																					
43					**minimum**	42.00	6.00		8.30		21.00	26.45	29.00	23.00	30.70	28.60					
44					**median**	**42.00**	**6.00**		**25.00**		**21.00**	**27.95**	**30.00**	**30.70**	**30.70**	**34.20**					
45					**maximum**	42.00	6.00		27.00		21.00	29.00	31.00	35.20	30.70	37.60					
46					**(n)**	1	1		4		1	4	3	13	1	6					

49			Estimates of Factors			Calculation of Metrics	Notes on Calculation Methods
50					DM2MOS	1.09	
51			Median CTM's	34.20	DM1MOS	**0.55**	MOS method 1: 20% rule with median UILT/UUILT and Optimum Temperature
52		2	Median CTM's-conversion	33.40	DM 2	32.31	
53		1	Median UILT/UUILT	30.70	**DM 1**	**30.15**	DM method 1: Median UILT/UUILT - MOS
54		1	Optimum Temperature for 1/3 Rule	27.95	**MWAT 1**	**28.8575**	MWAT method 1: 1/3 rule with Optimum Temperature
55		2	Pref Ave for 1/3 Rule	25.00	MWAT 2	26.881	
56		3	Avoided High for 1/3 Rule	42.00	MWAT 3	38.271	Median was used for Avoided High becauseacclimation temperatures were not known
57		4	Upper Optimum	30.00	MWAT 4	30.00	
58							
59		Notes:	data not used				
60			1= acclimation too low- below 15				
61			2= acclimation too high- above 30 or higher than min CTM				
62			3= lifestage = embryo/larvae				
63			4= field study				

[1] Preferred average in summer.
[2] Preferred average in winter.
[3] Optimum growth temperature.
[4] Listed as 'final preference' in Jobling article (secondary source).
[5] Lower optimum is the lower limit of growth.
[6] Also listed the range of temperatures over which growth is known to occur (24-31°C).
[7] Optimum is the growth MWAT (maximum weekly average temperature for growth).
[8] Optimum is the maximum temperature for short-term exposure during the growth season to protect against lethal effects.
[9] Also listed the range of temperatures over which growth is known to occur (19-29°C).
[10] Optimum for spawning.
[11] Range of spawning temperatures.
[12] 24-hour optimum for hatching.
[13] MWAT for peak spawning.
[14] 24-hour maximum for embryo survival.
[15] CTM endpoint is the onset of muscle spasms.

1	Common Name	Scientific Name	Life stage	Replicates/Sample Size	Acclimation Temperature	Avoid high	Avoid low	Pref high	Pref ave	Pref low	Lower Optimum	Optimum	Upper Optimum	UILT	UUILT	CTM	Rate of Increase (CTM)	Other Notes	Complete Reference	Lab (y/n)
2	Fathead Minnow	Pimephales promelas	adult	N=5	4				8									1	Jones and Irwin 1965	1
3	Fathead Minnow	Pimephales promelas	adult	2/n=9-10	5											28.6	0.3 C/min	2	Richards and Beitinger 1995	1
4	Fathead Minnow	Pimephales promelas	adult	n=10(N=144)	6									27				3	Jensen 1972	1
5	Fathead Minnow	Pimephales promelas	adult	n=10(N=144)	6									26.14				3	Jensen 1972	1
6	Fathead Minnow	Pimephales promelas	adult	n=10(N=144)	6									27.05				3	Jensen 1972	1
7	Fathead Minnow	Pimephales promelas	adult	n=10(N=144)	6									26.78				3	Jensen 1972	1
8	Fathead Minnow	Pimephales promelas	adult	n=10(N=144)	6									26.64				3	Jensen 1972	1
9	Fathead Minnow	Pimephales promelas	juvenile adult	3/n=5	10				24									4	Opuszynski 1971	1
10	Fathead Minnow	Pimephales promelas	juvenile adult	5	10									28.2					Hart 1947	1
11	Fathead Minnow	Pimephales promelas	adult	N=5	10				18									5	Jones and Irwin 1965	1
12	Fathead Minnow	Pimephales promelas	juvenile	2/n=8(N=16)	12				19.8									6	Cherry et al. 1975	1
13	Fathead Minnow	Pimephales promelas	juvenile adult	4/n=2(N=8)	12	22	10											6	Cherry et al. 1975	1
14	Fathead Minnow	Pimephales promelas	adult	2/n=9-10	12											30.7	0.3 C/min	7	Richards and Beitinger 1995	1
15	Fathead Minnow	Pimephales promelas	juvenile	(N=65 in 4 groups)	10									29				8	Brett 1944	1
16	Fathead Minnow	Pimephales promelas	juvenile	(N=27 in 3 groups)	14.5									30.1				9	Brett 1944	1
17	Fathead Minnow	Pimephales promelas	juvenile	(N=96 in 6 groups)	15									31.6				10	Brett 1944	1
18	Fathead Minnow	Pimephales promelas	adult	2/n=9-10	32											40.4	0.3 C/min	7	Richards and Beitinger 1995	1
19	Fathead Minnow	Pimephales promelas	adult	N=5	15				24									11	Jones and Irwin 1965	1
20	Fathead Minnow	Pimephales promelas	adult	N=5	22				20									12	Jones and Irwin 1965	1
21	Fathead Minnow	Pimephales promelas	adult	N=5	30				24									13	Jones and Irwin 1965	1
22	Fathead Minnow	Pimephales promelas	juvenile adult	2/n=8(N=16)	15				21.3									6	Cherry et al. 1975	1
23	Fathead Minnow	Pimephales promelas	juvenile adult	4/n=2(N=8)	15	25	14											6	Cherry et al. 1975	1
24	Fathead Minnow	Pimephales promelas	juvenile adult	3/n=5	15				26.3									4	Opuszynski 1971	1
25	Fathead Minnow	Pimephales promelas	adult	79	15											33.2	1 C/min	14	Maness and Hutchinson 1980	1
26	Fathead Minnow	Pimephales promelas	juvenile adult	2/n=8(N=16)	18				22.1									6	Cherry et al. 1975	1
27	Fathead Minnow	Pimephales promelas	juvenile adult	4/n=2(N=8)	18	26	16											6	Cherry et al. 1975	1
28	Fathead Minnow	Pimephales promelas	juvenile adult	3/n=5	20				27.3									4	Opuszynski 1971	1
29	Fathead Minnow	Pimephales promelas	adult	10/n=5	20											33.1	0.3 C/min		Castleberry and Cech 1992	1
30	Fathead Minnow	Pimephales promelas	juvenile adult	5	20									31.7					Hart 1947	1
31	Fathead Minnow	Pimephales promelas	juvenile adult	2/n=8(N=16)	21				23.8									6	Cherry et al. 1975	1
32	Fathead Minnow	Pimephales promelas	juvenile adult	4/n=2(N=8)	21	28	18											6	Cherry et al. 1975	1
33	Fathead Minnow	Pimephales promelas	adult	20	21											35.12	0.3 C/min	16	Watenpaugh et al. 1985	1
34	Fathead Minnow	Pimephales promelas	adult	2/n=9-10	22											36.4	0.3 C/min	7	Richards and Beitinger 1995	1
35	Fathead Minnow	Pimephales promelas	juvenile adult	2/n=8(N=16)	24				26.6									6	Cherry et al. 1975	1
36	Fathead Minnow	Pimephales promelas	juvenile adult	4/n=2(N=8)	24	30	23											6	Cherry et al. 1975	1
37	Fathead Minnow	Pimephales promelas	adult	13	24											36.8	0.3 C/min	17	Pyron and Beitinger 1993	1
38	Fathead Minnow	Pimephales promelas	adult	18	24											36.9	0.3 C/min	18	Pyron and Beitinger 1993	1
39	Fathead Minnow	Pimephales promelas	adult	13	24											36.7	0.3 C/min	19	Pyron and Beitinger 1993	1
40	Fathead Minnow	Pimephales promelas	adult	12	24											36.2	0.3 C/min	20	Pyron and Beitinger 1993	1
41	Fathead Minnow	Pimephales promelas	adult	3/n=4	25											36.1	0.3 C/min	21	Carveth et al. 2006	1
42	Fathead Minnow	Pimephales promelas	adult	3/n=4	25											36.9	0.3 C/min	21	Carveth et al. 2006	1
43	Fathead Minnow	Pimephales promelas	juvenile adult	2/n=5	25				28									4	Opuszynski 1971	1
44	Fathead Minnow	Pimephales promelas		8	26											36.5	2 C/hr		Smale and Rabeni 1995	1
45	Fathead Minnow	Pimephales promelas	juvenile adult	2/n=8(N=16)	27				28.9									6	Cherry et al. 1975	1
46	Fathead Minnow	Pimephales promelas	juvenile adult	4/n=2(N=8)	27	32	25											6	Cherry et al. 1975	1
47	Fathead Minnow	Pimephales promelas	juvenile adult	2/n=5	30				28.5									4	Opuszynski 1971	1
48	Fathead Minnow	Pimephales promelas	juvenile adult	5	30									33.2					Hart 1947	1
49	Fathead Minnow	Pimephales promelas	juvenile	(N=76 in 4 groups)	17									31.3				22	Brett 1944	1
50	Fathead Minnow	Pimephales promelas	juvenile	(N=61 in 4 groups)	21									33.6				23	Brett 1944	1
51	Fathead Minnow	Pimephales promelas	juvenile	(N=87 in 5 groups)	20									34				24	Brett 1944	1
52	Fathead Minnow	Pimephales promelas	juvenile	(N=70 in 6 groups)	22									33.8				25	Brett 1944	1
53	Fathead Minnow	Pimephales promelas	juvenile	(N=24 in 2 groups)	17.5									30.8				26	Brett 1944	1

55						minimum	25.00	14.00		21.30					30.80		33.10			
56						median	**28.00**	**18.00**		**26.60**					**33.20**		**36.40**			
57						maximum	32.00	25.00		28.90					34.00		36.90			
58						(n)	5	5		9					7		11			
59																				
60																				
61						**Estimates of Factors**						**Calculation of Metrics**			**Notes on Calculation Methods**					
62												DM2MOS	1.8							
63						Median CTM's				36.40		DM1MOS	**1.32**		MOS method 1: 20% rule with median UILT/UUILT and Preferred Average					
64						2 Median CTM's-conversion				35.60		DM 2	33.80							
65						1 Median UILT/UUILT				33.20		**DM 1**	**31.88**		DM method 1: Median UILT/UUILT - MOS					
66						1 Optimum Temperature for 1/3 Rule				no data		MWAT 1	no data							
67						2 Pref Ave for 1/3 Rule				26.60		**MWAT 2**	**28.778**		MWAT method 2: 1/3 rule with Preferred Average					
68						3 Avoided High for 1/3 Rule				32.00		MWAT 3	32.396		32 was chosen as Avoided High because the acclimation temperature (27) was closest to					
69						4 Upper Optimum				no data		MWAT 4	no data		the other known temperature optimum metrics					
70																				
71					Notes: data not used															
72						1= acclimation too low- below 15														
73						2= acclimation too high- above 30 or higher than min CTM														
74						3= lifestage = embryo/larvae														
75						4= field study														

[1] Sample size is number of fish; many observations made on each fish, but the number of observations was not reported. The modes are reported here (mean = 8.8°C).

[2] Control group is reported here. Temperature was the only independent variable; copper treatment CTM values were excluded from the database.

[3] The methods adhere to UILT protocols, but the author does not refer to the tests as such. Fish were fasted one day before tests. Fish were held at approximately 6°C and then maintained in lab for 24-72 hours at 6°C before testing.

[4] The average of modal preferred temperatures is reported. Minimum treatment temperature is the lowest that the temperature apparatus could achieve. Range of gradient was 20°C for all tests; peak temperatures not specified. Copper sulfate treatment was conducted in a separate experiment.

[5] Sample size is number of fish; many observations made on each fish, but the number of observations was not reported. The modes are reported here (mean = 15.2°C).

[6] Fish were assumed to be adults. Fish were fasted for 2.5-3 days before being tested.

[7] Fish reported here are the control group, where temperature is the only independent variable; copper treatment CTM values are excluded from database.

[8] No lab acclimation; fish were acclimated to natural conditions in Lake Amikeus, which authors suggest are similar to those in Lake Opeongo at the time of collection (May 9).

[9] No lab acclimation; fish were acclimated to natural conditions in Lake Amikeus, which authors suggest are similar to those in Lake Opeongo at the time of collection (May 16).

[10] No lab acclimation; fish were acclimated to natural conditions in Lake Amikeus, which authors suggest are similar to those in Lake Opeongo at the time of collection (May 23).

[11] Sample size is number of fish; many observations made on each fish, but the number of observations was not reported. The modes are reported here (mean = 23.3°C).

[12] Sample size is number of fish; many observations made on each fish, but the number of observations was not reported. The modes are reported here (mean = 20.7°C).
[13] Sample size is number of fish; many observations made on each fish, but the number of observations was not reported. The modes are reported here (mean = 22.6°C).
[14] Fish were fasted one day prior to being tested. CTM values are estimated from Figure 2 for fish not previously exposed to CTM testing only.
[16] Fish were the control group in a study of Se exposure on CTM.
[17] Post-spawn females.
[18] Non-spawning females.
[19] Post-spawn males.
[20] Non-spawning males.
[21] Fish were 72-80 mm in length. Reported replicates and sample size are the minimum for all species tested.
[22] No lab acclimation; fish were acclimated to natural conditions in Lake Amikeus, which authors suggest are similar to those in Lake Opeongo at the time of collection (June 10).
[23] No lab acclimation; fish were acclimated to natural conditions in Lake Amikeus, which authors suggest are similar to those in Lake Opeongo at the time of collection (June 23).
[24] No lab acclimation; fish were acclimated to natural conditions in Lake Amikeus, which authors suggest are similar to those in Lake Opeongo at the time of collection (July 5).
[25] No lab acclimation; fish were acclimated to natural conditions in Lake Amikeus, which authors suggest are similar to those in Lake Opeongo at the time of collection (July 23).
[26] No lab acclimation; fish were acclimated to natural conditions in Lake Amikeus, which authors suggest are similar to those in Lake Opeongo at the time of collection (August 24).

1	Common name	Scientific name	Life stage	Replicates/Sample Size	Acclimation Temperature	Avoid high	Avoid low	Pref high	Pref ave	Pref low	Lower Optimum	Optimum	Upper Optimum	UILT	UUILT	CTM	Rate of Increase (CTM)	Other Notes	Complete Reference	Lab (y/n)
2	Finescale Dace	Phoxinus neogaeus	juvenile	(N=40 in 4 groups)	10, est., see notes									31.1				1	Brett 1944	1
3	Finescale Dace	Phoxinus neogaeus	juvenile	(N=51 in 4 groups)	12.5, est., see notes									30.7				2	Brett 1944	1
4	Finescale Dace	Phoxinus neogaeus	juvenile	(N=54 in 4 groups)	15, est., see notes									31.6				3	Brett 1944	1
5	Finescale Dace	Phoxinus neogaeus	juvenile	(N=26 in 3 groups)	17, est., see notes									31.4				4	Brett 1944	1
6	Finescale Dace	Phoxinus neogaeus	juvenile	(N=41 in 4 groups)	21, est., see notes									32				5	Brett 1944	1
7	Finescale Dace	Phoxinus neogaeus	juvenile	(N=42 in 3 groups)	20, est., see notes									32.2				6	Brett 1944	1
8	Finescale Dace	Phoxinus neogaeus	juvenile	(N=45 in 4 groups)	22, est., see notes									32.3				7	Brett 1944	1
9	Finescale Dace	Phoxinus neogaeus	juvenile	(N=37 in 4 groups)	17.5, est., see notes									31.2				8	Brett 1944	1
10																				
11																				
12																				
13					**minimum**									31.20						
14					**median**									**32.00**						
15					**maximum**									32.30						
16					**(n)**									5						
17																				
18																				
19					**Estimates of Factors**						**Calculation of Metrics**			**Notes on Calculation Methods**						
20											DM2MOS	no data								
21					Median CTM's				no data		DM1MOS	2		MOS method 2: default = 2						
22					2 Median CTM's-conversion				no data		DM 2	no data								
23					1 Median UILT/UUILT				32.00		**DM 1**	**30.00**		DM method 1: Median UILT/UUILT - MOS						
24					1 Optimum Temperature for 1/3 Rule				no data		MWAT 1	no data		Cannot calculate MWAT; no optimal data						
25					2 Pref Ave for 1/3 Rule				no data		MWAT 2	no data								
26					3 Avoided High for 1/3 Rule				no data		MWAT 3	no data								
27					4 Upper Optimum				no data		MWAT 4	no data								
28																				
29				Notes: data not used																
30					1= acclimation too low- below 15															
31					2= acclimation too high- above 30 or higher than min CTM															
32					3= lifestage = embryo/larvae															
33					4= field study															

[1] No lab acclimation; fish were acclimated to natural conditions in Lake Amikeus at the time of collection (May 9).

[2] No lab acclimation; fish were acclimated to natural conditions in Lake Amikeus at the time of collection (September 13).

[3] No lab acclimation; fish were acclimated to natural conditions in Lake Amikeus at the time of collection (May 23).

[4] No lab acclimation; fish were acclimated to natural conditions in Lake Amikeus at the time of collection (June 10).

[5] No lab acclimation; fish were acclimated to natural conditions in Lake Amikeus at the time of collection (June 23).

[6] No lab acclimation; fish were acclimated to natural conditions in Lake Amikeus at the time of of collection (July 5).

[7] No lab acclimation; fish were acclimated to natural conditions in Lake Amikeus at the time of collection (July 23).

[8] No lab acclimation; fish were acclimated to natural conditions in Lake Amikeus at the time of collection (August 24).

1	Common Name	Scientific Name	Life stage	Replicates/Sample Size	Acclimation Temperature	Avoid high	Avoid low	Pref high	Pref ave	Pref low	Lower Optimum	Optimum	Upper Optimum	UILT	UUILT	CTM	Rate of Increase (CTM)	Spawning info	Other Notes	Complete Reference	Lab (y/n)
2	Flannelmouth Sucker	Catostomus latipinnis	larval									20-21								Lamarra 2007	1
3	Flannelmouth Sucker	Catostomus latipinnis		3	10				14							31.2	0.24C/min		endpoint is loss of equilibrium	Lamarra 2007	1
4	Flannelmouth Sucker	Catostomus latipinnis		6	25				26							36.9	0.24C/min		endpoint is loss of equilibrium	Lamarra 2007	1
5	Flannelmouth Sucker	Catostomus latipinnis	juvenile									20.5								Lamarra 2007	1
6	Flannelmouth Sucker	Catostomus latipinnis	adult									25								Lamarra 2007	1
7	Flannelmouth Sucker	Catostomus latipinnis							25											Rees et al. 2005b	1
8																					
9					**minimum**				14.00			20.50				31.20					
10					**median**				**25.00**			**22.75**				**34.05**					
11					**maximum**				26.00			25.00				36.90					
12					**(n)**				3			2				2					
13																					
14					**Estimates of Factors**						**Calculation of Metrics**			**Notes on Calculation Methods**							
15											DM2MOS	**2.1**		MOS method 1: 20% rule with converted CTM and Optimum Temperature							
16					Median CTM's				34.05		DM1MOS	no data									
17				2	Median CTM's-conversion				33.25		**DM 2**	**31.15**		DM method 2: Converted CTM - MOS							
18				1	Median UILT/UUILT				no data		DM 1	no data									
19				1	Optimum Temperature for 1/3 Rule				22.75		**MWAT 1**	**26.215**		MWAT method 1: 1/3 rule with Optimum Temperature							
20				2	Pref Ave for 1/3 Rule				25.00		MWAT 2	27.7225									
21				3	Avoided High for 1/3 Rule				no data		MWAT 3	no data									
22				4	Upper Optimum				no data		MWAT 4	no data									
23																					
24				Notes:	data not used																
25					1= acclimation too low- below 15																
26					2= acclimation too high- above 30 or higher than min CTM																
27					3= lifestage = embryo/larvae																
28					4= field study																
29																					

1	Common name	Scientific name	Life stage	Replicates/Sample Size	Acclimation Temperature	Avoid high	Avoid low	Pref high	Pref ave	Pref low	Lower Optimum	Optimum	Upper Optimum	UILT	UUILT	CTM	Rate of Increase (CTM)	Other Notes	Complete Reference	Lab (y/n)
2	Flathead Catfish	Pylodictis olivaris	see notes	see notes														Summer captures	Yoder and Gammon 1976	0
3	Flathead Catfish	Pylodictis olivaris	see notes	see notes														Fall captures	Yoder and Gammon 1976	0
4																				
5					**minimum**															
6					**median**															
7					**maximum**															
8					**(n)**															
9																				
10					**Estimates of Factors**						**Calculation of Metrics**			**Notes on Calculation Methods**						
11											DM2MOS	no data								
12					Median CTM's				no data		DM1MOS		**2**	MOS method 2: default = 2						
13				2	Median CTM's-conversion				no data		DM 2	no data								
14				1	Median UILT/UUILT				no data		DM 1	no data		Cannot calculate DM; no lethal data						
15				1	Optimum Temperature for 1/3 Rule				no data		MWAT 1	no data		Cannot calculate MWAT; no optimal data						
16				2	Pref Ave for 1/3 Rule				no data		MWAT 2	no data								
17				3	Avoided High for 1/3 Rule				no data		MWAT 3	no data								
18				4	Upper Optimum				no data		MWAT 4	no data								
19																				
20				Notes:	data not used															
21					1= acclimation too low- below 15															
22					2= acclimation too high- above 30 or higher than min CTM															
23					3= lifestage = embryo/larvae															
24					4= field study															

1	Common Name	Scientific Name	Life stage	Replicates/Sample Size	Acclimation Temperature	Avoid high	Avoid low	Pref high	Pref ave	Pref low	Lower Optimum	Optimum	Upper Optimum	UILT	UUILT	CTM	Rate of Increase (CTM)	Other Notes	Complete Reference	Lab (y/n)
2	Flathead Chub	Platygobio gracilis																		
3																				
4																				
5					**minimum**															
6					**median**															
7					**maximum**															
8					**(n)**															
9																				
10																				
11					**Estimates of Factors**						**Calculation of Metrics**			**Notes on Calculation Methods**						
12											DM2MOS	no data								
13					Median CTM's				no data		DM1MOS	2		MOS method 2: default = 2						
14				2	Median CTM's-conversion				no data		DM 2	no data								
15				1	Median UILT/UUILT				no data		DM 1	no data		Cannot calculate DM; no lethal data						
16				1	Optimum Temperature for 1/3 Rule				no data		MWAT 1	no data		Cannot calculate MWAT; no optimal data						
17				2	Pref Ave for 1/3 Rule				no data		MWAT 2	no data								
18				3	Avoided High for 1/3 Rule				no data		MWAT 3	no data								
19				4	Upper Optimum				no data		MWAT 4	no data								
20																				
21				Notes:	data not used															
22					1= acclimation too low- below 15															
23					2= acclimation too high- above 30 or higher than min CTM															
24					3= lifestage = embryo/larvae															
25					4= field study															

1	Common Name	Scientific Name	Life stage	Replicates/Sample Size	Acclimation Temperature	Avoid high	Avoid low	Pref high	Pref ave	Pref low	Lower Optimum	Optimum	Upper Optimum	UILT	UUILT	CTM	Rate of Increase (CTM)	Other Notes	Complete Reference	Lab (y/n)
2	Freshwater Drum	Aplodinotus grunniens		see notes														Fall captures	Yoder and Gammon 1976	0
3	Freshwater Drum	Aplodinotus grunniens	adult		21.2				26.5							34		Summer	Reutter and Herdendorf 1976	1
4	Freshwater Drum	Aplodinotus grunniens	yoy	300-400 fish										32.8			2-4 deg C	Summer	Cvancara et al. 1976	1
5	Freshwater Drum	Aplodinotus grunniens	yoy						31.3									Summer	Reutter and Herdendorf 1976	1
6																				
7					**minimum**				26.50					32.80		34.00				
8					**median**				**28.90**					**32.80**		**34.00**				
9					**maximum**				31.30					32.80		34.00				
10					**(n)**				2					1		1				
11																				
12					**Estimates of Factors**						**Calculation of Metrics**			**Notes on Calculation Methods**						
13											DM2MOS	0.86								
14					Median CTM's				34.00		DM1MOS	**0.78**		MOS method 2: 20% rule with median UILT/UUILT and Preferred Average						
15				2	Median CTM's-conversion				33.20		DM 2	32.34								
16				1	Median UILT/UUILT				32.80		**DM 1**	**32.02**		DM method 1: Median UILT/UUILT - MOS						
17				1	Optimum Temperature for 1/3 Rule				no data		MWAT 1	no data								
18				2	Pref Ave for 1/3 Rule				28.90		**MWAT 2**	**30.187**		MWAT method 2: 1/3 rule with Preferred Average						
19				3	Avoided High for 1/3 Rule				no data		MWAT 3	no data								
20				4	Upper Optimum				no data		MWAT 4	no data								
21																				
22				Notes: data not used																
23					1= acclimation too low- below 15															
24					2= acclimation too high- above 30 or higher than min CTM															
25					3= lifestage = embryo/larvae															
26					4= field study															

1	Common Name	Scientific Name	Life stage	Replicates/Sample Size	Acclimation Temperature	Avoid high	Avoid low	Pref high	Pref ave	Pref low	Lower Optimum	Optimum	Upper Optimum	UILT	UUILT	CTM	Rate of Increase (CTM)	Other Notes	Complete Reference	Lab (y/n)
2	Gizzard Shad	Dorosoma cepedianum	see notes															Summer	Yoder and Gammon 1976	0
3	Gizzard Shad	Dorosoma cepedianum	see notes															Fall	Yoder and Gammon 1976	0
4	Gizzard Shad	Dorosoma cepedianum	adult	btwn 1, 27	15.9			20								31.7		Fall	Reutter and Herdendorf 1976	1
5	Gizzard Shad	Dorosoma cepedianum	adult						30										Ellis 1984	1
6	Gizzard Shad	Dorosoma cepedianum	yoy	300-400 fish										28.5			2-4 deg C/hr	Summer	Cvancara et al. 1976	1
7																				
8					**minimum**			20.00	30.00					28.50		31.70				
9					**median**			**20.00**	**30.00**					**28.50**		**31.70**				
10					**maximum**			20.00	30.00					28.50		31.70				
11					**(n)**			1	1					1		1				
12																				
13																				
14					**Estimates of Factors**						**Calculation of Metrics**			**Notes on Calculation Methods**						
15											DM2MOS	**0.18**		MOS method 1: 20% rule with converted CTM and Preferred Average						
16					Median CTM's				31.70		DM1MOS	-0.3								
17					2 Median CTM's-conversion				30.90		**DM 2**	**30.72**		DM method 2: Converted CTM - MOS						
18					1 Median UILT/UUILT				28.50		DM 1	28.80								
19					1 Optimum Temperature for 1/3 Rule				no data		MWAT 1	no data								
20					2 Pref Ave for 1/3 Rule				30.00		**MWAT 2**	**30.297**		MWAT method 2: 1/3 rule with Preferred Average						
21					3 Avoided High for 1/3 Rule				no data		MWAT 3	no data								
22					4 Upper Optimum				no data		MWAT 4	no data								
23				*** Used converted CTM rather than median UILT/UUILT for all calculations in order to ensure DM value is higher than MWAT value.																
24				Notes: data not used																
25					1= acclimation too low- below 15															
26					2= acclimation too high- above 30 or higher than min CTM															
27					3= lifestage = embryo/larvae															
28					4= field study															

1	Common Name	Scientific Name	Life stage	Replicates/Sample Size	Acclimation Temperature	Avoid high	Avoid low	Pref high	Pref ave	Pref low	Lower Optimum	Optimum	Upper Optimum	UILT	UUILT	CTM	Rate of Increase (CTM)	Other Notes	Complete Reference	Lab (y/n)
2	Golden Shiner	Notemigonus crysoleucas		28	10											33.36	1 C/min		Lutterschmidt and Hutchinson 1997	1
3	Golden Shiner	Notemigonus crysoleucas		28	10											29.13	1 C/min		Lutterschmidt and Hutchinson 1997	1
4	Golden Shiner	Notemigonus crysoleucas	juvenile	(N=38 in 4 groups)	10, est., see notes									30.3				1	Brett 1944	1
5	Golden Shiner	Notemigonus crysoleucas	juvenile	(N=27 in 3 groups)	12.5, est., see notes									30.4				2	Brett 1944	1
6	Golden Shiner	Notemigonus crysoleucas	juvenile	(N=31 in 4 groups)	15, est., see notes									31.8				3	Brett 1944	1
7	Golden Shiner	Notemigonus crysoleucas			10									29.3					Brett 1956	1
8	Golden Shiner	Notemigonus crysoleucas	adult		14.4				22.3							30.5		Summer	Reutter and Herdendorf 1976	1
9	Golden Shiner	Notemigonus crysoleucas			15									30.5					Brett 1956	1
10	Golden Shiner	Notemigonus crysoleucas		8	26											36.8	2 C/hr		Smale and Rabeni 1995	1
11	Golden Shiner	Notemigonus crysoleucas	juvenile	(N=34 in 4 groups)	17, est., see notes									33.5				4	Brett 144	1
12	Golden Shiner	Notemigonus crysoleucas	juvenile	(N=12 in 2 groups)	17.5, est., see notes									31.6				5	Brett 144	1
13	Golden Shiner	Notemigonus crysoleucas	juvenile	(N=24 in 3 groups)	20, est., see notes									33.2				6	Brett 144	1
14	Golden Shiner	Notemigonus crysoleucas	juvenile	(N=46 in 5 groups)	21, est., see notes									33.4				7	Brett 144	1
15	Golden Shiner	Notemigonus crysoleucas	juvenile	(N=14 in 2 groups)	22, est., see notes									32.8				8	Brett 144	1
16	Golden Shiner	Notemigonus crysoleucas	juvenile	n=100/treatment								26						9	Melandri et al. 2008	1
17	Golden Shiner	Notemigonus crysoleucas	juvenile	n=100/treatment								24						10	Melandri et al. 2008	1
18	Golden Shiner	Notemigonus crysoleucas			20									31.8					Brett 1956	1
19	Golden Shiner	Notemigonus crysoleucas			25									33.2					Brett 1956	1
20	Golden Shiner	Notemigonus crysoleucas			30									34.7					Brett 1956	1
21																				
22					**minimum**							24.00		31.60		36.80				
23					**median**							**25.00**		**33.20**		**36.80**				
24					**maximum**							26.00		34.70		36.80				
25					**(n)**							2		8		1				
27																				
28					**Estimates of Factors**						**Calculation of Metrics**			**Notes on Calculation Methods**						
29											DM2MOS	2.2								
30					Median CTM's				36.80		DM1MOS	**1.64**		MOS method 1: 20% rule with median UILT/UUILT and Optimum Temperature						
31					2 Median CTM's-conversion				36.00		DM 2	33.80								
32					1 Median UILT/UUILT				33.20		**DM 1**	**31.56**		DM method 1: Median UILT/UUILT - MOS						
33					1 Optimum Temperature for 1/3 Rule				25.00		**MWAT 1**	**27.706**		MWAT method 1: 1/3 rule with Optimal Temperature						
34					2 Pref Ave for 1/3 Rule				no data		MWAT 2	no data								
35					3 Avoided High for 1/3 Rule				no data		MWAT 3	no data								
36					4 Upper Optimum				no data		MWAT 4	no data								
37																				
38				Notes: data not used																
39					1= acclimation too low- below 15															
40					2= acclimation too high- above 30 or higher than min CTM															
41					3= lifestage = embryo/larvae															
42					4= field study															

[1] No lab acclimation; fish were acclimated to natural conditions in Lake Opeongo, estimated from Figure 4, at the time of collection (May 28).
[2] No lab acclimation; fish were acclimated to natural conditions in Lake Opeongo, estimated from Figure 4, at the time of collection (September 8).
[3] No lab acclimation; fish were acclimated to natural conditions in Lake Opeongo, estimated from Figure 4, at the time of collection (June 17).
[4] No lab acclimation; fish were acclimated to natural conditions in Lake Opeongo, estimated from Figure 4, at the time of collection (June 28).
[5] No lab acclimation; fish were acclimated to natural conditions in Lake Opeongo, estimated from Figure 4, at the time of collection (August 26).
[6] No lab acclimation; fish were acclimated to natural conditions in Lake Opeongo, estimated from Figure 4, at the time of collection (July 28).
[7] No lab acclimation; fish were acclimated to natural conditions in Lake Opeongo, estimated from Figure 4, at the time of collection (July 8).
[8] No lab acclimation; fish were acclimated to natural conditions in Lake Opeongo, estimated from Figure 4, at the time of collection (August 9).
[9] Study 1: smaller fish (0.5 g).
[10] Study 2: larger fish (1.0 g). Reported optimum is the average of the length growth optimum (23.9°C) and the weight growth optimum (24.1°C).

1	Common Name	Scientific Name	Life stage	Replicates/Sample Size	Acclimation Temperature	Avoid high	Avoid low	Pref high	Pref ave	Pref low	Lower Optimum	Optimum	Upper Optimum	UILT	UUILT	CTM	Rate of Increase (CTM)	Other Notes	Complete Reference	Lab (y/n)
2	Golden Trout	Oncorhynchus aguabonita			10											27.7			Myrick and Cech 2003	1
3	Golden Trout	Oncorhynchus aguabonita			14											28.3			Myrick and Cech 2003	1
4	Golden Trout	Oncorhynchus aguabonita			19											28.4			Myrick and Cech 2003	1
5																				
6					**minimum**											27.70				
7					**median**											**28.30**				
8					**maximum**											28.40				
9					**(n)**											3				
10																				
11																				
12					**Estimates of Factors**						**Calculation of Metrics**			**Notes on Calculation Methods**						
13											DM2MOS	**2**		MOS method 2: default = 2						
14					Median CTM's				28.30		DM1MOS	2								
15				2	Median CTM's-conversion				27.50		**DM 2**	**25.50**		DM method 2: Converted CTM - MOS						
16				1	Median UILT/UUILT				no data		DM 1	no data								
17				1	Optimum Temperature for 1/3 Rule				no data		MWAT 1	no data		Cannot calculate MWAT; no optimal data						
18				2	Pref Ave for 1/3 Rule				no data		MWAT 2	no data								
19				3	Avoided High for 1/3 Rule				no data		MWAT 3	no data								
20				4	Upper Optimum				no data		MWAT 4	no data								
21																				
22				Notes:	data not used															
23					1= acclimation too low- below 7															
24					2= acclimation too high- above 23 or higher than min CTM															
25					3= lifestage = embryo/larvae															
26					4= field study															

1	Common Name	Scientific Name	Life stage	Replicates/Sample Size	Acclimation Temperature	Avoid high	Avoid low	Pref high	Pref ave	Pref low	Lower Optimum	Optimum	Upper Optimum	UILT	UUILT	CTM	Rate of Increase (CTM)	Other Notes	Complete Reference	Lab (y/n)
2	Goldeye	Hiodon alosoides																		
3																				
4																				
5																				
6																				
7					**minimum**															
8					**median**															
9					**maximum**															
10					**(n)**															
11																				
12					**Estimates of Factors**						**Calculation of Metrics**			**Notes on Calculation Methods**						
13											DM2MOS	2								
14					Median CTM's				no data		DM1MOS	2		MOS method 2: default = 2						
15				2	Median CTM's-conversion				no data		DM 2	no data								
16				1	Median UILT/UUILT				no data		DM 1	no data		Cannot calculate DM; no lethal data						
17				1	Optimum Temperature for 1/3 Rule				no data		MWAT 1	no data		Cannot calculate MWAT; no optimal data						
18				2	Pref Ave for 1/3 Rule				no data		MWAT 2	no data								
19				3	Avoided High for 1/3 Rule				no data		MWAT 3	no data								
20				4	Upper Optimum				no data		MWAT 4	no data								
21																				
22				Notes:	data not used															
23					1= acclimation too low- below 15															
24					2= acclimation too high- above 30 or higher than min CTM															
25					3= lifestage = embryo/larvae															
26					4= field study															

1	Common Name	Scientific Name	Life stage	Replicates/Sample Size	Acclimation Temperature	Avoid high	Avoid low	Pref high	Pref ave	Pref low	Lower Optimum	Optimum	Upper Optimum	UILT	UUILT	CTM	Rate of Increase (CTM)	Other Notes	Complete Reference	Lab (y/n)
2	Grass Carp	Ctenopharyngodon idella		3 fish per test, 6 tests	23											39.3	0.5C/min	1	Bettoli et al. 1985	1
3	Grass Carp	Ctenopharyngodon idella		6 trials	23				25.3										Bettoli et al. 1985	1
4	Grass Carp	Ctenopharyngodon idella									18	18.5						2	Cudmore and Mandrak 2004	1
5	Grass Carp	Ctenopharyngodon idella	fry											38.5					Chilton and Muoneke 1992	1
6	Grass Carp	Ctenopharyngodon idella	yoy									33							Opuszynski 1972	1
7																				
8					**minimum**				25.30		18.00	18.50		38.50		39.30				
9					**median**				**25.30**		**18.00**	**25.75**		**38.50**		**39.30**				
10					**maximum**				25.30		18.00	33.00		38.50		39.30				
11					**(n)**				1		1	2		1		1				
12																				
13																				
14					**Estimates of Factors**						**Calculation of Metrics**			**Notes on Calculation Methods**						
15											DM2MOS	2.55								
16					Median CTM's				39.30		DM1MOS	**2.55**		MOS method 1: 20% rule with median UILT/UUILT and Optimum Temperature						
17					2 Median CTM's-conversion				38.50		DM 2	35.95								
18					1 Median UILT/UUILT				38.50		**DM 1**	**35.95**		DM method 1: Median UILT/UUILT - MOS						
19					1 Optimum Temperature for 1/3 Rule				25.75		**MWAT 1**	**29.9575**		MWAT method 1: 1/3 rule with Optimal Temperature						
20					2 Pref Ave for 1/3 Rule				25.30		MWAT 2	29.656								
21					3 Avoided High for 1/3 Rule				no data		MWAT 3	no data								
22					4 Upper Optimum				no data		MWAT 4	no data								
23																				
24				Notes: data not used																
25					1= acclimation too low- below 15															
26					2= acclimation too high- above 30 or higher than min CTM															
27					3= lifestage = embryo/larvae															
28					4= field study															

[1] CTM endpoint is the Death Point.

[2] Low survival of eggs occurred below 18°C; optimum egg survival occurred between 18-19°C.

1	Common name	Scientific name	Life stage	Replicates/Sample Size	Acclimation Temperature	Avoid high	Avoid low	Pref high	Pref ave	Pref low	Lower Optimum	Optimum	Upper Optimum	UILT	UUILT	CTM	Rate of Increase (CTM)	Other Notes	Complete Reference	Lab (y/n)
2	Green Sunfish	Lepomis cyanellus		N=5	4				10									1	Jones and Irwin 1965	1
3	Green Sunfish	Lepomis cyanellus		2/n=8(N=16)	6				16.9									2	Cherry et al. 1975	1
4	Green Sunfish	Lepomis cyanellus		4/n=2(N=8)	6	20	4											2	Cherry et al. 1975	1
5	Green Sunfish	Lepomis cyanellus		2/n=8(N=16)	9				18.2									2	Cherry et al. 1975	1
6	Green Sunfish	Lepomis cyanellus		4/n=2(N=8)	9	21	6											2	Cherry et al. 1975	1
7	Green Sunfish	Lepomis cyanellus		15	10											34.18	1 C/min		Lutterschmidt and Hutchinson 1997	1
8	Green Sunfish	Lepomis cyanellus		15	10											31.09	1 C/min		Lutterschmidt and Hutchinson 1997	1
9	Green Sunfish	Lepomis cyanellus		N=5	10				16									2	Jones and Irwin 1965	1
10	Green Sunfish	Lepomis cyanellus		2/n=8(N=16)	12				21.1									2	Cherry et al. 1975	1
11	Green Sunfish	Lepomis cyanellus		4/n=2(N=8)	12	24	10											2	Cherry et al. 1975	1
12	Green Sunfish	Lepomis cyanellus		N=5	22				30									3	Jones and Irwin 1965	1
13	Green Sunfish	Lepomis cyanellus		N=5	30				26									4	Jones and Irwin 1965	1
14	Green Sunfish	Lepomis cyanellus		2/n=8(N=16)	15				20.7									2	Cherry et al. 1975	1
15	Green Sunfish	Lepomis cyanellus		4/n=2(N=8)	15	25	14											2	Cherry et al. 1975	1
16	Green Sunfish	Lepomis cyanellus		2/n=8(N=16)	18				25.2									2	Cherry et al. 1975	1
17	Green Sunfish	Lepomis cyanellus		4/n=2(N=8)	18	29	17											2	Cherry et al. 1975	1
18	Green Sunfish	Lepomis cyanellus		9	20											35.79	0.3 C/min	5	Carrier and Beitinger 1988	1
19	Green Sunfish	Lepomis cyanellus		11	20											35.76	0.3 C/min	5	Carrier and Beitinger 1988	1
20	Green Sunfish	Lepomis cyanellus		9	20											35.92	0.3 C/min	5	Carrier and Beitinger 1988	1
21	Green Sunfish	Lepomis cyanellus		2/n=8(N=16)	21				28.1									2	Cherry et al. 1975	1
22	Green Sunfish	Lepomis cyanellus		4/n=2(N=8)	21	31	20											2	Cherry et al. 1975	1
23	Green Sunfish	Lepomis cyanellus		2/n=8(N=16)	24				30.4									2	Cherry et al. 1975	1
24	Green Sunfish	Lepomis cyanellus		4/n=2(N=8)	24	33	23											2	Cherry et al. 1975	1
25	Green Sunfish	Lepomis cyanellus		3/n=4	25											37.4	0.3 C/min	6	Carveth et al. 2006	1
26	Green Sunfish	Lepomis cyanellus		3/n=4	25											39.3	0.3 C/min	6	Carveth et al. 2006	1
27	Green Sunfish	Lepomis cyanellus		8	26											37.9	2 C/hr		Smale and Rabeni 1995	1
28	Green Sunfish	Lepomis cyanellus		2/n=8(N=16)	27				30.7									2	Cherry et al. 1975	1
29	Green Sunfish	Lepomis cyanellus		4/n=2(N=8)	27	33	23											2	Cherry et al. 1975	1
30	Green Sunfish	Lepomis cyanellus		3/n=4	30											40.2	0.3 C/min	6	Carveth et al. 2006	1
31	Green Sunfish	Lepomis cyanellus		3/n=4	30											41.5	0.3 C/min	6	Carveth et al. 2006	1
32	Green Sunfish	Lepomis cyanellus		2/n=8(N=16)	30				30.6									2	Cherry et al. 1975	1
33	Green Sunfish	Lepomis cyanellus		4/n=2(N=8)	30	33	23											2	Cherry et al. 1975	1
34	Green Sunfish	Lepomis cyanellus		N=13	20-22 C range	30.4	26.8		28.2									7	Beitinger et al. 1975	1
36					**minimum**	25.00	14.00		20.70							35.76				
37					**median**	**31.00**	**23.00**		**28.20**							**37.65**				
38					**maximum**	33.00	26.80		30.70							41.50				
39					**(n)**	7	7		7							8				

42	**Estimates of Factors**			**Calculation of Metrics**		**Notes on Calculation Methods**
43				DM2MOS	**1.73**	MOS method 1: 20% rule with converted CTM and Preferred Average
44		Median CTM's	37.65	DM1MOS	no data	
45	2	Median CTM's-conversion	36.85	**DM 2**	**35.12**	DM method 2: Converted CTM - MOS
46	1	Median UILT/UUILT	no data	DM 1	no data	
47	1	Optimum Temperature for 1/3 Rule	no data	MWAT 1	no data	
48	2	Pref Ave for 1/3 Rule	28.20	**MWAT 2**	**31.0545**	MWAT method 2: 1/3 rule with Preferred Average
49	3	Avoided High for 1/3 Rule	33.00	MWAT 3	34.2705	33 was chosen as Avoided High because the acclimation temperature (27) was closest to
50	4	Upper Optimum	no data	MWAT 4	no data	the other known temperature optimum metrics

52 Notes: data not used
53 1= acclimation too low- below 15
54 2= acclimation too high- above 30 or higher than min CTM
55 3= lifestage = embryo/larvae
56 4= field study
57 5= other

[1] Sample size is number of fish; many observations were made on each fish, but the number of observations was not reported. The mode is reported here (mean = 10.6°C).
[2] Fish are assumed to be adults. Fish were fasted for 2.5-3 days before being tested.
[3] Sample size is number of fish; many observations were made on each fish, but the number of observations was not reported. The mode is reported here (mean = 27.0°C).
[4] Sample size is number of fish; many observations were made on each fish, but the number of observations was not reported. The mode is reported here (mean = 26.8°C).
[5] Fish from are control group (no Cadmium exposure) in a study testing Cadmium exposure.
[6] Fish were 48-109 mm in length. Recorded replicates and sample size are the minimum for all species tested.
[7] Fish were given a 2-5 day adaptation period in the apparatus before being tested. Sample size is the number of fish studied; each fish had many observations. Avoidances are grand means (grand medians = 26.5, 30.3); Preferred Average is grand median (grand modal preference was 28.0).

1	Common name	Scientific Name	Life stage	Replicates/Sample Size	Acclimation Temperature	Avoid high	Avoid low	Pref high	Pref ave	Pref low	Lower Optimum	Optimum	Upper Optimum	UILT	UUILT	CTM	Rate of Increase (CTM)	Other Notes	Complete Reference	Lab (y/n)
2	Hornyhead Chub	Nocomis biguttatus		8	26											35.6	2 C/hr		Smale and Rabeni 1995	1
3																				
4																				
5					**minimum**											35.60				
6					**median**											**35.60**				
7					**maximum**											35.60				
8					**(n)**											1				
9																				
10																				
11					**Estimates of Factors**						**Calculation of Metrics**			**Notes on Calculation Methods**						
12											DM2MOS	**2**		MOS method 2: default = 2						
13					Median CTM's				35.60		DM1MOS	2								
14				2	Median CTM's-conversion				34.80		**DM 2**	**32.80**		DM method 2: Converted CTM - MOS						
15				1	Median UILT/UUILT				no data		DM 1	no data								
16				1	Optimum Temperature for 1/3 Rule				no data		MWAT 1	no data		Cannot calculate MWAT; no optimal data						
17				2	Pref Ave for 1/3 Rule				no data		MWAT 2	no data								
18				3	Avoided High for 1/3 Rule				no data		MWAT 3	no data								
19				4	Upper Optimum				no data		MWAT 4	no data								
20																				
21				Notes:	data not used															
22					1= acclimation too low- below 15															
23					2= acclimation too high- above 30 or higher than min CTM															
24					3= lifestage = embryo/larvae															
25					4= field study															

1	Common Name	Scientific Name	Life stage	Replicates/Sample Size	Acclimation Temperature	Avoid high	Avoid low	Pref high	Pref ave	Pref low	Lower Optimum	Optimum	Upper Optimum	UILT	UUILT	CTM	Rate of Increase (CTM)	Spawning Info	Other Notes	Complete Reference	Lab (y/n)
2	Iowa Darter	Etheostoma exile																			
3																					
4																					
5																					
6					**minimum**																
7					**median**																
8					**maximum**																
9					**(n)**																
10																					
11																					
12					**Estimates of Factors**						**Calculation of Metrics**			**Notes on Calculation Methods**							
13											DM2MOS	2									
14					Median CTM's				no data		DM1MOS	2		MOS method 2: default = 2							
15				2	Median CTM's-conversion				no data		DM 2	no data									
16				1	Median UILT/UUILT				no data		DM 1	no data		Cannot calculate DM; no lethal data							
17				1	Optimum Temperature for 1/3 Rule				no data		MWAT 1	no data		Cannot calculate MWAT; no optimal data							
18				2	Pref Ave for 1/3 Rule				no data		MWAT 2	no data									
19				3	Avoided High for 1/3 Rule				no data		MWAT 3	no data									
20				4	Upper Optimum				no data		MWAT 4	no data									
21																					
22				Notes:	data not used																
23					1= acclimation too low- below 15																
24					2= acclimation too high- above 30 or higher than min CTM																
25					3= lifestage = embryo/larvae																
26					4= field study																

1	Common name	Scientific Name	Life stage	Replicates/Sample Size	Acclimation Temperature	Avoid high	Avoid low	Pref high	Pref ave	Pref low	Lower Optimum	Optimum	Upper Optimum	UILT	UUILT	CTM	Rate of Increase (CTM)	Other Notes	Complete Reference	Lab (y/n)
2	Johnny Darter	Etheostoma nigrum	adult	10	15											30.9	1 C/min	1	Ingersoll and Claussen 1984	1
3	Johnny Darter	Etheostoma nigrum	adult	11	15											30.5	1 C/min	2	Ingersoll and Claussen 1984	1
4	Johnny Darter	Etheostoma nigrum	adult	2/n=6	15			26.8	22.7	17.6								1	Ingersoll and Claussen 1984	1
5	Johnny Darter	Etheostoma nigrum	adult	2/n=6	15			28.2	22.9	18.9								2	Ingersoll and Claussen 1984	1
6	Johnny Darter	Etheostoma nigrum	adult	4	15											30.7	1 C/min	January	Kowalski et al. 1978	1
7	Johnny Darter	Etheostoma nigrum	adult	7	15											31.4	1 C/min	March	Kowalski et al. 1978	1
8	Johnny Darter	Etheostoma nigrum	adult	7	15											31.1	1 C/min	May	Kowalski et al. 1978	1
9	Johnny Darter	Etheostoma nigrum	adult	7	15											31.4	1 C/min	March	Kowalski et al. 1978	1
10	Johnny Darter	Etheostoma nigrum	adult	7	15											31.1	1 C/min	3	Kowalski et al. 1978	1
11	Johnny Darter	Etheostoma nigrum	adult	14	20											33	1 C/min	4	Lydy and Wissing 1988	1
12	Johnny Darter	Etheostoma nigrum	adult	15	20											33.9	0.5 C/min	5	Smith and Fausch 1997	1
13	Johnny Darter	Etheostoma nigrum	adult	15	25											35.6	0.5 C/min	5	Smith and Fausch 1997	1
14	Johnny Darter	Etheostoma nigrum		7	26											36.4	2 C/hr		Smale and Rabeni 1995	1
15	Johnny Darter	Etheostoma nigrum	adult	15	27.5											36.4	0.5 C/min	5	Smith and Fausch 1997	1
16	Johnny Darter	Etheostoma nigrum	adult	15	30											37.3	0.5 C/min	5	Smith and Fausch 1997	1
17																				
18					**minimum**			26.80	22.70	17.60						30.50				
19					**median**			**27.50**	**22.80**	**18.25**						**31.40**				
20					**maximum**			28.20	22.90	18.90						37.30				
21					**(n)**			2	2	2						13				
22																				
23																				
24					**Estimates of Factors**						**Calculation of Metrics**			**Notes on Calculation Methods**						
25											DM2MOS	**1.56**		MOS method 1: 20% rule with converted CTM and Preferred Average						
26					Median CTM's				31.40		DM1MOS	no data								
27					2 Median CTM's-conversion				30.60		**DM 2**	**29.04**		DM method 2: Converted CTM - MOS						
28					1 Median UILT/UUILT				no data		DM 1	no data								
29					1 Optimum Temperature for 1/3 Rule				no data		MWAT 1	no data								
30					2 Pref Ave for 1/3 Rule				22.80		**MWAT 2**	**25.374**		MWAT method 2: 1/3 rule with Preferred Average						
31					3 Avoided High for 1/3 Rule				no data		MWAT 3	no data								
32					4 Upper Optimum				no data		MWAT 4	no data								
34				Notes:	data not used															
35					1= acclimation too low- below 15															
36					2= acclimation too high- above 30 or higher than min CTM															
37					3= lifestage = embryo/larvae															
38					4= field study															

[1] Fish were caught and tested in winter. The mean Preferred Average is used here; median Preferred Averaged was also reported (22.7°C); Preferred Low and Preferred High are from the reported modal range.

[2] Fish were caught and tested in summer. The mean Preferred Average is used here; median Preferred Averaged was also reported (23.0°C); Preferred Low and Preferred High are from the reported modal range.

[3] Fish were caught and tested in March. CTM values were derived from the Figure 3 plot.

[4] Results are from the control group in study of copper dose effects on CTM.

[5] CTM values are predicted from the linear regression equation for fish of average length used in the study (shown in Figure 1).

1	Common Name	Scientific Name	Life stage	Replicates/Sample Size	Acclimation Temperature	Avoid high	Avoid low	Pref high	Pref ave	Pref low	Lower Optimum	Optimum	Upper Optimum	UILT	UUILT	CTM	Rate of Increase (CTM)	Other Notes	Complete Reference	Lab (y/n)
2	Kendall Warm Springs Dace	Rhinichthys osculus thermalis		12	24											34.5	0.45C/min		Kaya et al. 1992	1
3	Kendall Warm Springs Dace	Rhinichthys osculus thermalis		14	27											34.6	0.45C/min		Kaya et al. 1992	1
4																				
5					**minimum**											34.50				
6					**median**											**34.55**				
7					**maximum**											34.60				
8					**(n)**											2				
9																				
10																				
11					**Estimates of Factors**						**Calculation of Metrics**			**Notes on Calculation Methods**						
12											DM2MOS	**2**		MOS method 2: default = 2						
13					Median CTM's				34.55		DM1MOS	no data								
14				2	Median CTM's-conversion				33.75		**DM 2**	**31.75**		DM method 2: Converted CTM - MOS						
15				1	Median UILT/UUILT				no data		DM 1	no data								
16				1	Optimum Temperature for 1/3 Rule				no data		MWAT 1	no data		Cannot calculate MWAT; no optimal data						
17				2	Pref Ave for 1/3 Rule				no data		MWAT 2	no data								
18				3	Avoided High for 1/3 Rule				no data		MWAT 3	no data								
19				4	Upper Optimum				no data		MWAT 4	no data								
20																				
21				Notes:	data not used															
22					1= acclimation too low- below 15															
23					2= acclimation too high- above 30 or higher than min CTM															
24					3= lifestage = embryo/larvae															
25					4= field study															

	Common Name	Scientific Name	Life stage	Replicates/Sample Size	Acclimation Temperature	Avoid high	Avoid low	Pref high	Pref ave	Pref low	Lower Optimum	Optimum	Upper Optimum	UILT	UUILT	CTM	Rate of Increase (CTM)	Other Notes	Complete Reference	Lab (y/n)
2	Kokanee	Oncorhynchus nerka	fry	see notes	5									22.2				1	Brett 1952	1
3	Kokanee	Oncorhynchus nerka	embryo								1		15.5					2	Beacham and Murray 1990	1
4	Kokanee	Oncorhynchus nerka	juvenile	n=10-25 per group								15							Brett et al. 1969	0
5	Kokanee	Oncorhynchus nerka	adult	8	(see notes)							15						3	Lee et al. 2003	1
6	Kokanee	Oncorhynchus nerka	fry	see notes	23									24.8	24.8			1	Brett 1952	1
7	Kokanee	Oncorhynchus nerka	fry	see notes	20									24.8				1	Brett 1952	1
8	Kokanee	Oncorhynchus nerka	fry	see notes	15									24.4				1	Brett 1952	1
9	Kokanee	Oncorhynchus nerka	fry	see notes	10									23.4				1	Brett 1952	1
10	Kokanee	Oncorhynchus nerka	adult	17	(see notes)							17.5						4	Lee et al. 2003	1
11	Kokanee	Oncorhynchus nerka kennerlyi	fry		11									22					Black 1953	1
12																				
13					**minimum**							15.00		22.00	24.80					
14					**median**							**16.25**		**24.40**	**24.80**					
15					**maximum**							17.50		24.80	24.80					
16					**(n)**							2		5	1					
17																				
18																				
19					**Estimates of Factors**						**Calculation of Metrics**			**Notes on Calculation Methods**						
20											DM2MOS	no data								
21					Median CTM's				no data		DM1MOS	**1.67**		MOS method 1: 20% rule with median UILT/UUILT and Optimum Temperature						
22					2 Median CTM's-conversion				no data		DM 2	no data								
23					1 Median UILT/UUILT				24.60		**DM 1**	**22.93**		DM method 1: Median UILT/UUILT - MOS						
24					1 Optimum Temperature for 1/3 Rule				16.25		**MWAT 1**	**19.0055**		MWAT method 1: 1/3 rule with Optimum Temperature						
25					2 Pref Ave for 1/3 Rule				no data		MWAT 2	no data								
26					3 Avoided High for 1/3 Rule				no data		MWAT 3	no data								
27					4 Upper Optimum				no data		MWAT 4	no data								
28																				
29				Notes: data not used																
30					1= acclimation too low- below 15															
31					2= acclimation too high- above 30 or higher than min CTM															
32					3= lifestage = embryo/larvae															
33					4= field study															

[1] Sample size was not specified, but sample sizes for cited methods (Brett 1941) include several fish at each temperature level tested for each acclimation temp. UILT value was derived from Figure 6.

[2] The hatch rate optima are calculated with data from the Velson 1987 report.

[3] Gates Creek Stock. Optimum is for swimming performance. Fish were acclimated to field ambient (mean 12.2°C), lab ambient (mean 15.9°C), or lab adjusted (13.0-19.5°C) temperatures.

[4] Gates Creek Stock. Optimum is for swimming performance. Fish were acclimated to field ambient (mean 18.0°C) or lab adjusted (10.9-22.7°C) temperatures.

	Common Name	Scientific Name	Life stage	Replicates/Sample Size	Acclimation Temperature	Avoid high	Avoid low	Pref high	Pref ave	Pref low	Lower Optimum	Optimum	Upper Optimum	UILT	UUILT	CTM	Rate of Increase (CTM)	Other Notes	Complete Reference	Lab (y/n)
2	Lake Chub	Couesius plumbeus																		
3																				
4					**minimum**															
5					**median**															
6					**maximum**															
7					**(n)**															
8																				
9																				
10					**Estimates of Factors**						**Calculation of Metrics**			**Notes on Calculation Methods**						
11											DM2MOS	no data								
12					Median CTM's				no data		DM1MOS	2		MOS method 2: default = 2						
13				2	Median CTM's-conversion				no data		DM 2	no data								
14				1	Median UILT/UUILT				no data		DM 1	no data		Cannot calculate DM; no lethal data						
15				1	Optimum Temperature for 1/3 Rule				no data		MWAT 1	no data		Cannot calculate MWAT; no optimal data						
16				2	Pref Ave for 1/3 Rule				no data		MWAT 2	no data								
17				3	Avoided High for 1/3 Rule				no data		MWAT 3	no data								
18				4	Upper Optimum				no data		MWAT 4	no data								
19																				
20				Notes:	data not used															
21					1= acclimation too low- below 15															
22					2= acclimation too high- above 30 or higher than min CTM															
23					3= lifestage = embryo/larvae															
24					4= field study															

1	Common Name	Scientific Name	Life stage	Replicates/Sample Size	Acclimation Temperature	Avoid high	Avoid low	Pref high	Pref ave	Pref low	Lower Optimum	Optimum	Upper Optimum	UILT	UUILT	CTM	Rate of Increase (CTM)	Other Notes	Complete Reference	Lab (y/n)
2	Lake Trout	Salvelinus namaycush	juvenile	7 replicates/ n=10/replicate	5				11.7									1	McCauley and Tait 1970	1
3	Lake Trout	Salvelinus namaycush	fry	15 fish (271 observations)	5.2				9.7									2	Edsall and Cleland 2000	1
4	Lake Trout	Salvelinus namaycush	adult	N=35														3	MacKenzie-Grieve and Post 2006	0
5	Lake Trout	Salvelinus namaycush	adult	N=46														4	MacKenzie-Grieve and Post 2006	0
6	Lake Trout	Salvelinus namaycush	adult	N=12														5	MacKenzie-Grieve and Post 2006	0
7	Lake Trout	Salvelinus namaycush	adult	N=37														6	MacKenzie-Grieve and Post 2006	0
8	Lake Trout	Salvelinus namaycush	adult	N=49														7	MacKenzie-Grieve and Post 2006	0
9	Lake Trout	Salvelinus namaycush	adult	N=49														8	MacKenzie-Grieve and Post 2006	0
10	Lake Trout	Salvelinus namaycush	adult	N=36														9	MacKenzie-Grieve and Post 2006	0
11	Lake Trout	Salvelinus namaycush	see notes	500 (est. see notes)														10	Michaud 1981	0
12	Lake Trout	Salvelinus namaycush	see notes	500 (est. see notes)														10	Michaud 1981	0
13	Lake Trout	Salvelinus namaycush	adult	N=166														11	MacKenzie-Grieve and Post 2006	0
14	Lake Trout	Salvelinus namaycush	juvenile	6 replicates/ n=10/replicate	10				11.7									12	McCauley and Tait 1970	1
15	Lake Trout	Salvelinus namaycush	juvenile	6 replicates/ n=10/replicate	10				11.5									13	McCauley and Tait 1970	1
16	Lake Trout	Salvelinus namaycush	fry	15 fish (271 observations)	10.1				10.2									14	Edsall and Cleland 2000	1
17	Lake Trout	Salvelinus namaycush	fry	15 fish (271 observations)	14.9				10.2									14	Edsall and Cleland 2000	1
18	Lake Trout	Salvelinus namaycush	juvenile	7 replicates/ n=10/replicate	15				11.9									15	McCauley and Tait 1970	1
19	Lake Trout	Salvelinus namaycush	fry	15 fish (271 observations)	18.1				11.5									2	Edsall and Cleland 2000	1
20	Lake Trout	Salvelinus namaycush	juvenile	7 replicates/ n=10/replicate	20				11.8									16	McCauley and Tait 1970	1
21	Lake Trout	Salvelinus namaycush	juvenile	8 replicates/ n=10/replicate	20				11.8									17	McCauley and Tait 1970	1
22	Lake Trout	Salvelinus namaycush	juvenile	N=7	10				9.2									18	Mac 1985	1
23	Lake Trout	Salvelinus namaycush	juvenile	N=7	10				10.6									19	Mac 1985	1
24	Lake Trout	Salvelinus namaycush	juvenile	N=7	10				11.7									20	Mac 1985	1
25	Lake Trout	Salvelinus namaycush	juvenile	N=7	10				12.6									21	Mac 1985	1
26	Lake Trout	Salvelinus namaycush	fry	n=30								12.5						22	Edsall and Cleland 2000	1
27	Lake Trout	Salvelinus namaycush												25.1					Parker and Krenkel 1969	1
28	Lake Trout	Salvelinus namaycush							12										Spotila et al. 1979	1
29																				
30					**minimum**				9.20			12.50		25.10						
31					**median**				**11.70**			**12.50**		**25.10**						
32					**maximum**				12.60			12.50		25.10						
33					**(n)**				13			1		1						
35																				
36					**Estimates of Factors**						**Calculation of Metrics**			**Notes on Calculation Methods**						
37											DM2MOS	no data								
38					Median CTM's				no data		DM1MOS	**2.52**		MOS method 1: 20% rule with median UILT/UUILT and Optimum Temperature						
39					2 Median CTM's-conversion				no data		DM 2	no data								
40					1 Median UILT/UUILT				25.10		**DM 1**	**22.58**		DM method 1: Median UILT/UUILT - MOS						
41					1 Optimum Temperature for 1/3 Rule				12.50		**MWAT 1**	**16.658**		MWAT method 1: 1/3 rule with Optimum Temperature						
42					2 Pref Ave for 1/3 Rule				11.70		MWAT 2	16.122								
43					3 Avoided High for 1/3 Rule				no data		MWAT 3	no data								
44					4 Upper Optimum				no data		MWAT 4	no data								
45																				
46				Notes: data not used																
47					1= acclimation too low- below 15															
48					2= acclimation too high- above 30 or higher than min CTM															
49					3= lifestage = embryo/larvae															
50					4= field study															

[1] 1351 total observations were recorded (combined mode = 12.0°C; combined mean = 11.0°C).
[2] Preference was estimated from Figure 3 to the nearest 0.5°C; 10.2°C was the estimated Final Preferendum.
[3] Fish were collected in summer 2002 from Dezadeash Lake, which warms above reported optimum for Lake trout, but has cold stream inlet refugia. Sample size refers to number of relocations of 17 tagged fish.
[4] Fish were collected in fall 2001 from Dezadeash Lake, which warms above reported optimum for Lake trout, but has cold stream inlet refugia. Sample size refers to number of relocations of 20 tagged fish.
[5] Fish were collected in fall 2002 from Dezadeash Lake, which warms above reported optimum for Lake trout, but has cold stream inlet refugia. Sample size refers to number of relocations of 17 tagged fish.
[6] Fish were collected in summer 2001 from Kathleen Lake, which is cold and deep. Sample size refers to number of relocations of 19 tagged fish.
[7] Fish were collected in summer 2002 from Kathleen Lake, which is cold and deep. Sample size refers to number of relocations of 19 tagged fish.
[8] Fish were collected in fall 2001 from Kathleen Lake, which is cold and deep. Sample size refers to number of relocations of 19 tagged fish.
[9] Fish were collected in fall 2002 from Kathleen Lake, which is cold and deep. Sample size refers to number of relocations of 19 tagged fish.
[10] Sample size was estimated from the temperature-frequency histogram. Temperature measurement method was not confirmed.
[11] Fish were collected in summer 2001 from Dezadeash Lake, which warms above reported optimum for Lake trout, but has cold stream inlet refugia. Sample size refers to number of relocations of 20 tagged fish.
[12] 1557 total observations were recorded (combined mode = 12.0°C; combined mean = 11.9°C).
[13] 1189 total observations were recorded (combined mode = 12.0°C; combined mean = 11.8°C).
[14] Preferred Average is the median of the temperature range in a vertical position where modal preference was noted; 10.2°C was the estimated Final Preferendum.
[15] 1407 total observations were recorded (combined mode = 12.0°C; combined mean = 11.6°C).
[16] 377 total observations were recorded (combined mode = 12.0°C; combined mean = 11.6°C).
[17] 1529 total observations were recorded (combined mode = 11.0°C; combined mean = 11.5°C).
[18] Fish were offspring of wild adults. Ration was 0.3% of body mass; fish lost weight at this ration.
[19] Fish were offspring of wild adults. Ration was 0.8% of body mass; fish lost weight at this ration.
[20] Fish were offspring of wild adults. Ration was 2.0% of body mass; fish gained weight at this ration.
[21] Fish were offspring of wild adults. Ration was 5.5% of body mass; fish gained weight at this ration.
[22] Third-order polynomial fit was used to estimate the optimum growth temperature; four temperatures were studied (5°C, 10°C, 15°C, 18°C).

1	Common Name	Scientific Name	Life stage	Replicates/Sample Size	Acclimation Temperature	Avoid high	Avoid low	Pref high	Pref ave	Pref low	Lower Optimum	Optimum	Upper Optimum	UILT	UUILT	CTM	Rate of Increase (CTM)	Other Notes	Complete Reference	Lab (y/n)
2	Largemouth Bass	Micropterus salmoides	fry	25	8				24.6									1	Koppelman et al. 1988	1
3	Largemouth Bass	Micropterus salmoides	fry	23	8				22									2	Koppelman et al. 1988	1
4	Largemouth Bass	Micropterus salmoides	fry	25	8				24.2									3	Koppelman et al. 1988	1
5	Largemouth Bass	Micropterus salmoides	fry	25	8				24.4									4	Koppelman et al. 1988	1
6	Largemouth Bass	Micropterus salmoides	juvenile	10	8											30.4	0.3 C/min	5	Fields et al. 1987	1
7	Largemouth Bass	Micropterus salmoides	juvenile	10	8											29.2	0.3 C/min	5	Fields et al. 1987	1
8	Largemouth Bass	Micropterus salmoides	juvenile	3/N=20	10									31.5				6	Hathaway 1928	1
9	Largemouth Bass	Micropterus salmoides	juvenile	3/N=16	10									30				6	Hathaway 1928	1
10	Largemouth Bass	Micropterus salmoides		17	10											33.35	1 C/min		Lutterschmidt and Hutchinson 1997	1
11	Largemouth Bass	Micropterus salmoides		17	10											30.69	1 C/min		Lutterschmidt and Hutchinson 1997	1
12	Largemouth Bass	Micropterus salmoides		N=28/n=6	11									28.9					Black 1953	1
13	Largemouth Bass	Micropterus salmoides	fry	25	12				25.8									1	Koppelman et al. 1988	1
14	Largemouth Bass	Micropterus salmoides	fry	25	12				25.8									2	Koppelman et al. 1988	1
15	Largemouth Bass	Micropterus salmoides	fry	25	12				26.3									3	Koppelman et al. 1988	1
16	Largemouth Bass	Micropterus salmoides	fry	25	12				26.3									4	Koppelman et al. 1988	1
17	Largemouth Bass	Micropterus salmoides	fry	19	32				29.5									1	Koppelman et al. 1988	1
18	Largemouth Bass	Micropterus salmoides	fry	22	32				27.3									2	Koppelman et al. 1988	1
19	Largemouth Bass	Micropterus salmoides	fry	23	32				27.9									3	Koppelman et al. 1988	1
20	Largemouth Bass	Micropterus salmoides	fry	24	32				28.2									4	Koppelman et al. 1988	1
21	Largemouth Bass	Micropterus salmoides	juvenile	10	32											40.9	0.3 C/min	5	Fields et al. 1987	1
22	Largemouth Bass	Micropterus salmoides	juvenile	10	32											41.8	0.3 C/min	5	Fields et al. 1987	1
23	Largemouth Bass	Micropterus salmoides	fry	10	36											39.3	1 C/day	7	Guest 1985	1
24	Largemouth Bass	Micropterus salmoides	fry	10	36											39.1	1 C/day	8	Guest 1985	1
25	Largemouth Bass	Micropterus salmoides	juvenile	4 reps/5 treatments	32			31	30.1	28.2								9	Díaz et al. 2007	1
26	Largemouth Bass	Micropterus salmoides	embryos	15 replicates								20						10	Badenhuizen 1969	1
27	Largemouth Bass	Micropterus salmoides	see notes	see notes														11	Yoder and Gammon 1976	0
28	Largemouth Bass	Micropterus salmoides	see notes	see notes														12	Yoder and Gammon 1976	0
29	Largemouth Bass	Micropterus salmoides	fry	25	16				25.8									1	Koppelman et al. 1988	1
30	Largemouth Bass	Micropterus salmoides	fry	25	16				27.9									2	Koppelman et al. 1988	1
31	Largemouth Bass	Micropterus salmoides	fry	25	16				25.6									3	Koppelman et al. 1988	1
32	Largemouth Bass	Micropterus salmoides	fry	25	16				26.8									4	Koppelman et al. 1988	1
33	Largemouth Bass	Micropterus salmoides	juvenile	10	16											33.6	0.3 C/min	5	Fields et al. 1987	1
34	Largemouth Bass	Micropterus salmoides	juvenile	10	16											34.1	0.3 C/min	5	Fields et al. 1987	1
35	Largemouth Bass	Micropterus salmoides	fry	25	20				25.9									1	Koppelman et al. 1988	1
35	Largemouth Bass	Micropterus salmoides	fry	25	20				25.9									1	Koppelman et al. 1988	1
36	Largemouth Bass	Micropterus salmoides	fry	25	20				26									2	Koppelman et al. 1988	1
37	Largemouth Bass	Micropterus salmoides	fry	25	20				27.9									3	Koppelman et al. 1988	1
38	Largemouth Bass	Micropterus salmoides	fry	25	20				27.8									4	Koppelman et al. 1988	1
39	Largemouth Bass	Micropterus salmoides	yoy	40	20											36.71	0.1 C/min	13	Smith and Scott 1975	1
40	Largemouth Bass	Micropterus salmoides	juvenile adult	N=20	22			33.3	30	24.4								14	Reynolds and Casterlin 1976	1
41	Largemouth Bass	Micropterus salmoides	juvenile adult	N=20	22			32.8	26.7	21.7								15	Reynolds and Casterlin 1976	1
42	Largemouth Bass	Micropterus salmoides		N=12	22			29.5	28.3	27.1								16	Reynolds and Casterlin 1978a	1
43	Largemouth Bass	Micropterus salmoides	juvenile	3/N=16	22.5									32.2				6	Hathaway 1928	1
44	Largemouth Bass	Micropterus salmoides	adult	N=4	23				29									17	Venables et al. 1978	1
45	Largemouth Bass	Micropterus salmoides	fry	25	24				25.8									1	Koppelman et al. 1988	1
46	Largemouth Bass	Micropterus salmoides	fry	25	24				26.3									2	Koppelman et al. 1988	1
47	Largemouth Bass	Micropterus salmoides	fry	25	24				26.2									3	Koppelman et al. 1988	1
48	Largemouth Bass	Micropterus salmoides	fry	25	24				26.5									4	Koppelman et al. 1988	1
49	Largemouth Bass	Micropterus salmoides	juvenile	10	24											37.5	0.3 C/min	5	Fields et al. 1987	1
50	Largemouth Bass	Micropterus salmoides	juvenile	10	24											36.5	0.3 C/min	5	Fields et al. 1987	1
51	Largemouth Bass	Micropterus salmoides		N=5	24				30.2									18	Reynolds et al. 1976	1
52	Largemouth Bass	Micropterus salmoides	juvenile	3/n=4	25											37.8	0.3 C/min	19	Carveth et al. 2006	1
53	Largemouth Bass	Micropterus salmoides	juvenile	3/n=4	25											39.1	0.3 C/min	19	Carveth et al. 2006	1
54	Largemouth Bass	Micropterus salmoides		10	26											36.3	2 C/hr		Smale and Rabeni 1995	1
55	Largemouth Bass	Micropterus salmoides	fry	25	28				27.7									1	Koppelman et al. 1988	1
56	Largemouth Bass	Micropterus salmoides	fry	25	28				28.1									2	Koppelman et al. 1988	1
57	Largemouth Bass	Micropterus salmoides	fry	25	28				28.1									3	Koppelman et al. 1988	1
58	Largemouth Bass	Micropterus salmoides	fry	25	28				28.8									4	Koppelman et al. 1988	1

1	Common Name	Scientific Name	Life stage	Replicates/Sample Size	Acclimation Temperature	Avoid high	Avoid low	Pref high	Pref ave	Pref low	Lower Optimum	Optimum	Upper Optimum	UILT	UUILT	CTM	Rate of Increase (CTM)	Other Notes	Complete Reference	Lab (y/n)
59	Largemouth Bass	Micropterus salmoides	yoy	40	28											40.08	0.1 C/min	13	Smith and Scott 1975	1
60	Largemouth Bass	Micropterus salmoides	juvenile	3/N=16	30									35.2				6	Hathaway 1928	1
61	Largemouth Bass	Micropterus salmoides	fry	10	30											39.4	1 C/day	8	Guest 1985	1
62	Largemouth Bass	Micropterus salmoides	juvenile	8	30											38.9	1 C/day	7	Guest 1985	1
63	Largemouth Bass	Micropterus salmoides	juvenile	8	30											38.2	1 C/day	8	Guest 1985	1
64	Largemouth Bass	Micropterus salmoides	adult	7	30											39.1	1 C/day	7	Guest 1985	1
65	Largemouth Bass	Micropterus salmoides	adult	8	30											39.8	1 C/day	8	Guest 1985	1
66	Largemouth Bass	Micropterus salmoides	juvenile	2/N=14	30									36				6	Hathaway 1928	1
67	Largemouth Bass	Micropterus salmoides	fry	10	30											39.8	1 C/day	7	Guest 1985	1
68	Largemouth Bass	Micropterus salmoides	fry	see notes	see notes													20	Strawn 1961	1
69	Largemouth Bass	Micropterus salmoides	juvenile	N=12 (n=3)								26						21	Coutant and Cox 1976	1
70	Largemouth Bass	Micropterus salmoides	fry	N=280								27							Coutant and Cox 1976	1
71	Largemouth Bass	Micropterus salmoides	juvenile	2/N=155								32						22	McCormick and Wegner 1981	1
72	Largemouth Bass	Micropterus salmoides	juvenile	2/N=160								32						23	McCormick and Wegner 1981	1
73	Largemouth Bass	Micropterus salmoides	juvenile	n=10	20											35.4	0.3 C/min		Currie et al. 2004	1
74	Largemouth Bass	Micropterus salmoides	juvenile	n=10	25											36.7	0.3 C/min		Currie et al. 2004	1
75	Largemouth Bass	Micropterus salmoides	juvenile	n=10	30											38.5	0.3 C/min		Currie et al. 2004	1
76	Largemouth Bass	Micropterus salmoides	juvenile	n=10	20-30 (diel cycling)											36.9	0.3 C/min		Currie et al. 2004	1
77	Largemouth Bass	Micropterus salmoides	juvenile	4 Replicates/n=5/trea	20			29.2	28.1	27.1								9	Díaz et al. 2007	1
78	Largemouth Bass	Micropterus salmoides	juvenile	4 Replicates/n=5/trea	29			30.9	29	25.6								9	Díaz et al. 2007	1
79	Largemouth Bass	Micropterus salmoides	juvenile	4 Replicates/n=5/trea	20			29.2	27.1	24.6								9	Díaz et al. 2007	1
80	Largemouth Bass	Micropterus salmoides	juvenile	4 Replicates/n=5/trea	23			28.8	27.5	25								9	Díaz et al. 2007	1
81	Largemouth Bass	Micropterus salmoides	juvenile	4 Replicates/n=5/trea	26			29.2	28	26.7								9	Díaz et al. 2007	1
82	Largemouth Bass	Micropterus salmoides			20									32.5					Brett 1956	1
83	Largemouth Bass	Micropterus salmoides			25									34.5					Brett 1956	1
84	Largemouth Bass	Micropterus salmoides			30									36.4					Brett 1956	1
85	Largemouth Bass	Micropterus salmoides	yoy	300-400 fish										35.6			2-4 deg C	24	Cvancara et al. 1976	1
86	Largemouth Bass	Micropterus salmoides							31										Ferguson 1958	1
87	Largemouth Bass	Micropterus salmoides							27.15										Bennett 1965	1
88	Largemouth Bass	Micropterus salmoides	adult			29	25.5		27										Coutant 1975	1
89																				
90					**minimum**	29.00	25.50	28.80	25.60	21.70		26.00		32.20		33.60				
91					**median**	**29.00**	**25.50**	**29.35**	**27.70**	**25.30**		**29.50**		**35.20**		**37.80**				
92					**maximum**	29.00	25.50	33.30	31.00	27.10		32.00		36.40		40.08				
93					**(n)**	1	1	8	29	8		4		7		19				
94																				
95																				
96					**Estimates of Factors**						**Calculation of Metrics**			**Notes on Calculation Methods**						
97											DM2MOS	1.5								
98					Median CTM's				37.80		DM1MOS	**1.14**		MOS method 1: 20% rule with median UILT/UUILT and Optimum Temperature						
99					2 Median CTM's-conversion				37.00		DM 2	35.50								
100					1 Median UILT/UUILT				35.20		**DM 1**	**34.06**		DM method 1: Median UILT/UUILT - MOS						
101					1 Optimum Temperature for 1/3 Rule				29.50		**MWAT 1**	**31.381**		MWAT method 1: 1/3 rule with Optimum Temperature						
102					2 Pref Ave for 1/3 Rule				27.70		MWAT 2	30.175								
103					3 Avoided High for 1/3 Rule				29.00		MWAT 3	31.046		29 was chosen as Avoided High because there were no known acclimation temperatures						
104					4 Upper Optimum				no data		MWAT 4	no data								
105																				
106				Notes: data not used																
107					1= acclimation too low- below 15															
108					2= acclimation too high- above 30 or higher than min CTM															
109					3= lifestage = embryo/larvae															
110					4= field study															

[1] Northern subspecies; fish were tested during fall. 'Final Preferenda' were calculated via the method of Fry 1947 also reported in Table 1, but not included in the database.
[2] Florida subspecies; fish were tested during fall. 'Final Preferenda' were calculated via the method of Fry 1947 also reported in Table 1, but not included in the database.
[3] Northern X Florida subspecies; fish were tested during fall. 'Final Preferenda' were calculated via the method of Fry 1947 also reported in Table 1, but not included in the database.
[4] Florida X Northern subspecies; fish were tested during fall. 'Final Preferenda' were calculated via the method of Fry 1947 also reported in Table 1, but not included in the database.
[5] Pure Northern stock; parental stocks were wild caught, then crossed in the laboratory. Study tested Northern X Florida and hybrid strains; hybrids had intermediate values and were not includes in the database.
[6] Study methods are an early predecessor to UILT methods. The study tested tolerance over 24 hour, four minute, 15 minute, 1 hour, and 4 hour intervals. Tolerances were also reported; author used a weighted average for lethal temperature.
[7] Northern Strain. Fish were tested in June. CTM was reported as "mean lethal temperature" in Table 2.
[8] Florida Strain. Fish were tested in June. CTM was reported as "mean lethal temperature" in Table 2.
[9] Fish were fasted for 24 hours before being tested. Upper, Lower, and Average preferred temperatures are the bounds of the middle 50th percentile of preferences of individual fish (estimated by ruler from Figure 2).
[10] The optimum reported here is the median of the three temperature treatments with the lowest mortality rates in the study (17.5°C, 20°C, 22.5°C), although mortality remained relatively low through 30°C when fish embryos were tempered rather than directly transferred.
[11] Summer captures. Sample size was not given, but sampling design and other plots suggest they are high for most species; Winter data also provided but not included in database.
[12] Fall captures. Sample size was not given, but sampling design and other plots suggest they are high for most species; Winter data also provided but not included in database.
[13] Par Pond System, Savannah River Labs. The site receives nuclear plant heated effluent.
[14] Results indicate daytime preference. The acclimation temperature is the median of the range reported (20-24°C). Sample size refers to number of fish, and several measurements from each taken over time.
[15] Results indicate nighttime preference. The acclimation temperature is the median of the range reported (20-24°C). Sample size refers to number of fish, and several measurements from each taken over time.
[16] The Preferred Average is the median of minimum and maximum preferred temperatures recorded during a 24-hour period, which are reported as the Lower and Upper Preferred temperatures here.
[17] The Preferred Average is the median of the average preferred daytime and nighttime temperatures of four adult bass in the study.
[18] The Preferred Average is the average occupied temperature of five fish used in the study.
[19] Fish were 51-79 mm in length. Recorded replicates and sample size are the minimum for all species tested.
[20] Acclimation took place in a nest in a hatchery pond. Optima are the top two temperatures reported, but this is supported by author claims that fry from another nest survived and grew poorly at 32.5°C. Sample size was very large; 10 fish/day were sampled in each tank over the study.

[21] October-November testing.
[22] Northern stock.
[23] Southern stock.
[24] Summer.

1	Common name	Scientific name	Life stage	Replicates/Sample Size	Acclimation Temperature	Avoid high	Avoid low	Pref high	Pref ave	Pref low	Lower Optimum	Optimum	Upper Optimum	UILT	UUILT	CTM	Rate of Increase (CTM)	Other Notes	Complete Reference	Lab (y/n)
2	Longnose Dace	Rhinichthys cataractae	adult	12	15											31.4	1 C/min		Kowalski et al. 1978	1
3																				
4																				
5					**minimum**											31.40				
6					**median**											**31.40**				
7					**maximum**											31.40				
8					**(n)**											1				
9																				
10																				
11					**Estimates of Factors**						**Calculation of Metrics**			**Notes on Calculation Methods**						
12											DM2MOS	**2**		MOS method 2: default = 2						
13					Median CTM's				31.40		DM1MOS	2								
14				2	Median CTM's-conversion				30.60		**DM 2**	**28.60**		DM method 2: Converted CTM - MOS						
15				1	Median UILT/UUILT				no data		DM 1	no data								
16				1	Optimum Temperature for 1/3 Rule				no data		MWAT 1	no data		Cannot calculate MWAT; no optimal data						
17				2	Pref Ave for 1/3 Rule				no data		MWAT 2	no data								
18				3	Avoided High for 1/3 Rule				no data		MWAT 3	no data								
19				4	Upper Optimum				no data		MWAT 4	no data								
20																				
21				Notes:	data not used															
22					1= acclimation too low- below 15															
23					2= acclimation too high- above 30 or higher than min CTM															
24					3= lifestage = embryo/larvae															
25					4= field study															

	Common Name	Scientific Name	Life stage	Replicates/Sample Size	Acclimation Temperature	Avoid high	Avoid low	Pref high	Pref ave	Pref low	Lower Optimum	Optimum	Upper Optimum	UILT	UUILT	CTM	Rate of Increase (CTM)	Other Notes	Complete Reference	Lab (y/n)
1																				
2	Longnose Sucker	Catastomus catastomus	see notes	500															Michaud 1981	0
3	Longnose Sucker	Catastomus catastomus		N=36/n=6	11.5									27					Black 1953	1
4	Longnose Sucker	Catastomus catastomus			14									26.6					Black 1953	1
5																				
6					**minimum**									26.60						
7					**median**									**26.80**						
8					**maximum**									27.00						
9					**(n)**									2						
10																				
11																				
12					**Estimates of Factors**						**Calculation of Metrics**			**Notes on Calculation Methods**						
13											DM2MOS	2								
14					Median CTM's				no data		DM1MOS	**2**		MOS method 2: default = 2						
15				2	Median CTM's-conversion				no data		DM 2	no data								
16				1	Median UILT/UUILT				26.80		**DM 1**	**24.80**		DM method 1: Median UILT/UUILT - MOS						
17				1	Optimum Temperature for 1/3 Rule				no data		MWAT 1	no data		Cannot calculate MWAT; no optimal data						
18				2	Pref Ave for 1/3 Rule				no data		MWAT 2	no data								
19				3	Avoided High for 1/3 Rule				no data		MWAT 3	no data								
20				4	Upper Optimum				no data		MWAT 4	no data								
21																				
22				Notes: data not used																
23					1= acclimation too low- below 15															
24					2= acclimation too high- above 30 or higher than min CTM															
25					3= lifestage = embryo/larvae															
26					4= field study															

1	Common Name	Scientific Name	Life stage	Replicates/Sample Size	Acclimation Temperature	Avoid high	Avoid low	Pref high	Pref ave	Pref low	Lower Optimum	Optimum	Upper Optimum	UILT	UUILT	CTM	Rate of Increase (CTM)	Other Notes	Complete Reference	Lab (y/n)
2	Mottled Sculpin	Cottus bairdii	adult	9	15											30.9	1 C/min		Kowalski et al. 1978	1
3																				
4																				
5					**minimum**											30.90				
6					**median**											**30.90**				
7					**maximum**											30.90				
8					**(n)**											1				
9																				
10																				
11					**Estimates of Factors**						**Calculation of Metrics**			**Notes on Calculation Methods**						
12											DM2MOS	2		MOS method 2: default = 2						
13					Median CTM's				30.90		DM1MOS	2								
14					2 Median CTM's-conversion				29.85		**DM 2**	**27.85**		DM method 2: Converted CTM - MOS						
15					1 Median UILT/UUILT				no data		DM 1	no data								
16					1 Optimum Temperature for 1/3 Rule				no data		MWAT 1	no data		Cannot calculate MWAT; no optimal data						
17					2 Pref Ave for 1/3 Rule				no data		MWAT 2	no data								
18					3 Avoided High for 1/3 Rule				no data		MWAT 3	no data								
19					4 Upper Optimum				no data		MWAT 4	no data								
20				** 1.05 used as CTM conversion factor																
21				Notes: data not used																
22					1= acclimation too low- below 7															
23					2= acclimation too high- above 23 or higher than min CTM															
24					3= lifestage = embryo/larvae															
25					4= field study															

1	Common Name	Scientific Name	Life stage	Replicates/Sample Size	Acclimation Temperature	Avoid high	Avoid low	Pref high	Pref ave	Pref low	Lower Optimum	Optimum	Upper Optimum	UILT	UUILT	CTM	Rate of Increase (CTM)	Other Notes	Complete Reference	Lab (y/n)
2	Mountain Sucker	Catostomus platyrhynchus							17									Summer	Wydoski and Whitney 1979	1
3	Mountain Sucker	Catostomus platyrhynchus		18	20											31.5	0.3C/min		Schultz and Bertrand 2011	1
4	Mountain Sucker	Catostomus platyrhynchus		18	20											32.3	0.3C/min		Schultz and Bertrand 2011	1
5	Mountain Sucker	Catostomus platyrhynchus		18	20											32.5	0.3C/min		Schultz and Bertrand 2011	1
6	Mountain Sucker	Catostomus platyrhynchus		18	20											32.9	0.3C/min		Schultz and Bertrand 2011	1
7	Mountain Sucker	Catostomus platyrhynchus		18	22.5											32.4	0.3C/min		Schultz and Bertrand 2011	1
8	Mountain Sucker	Catostomus platyrhynchus		18	22.5											32.6	0.3C/min		Schultz and Bertrand 2011	1
9	Mountain Sucker	Catostomus platyrhynchus		18	22.5											32.7	0.3C/min		Schultz and Bertrand 2011	1
10	Mountain Sucker	Catostomus platyrhynchus		18	22.5											33.2	0.3C/min		Schultz and Bertrand 2011	1
11	Mountain Sucker	Catostomus platyrhynchus		18	25											33.4	0.3C/min		Schultz and Bertrand 2011	1
12	Mountain Sucker	Catostomus platyrhynchus		18	25											33.6	0.3C/min		Schultz and Bertrand 2011	1
13	Mountain Sucker	Catostomus platyrhynchus		18	25											33.7	0.3C/min		Schultz and Bertrand 2011	1
14	Mountain Sucker	Catostomus platyrhynchus		18	25											34	0.3C/min		Schultz and Bertrand 2011	1
15																				
16					**minimum**				17.00							31.50				
17					**median**				**17.00**							**32.80**				
18					**maximum**				17.00							34.00				
19					**(n)**				1							12				
20																				
21																				

22	**Estimates of Factors**		**Calculation of Metrics**		**Notes on Calculation Methods**
23			DM2MOS	3	MOS method 1: 20% rule with converted CTM and Preferred Average
24	Median CTM's	32.80	DM1MOS	no data	
25	2 Median CTM's-conversion	32.00	**DM 2**	**29.00**	DM method 2: Converted CTM - MOS
26	1 Median UILT/UUILT	no data	DM 1	no data	
27	1 Optimum Temperature for 1/3 Rule	no data	MWAT 1	no data	
28	2 Pref Ave for 1/3 Rule	17.00	**MWAT 2**	**21.95**	MWAT method 2: 1/3 rule with Preferred Average
29	3 Avoided High for 1/3 Rule	no data	MWAT 3	no data	
30	4 Upper Optimum	no data	MWAT 4	no data	
31					

32	Notes: data not used
33	1= acclimation too low- below 7
34	2= acclimation too high- above 23 or higher than min CTM
35	3= lifestage = embryo/larvae
36	4= field study

1	Common Name	Scientific Name	Life stage	Replicates/Sample Size	Acclimation Temperature	Avoid high	Avoid low	Pref high	Pref ave	Pref low	Lower Optimum	Optimum	Upper Optimum	UILT	UUILT	CTM	Rate of Increase (CTM)	Other Notes	Complete Reference	Lab (y/n)
2	Mountain Whitefish	Prosopium williamsoni	adult	N=12	5			16.9	12.6	9.7								1	Inhat and Bulkley 1984	1
3	Mountain Whitefish	Prosopium williamsoni	adult	N=11	5			17.8	10.9	6.9								2	Inhat and Bulkley 1984	1
4	Mountain Whitefish	Prosopium williamsoni	adult	N=10	5			18.9	10	5								3	Inhat and Bulkley 1984	1
5	Mountain Whitefish	Prosopium williamsoni	adult	N=10	5			14.8	11.1	8.1								4	Inhat and Bulkley 1984	1
6	Mountain Whitefish	Prosopium williamsoni	adult	N=10	4 C (ambient Logan River)			16.5	10.8	4.8								3	Inhat and Bulkley 1984	1
7	Mountain Whitefish	Prosopium williamsoni	adult	N=12	4-8 C (ambient Logan River)			13.8	9.6	5.3								5	Inhat and Bulkley 1984	1
8	Mountain Whitefish	Prosopium williamsoni	adult	N=10	10			15.9	12.6	9.7								6	Inhat and Bulkley 1984	1
9	Mountain Whitefish	Prosopium williamsoni	adult	N=12	10			19.5	11.8	6								2	Inhat and Bulkley 1984	1
10	Mountain Whitefish	Prosopium williamsoni	adult	N=10	10			15	9.9	5.9								3	Inhat and Bulkley 1984	1
11	Mountain Whitefish	Prosopium williamsoni	adult	N=10	10			22	14.3	8.9								4	Inhat and Bulkley 1984	1
12	Mountain Whitefish	Prosopium williamsoni	adult	N=12	15			23	17.4	11.1								1	Inhat and Bulkley 1984	1
13	Mountain Whitefish	Prosopium williamsoni	adult	N=9	15			16.9	12.6	7.1								2	Inhat and Bulkley 1984	1
14	Mountain Whitefish	Prosopium williamsoni	adult	N=10	15			15	11.4	7.6								3	Inhat and Bulkley 1984	1
15	Mountain Whitefish	Prosopium williamsoni	adult	N=10	15			22.9	16.3	9.9								4	Inhat and Bulkley 1984	1
16	Mountain Whitefish	Prosopium williamsoni	adult	N=9	7-10 C (ambient Logan River)			20.8	16.4	9.8								4	Inhat and Bulkley 1984	1
17	Mountain Whitefish	Prosopium williamsoni	adult	N=13	9-11 C (ambient Logan River)			17	12.8	7.9								1	Inhat and Bulkley 1984	1
18																				
19					**minimum**			15.00	9.90	5.90										
20					**median**			**18.25**	**12.70**	**8.40**										
21					**maximum**			23.00	17.40	11.10										
22					**(n)**			10	10	10										
23																				
24																				
25					**Estimates of Factors**						**Calculation of Metrics**			**Notes on Calculation Methods**						
26											DM2MOS	2								
27					Median CTM's				no data		DM1MOS	2		MOS method 2: default = 2						
28				2	Median CTM's-conversion				no data		DM 2	no data								
29				1	Median UILT/UUILT				no data		DM 1	no data		Cannot calculate DM; no lethal data						
30				1	Optimum Temperature for 1/3 Rule				no data		MWAT 1	no data		Cannot calculate MWAT; no lethal data or Upper Optimum						
31				2	Pref Ave for 1/3 Rule				12.70		MWAT 2	no data								
32				3	Avoided High for 1/3 Rule				no data		MWAT 3	no data								
33				4	Upper Optimum				no data		MWAT 4	no data								
34																				
35				Notes: data not used																
36					1= acclimation too low- below 15															
37					2= acclimation too high- above 30 or higher than min CTM															
38					3= lifestage = embryo/larvae															
39					4= field study															

[1] Pre-spawning stage; total length of fish averaged 338 mm. Preferred Average is the mean of modes for the sample of fish tested.

[2] Post-spawning stage; total length of fish averaged 338 mm. Preferred Average is the mean of modes for the sample of fish tested.

[3] Winter; total length of fish averaged 338 mm. Preferred Average is the mean of modes for the sample of fish tested.

[4] Spring; total length of fish averaged 338 mm. Preferred Average is the mean of modes for the sample of fish tested.

[5] Post-spawning stage; total length of fish averaged 338 mm. Preferred Average is the mode (mean = 10.4°C; median = 10.1°C).

[6] Pre-spawning stage; total length of fish averaged 338 mm. Preferred Average is the mode (mean = 12.7°C; median = 12.4°C).

1	Common Name	Scientific Name	Life stage	Replicates/Sample Size	Acclimation Temperature	Avoid high	Avoid low	Pref high	Pref ave	Pref low	Lower Optimum	Optimum	Upper Optimum	UILT	UUILT	CTM	Rate of Increase (CTM)	Spawning info	Other Notes	Complete Reference	Lab (y/n)
2	Northern Leatherside Chub	Lepidomeda copei																18.4	1	Bartley et al. 2012	1
3	Northern Leatherside Chub	Lepidomeda copei	juvenile									23							2	Billman et al. 2008	1
4	Northern Leatherside Chub	Lepidomeda copei	juvenile									23.2							3	Billman et al. 2008	1
5	Northern Leatherside Chub	Lepidomeda copei	juvenile	10	15											29.6	0.2C/min			Billman et al. 2008	1
6	Northern Leatherside Chub	Lepidomeda copei	juvenile	10	18											31.8	0.2C/min			Billman et al. 2008	1
7	Northern Leatherside Chub	Lepidomeda copei	juvenile	10	23											34.6	0.2C/min			Billman et al. 2008	1
8	Northern Leatherside Chub	Lepidomeda copei	juvenile	10	28											35	0.2C/min			Billman et al. 2008	1
9	Northern Leatherside Chub	Lepidomeda copei	juvenile	10 in 12-15 trt	15									26.5						Billman et al. 2008	1
10	Northern Leatherside Chub	Lepidomeda copei	juvenile	11 in 12-15 trt	18									28.7						Billman et al. 2008	1
11	Northern Leatherside Chub	Lepidomeda copei	juvenile	12 in 12-15 trt	23									30.4						Billman et al. 2008	1
12	Northern Leatherside Chub	Lepidomeda copei	juvenile	13 in 12-15 trt	28									30.2						Billman et al. 2008	1
13	Northern Leatherside Chub	Lepidomeda copei	yoy	90-120 fish								19							4	Johnson et al. 2004	1
14	Northern Leatherside Chub	Lepidomeda copei	yoy	100 fish								19							5	Johnson et al. 2004	1
15																					
16																					
17					**minimum**							19.00		26.50		29.60					
18					**median**							**21.00**		**29.45**		**33.20**					
19					**maximum**							23.20		30.40		35.00					
20					**(n)**							4		4		4					
21																					
22																					
23					**Estimates of Factors**						**Calculation of Metrics**			**Notes on Calculation Methods**							
24											DM2MOS	2.28									
25					Median CTM's				33.20		DM1MOS	**1.69**		MOS method 1: 20% rule with median UILT/UUILT and Optimum Temperature							
26				2	Median CTM's-conversion				32.40		DM 2	30.12									
27				1	Median UILT/UUILT				29.45		**DM 1**	**27.76**		DM method 1: Median UILT/UUILT - MOS							
28				1	Optimum Temperature for 1/3 Rule				21.00		**MWAT 1**	**23.7885**		MWAT method 1: 1/3 rule with Optimum Temperature							
29				2	Pref Ave for 1/3 Rule				no data		MWAT 2	no data									
30				3	Avoided High for 1/3 Rule				no data		MWAT 3	no data									
31				4	Upper Optimum				no data		MWAT 4	no data									
32																					
33				Notes: data not used																	
34					1= acclimation too low- below 15																
35					2= acclimation too high- above 30 or higher than min CTM																
36					3= lifestage = embryo/larvae																
37					4= field study																

[1] Optimum temperature for egg survival.

[2] Optimal temperature for growth; first trial.

[3] Optimal temperature for growth; second trial.

[4] Growth rate increased with increasing temperature up to 19°C and then leveled off.

[5] Feeding rate increased with increasing temperature up to 19°C, and decreased above 19°C.

1	Common Name	Scientific Name	Life stage	Replicates/Sample Size	Acclimation Temperature	Avoid high	Avoid low	Pref high	Pref ave	Pref low	Lower Optimum	Optimum	Upper Optimum	UILT	UUILT	CTM	Rate of Increase (CTM)	Other Notes	Complete Reference	Lab (y/n)
2	Pearl Dace	Margariscus margarita							16.2										Becker 1983	1
3																				
4					**minimum**				16.20											
5					**median**				**16.20**											
6					**maximum**				16.20											
7					**(n)**				1											
8																				
9																				
10					**Estimates of Factors**						**Calculation of Metrics**			**Notes on Calculation Methods**						
11											DM2MOS	2								
12					Median CTM's				no data		DM1MOS	2		MOS method 2: default = 2						
13				2	Median CTM's-conversion				no data		DM 2	no data								
14				1	Median UILT/UUILT				no data		DM 1	no data		Cannot calculate DM; no lethal data						
15				1	Optimum Temperature for 1/3 Rule				no data		MWAT 1	no data		Cannot calculate MWAT; no lethal data or Upper Optimum						
16				2	Pref Ave for 1/3 Rule				16.20		MWAT 2	no data								
17				3	Avoided High for 1/3 Rule				no data		MWAT 3	no data								
18				4	Upper Optimum				no data		MWAT 4	no data								
19																				
20				Notes:	data not used															
21					1= acclimation too low- below 15															
22					2= acclimation too high- above 30 or higher than min CTM															
23					3= lifestage = embryo/larvae															
24					4= field study															

1	Common Name	Scientific Name	Life stage	Replicates/Sample Size	Acclimation Temperature	Avoid high	Avoid low	Pref high	Pref ave	Pref low	Lower Optimum	Optimum	Upper Optimum	UILT	UUILT	CTM	Rate of Increase (CTM)	Other Notes	Complete Reference	Lab (y/n)
2	Northern Pike	Esox lucius	larvae		17.7									24.8					Hokanson et al. 1973	1
3	Northern Pike	Esox lucius	larvae		11.8									24.1					Hokanson et al. 1973	1
4	Northern Pike	Esox lucius	larvae		6.1									20.6					Hokanson et al. 1973	1
5	Northern Pike	Esox lucius	juvenile	N=130	25									32				1	Scott 1964	1
6	Northern Pike	Esox lucius	juvenile	N=130	30									33				1	Scott 1964	1
7	Northern Pike	Esox lucius	yoy	300-400 fish										30.8			2-4 deg C/hr	2	Cvancara et al. 1976	1
8																				
9					**minimum**									30.80						
10					**median**									**32.00**						
11					**maximum**									33.00						
12					**(n)**									3						
13																				
14																				
15					**Estimates of Factors**						**Calculation of Metrics**			**Notes on Calculation Methods**						
16											DM2MOS	2								
17					Median CTM's				no data		DM1MOS	**2**		MOS method 2: default = 2						
18				2	Median CTM's-conversion				no data		DM 2	no data								
19				1	Median UILT/UUILT				32.00		**DM 1**	**30.00**		DM method 1: Median UILT/UUILT - MOS						
20				1	Optimum Temperature for 1/3 Rule				no data		MWAT 1	no data		Cannot calculate MWAT; no optimal data						
21				2	Pref Ave for 1/3 Rule				no data		MWAT 2	no data								
22				3	Avoided High for 1/3 Rule				no data		MWAT 3	no data								
23				4	Upper Optimum				no data		MWAT 4	no data								
24																				
25				Notes: data not used																
26					1= acclimation too low- below 15															
27					2= acclimation too high- above 30 or higher than min CTM															
28					3= lifestage = embryo/larvae															
29					4= field study															

[1] The UILT is estimated from a plot of mean survival time after transfer to a range of lethal temperatures. Only values from tests of 24 hours or longer were used.

[2] Summer.

1	Common Name	Scientific Name	Life stage	Replicates/Sample Size	Acclimation Temperature	Avoid high	Avoid low	Pref high	Pref ave	Pref low	Lower Optimum	Optimum	Upper Optimum	UILT	UUILT	CTM	Rate of Increase (CTM)	Other Notes	Complete Reference	Lab (y/n)
2	Orangethroat Darter	Etheostoma spectabile		19	10											31.54	1 C/min		Lutterschmidt and Hutchinson 1997	1
3	Orangethroat Darter	Etheostoma spectabile		19	10											29.8	1 C/min		Lutterschmidt and Hutchinson 1997	1
4	Orangethroat Darter	Etheostoma spectabile	adult	N=4791	32.0 C				25.9									1	Hill and Matthews 1980	1
5	Orangethroat Darter	Etheostoma spectabile	adults	N=25	16											31.66	1 C/min	2	Strange et al. 2002	1
6	Orangethroat Darter	Etheostoma spectabile	adults	N=25	16											32.04	1 C/min	2	Strange et al. 2002	1
7	Orangethroat Darter	Etheostoma spectabile	adults	N=25	16											30.97	1 C/min	3	Strange et al. 2002	1
8	Orangethroat Darter	Etheostoma spectabile	adults	N=25	16											31.3	1 C/min	3	Strange et al. 2002	1
9	Orangethroat Darter	Etheostoma spectabile		NS (95 overall)	20											35.36	1 C/min	4	Feminella and Matthews 1984	1
10	Orangethroat Darter	Etheostoma spectabile		NS (95 overall)	20											34	1 C/min	5	Feminella and Matthews 1984	1
11	Orangethroat Darter	Etheostoma spectabile		NS (95 overall)	20											32.85	1 C/min	6	Feminella and Matthews 1984	1
12	Orangethroat Darter	Etheostoma spectabile		NS (95 overall)	20											32.2	1 C/min	7	Feminella and Matthews 1984	1
13	Orangethroat Darter	Etheostoma spectabile		NS (95 overall)	20											34.36	1 C/min	8	Feminella and Matthews 1984	1
14	Orangethroat Darter	Etheostoma spectabile		NS (95 overall)	20											33.46	1 C/min	9	Feminella and Matthews 1984	1
15	Orangethroat Darter	Etheostoma spectabile		NS (95 overall)	20											34.36	1 C/min	10	Feminella and Matthews 1984	1
16	Orangethroat Darter	Etheostoma spectabile		NS (95 overall)	20											32.81	1 C/min	11	Feminella and Matthews 1984	1
17	Orangethroat Darter	Etheostoma spectabile		8	26											36.5	2 C/hr		Smale and Rabeni 1995	1
18	Orangethroat Darter	Etheostoma spectabile	juvenile adult	N=15	29											37.92	1 C/min	12	Matthews et al. 1982	1
19	Orangethroat Darter	Etheostoma spectabile	adult	N=1889	16.0 C				19.6									1	Hill and Matthews 1980	1
20	Orangethroat Darter	Etheostoma spectabile	adult	N=6849	21.0 C				20.5									1	Hill and Matthews 1980	1
21	Orangethroat Darter	Etheostoma spectabile	adult	N=3475	26.0 C				23.6									1	Hill and Matthews 1980	1
22																				
23					**minimum**				19.60							30.97				
24					**median**				**20.50**							**33.16**				
25					**maximum**				23.60							37.92				
26					**(n)**				3							14				
27																				

29	**Estimates of Factors**		**Calculation of Metrics**	**Notes on Calculation Methods**
30			DM2MOS **2.371**	MOS method 1: Converted CTM - Preferred Average
31	Median CTM's	33.16	DM1MOS 2	
32	2 Median CTM's-conversion	32.36	**DM 2 29.98**	DM method 2: Converted CTM - MOS
33	1 Median UILT/UUILT	no data	DM 1 no data	
34	1 Optimum Temperature for 1/3 Rule	no data	MWAT 1 no data	
35	2 Pref Ave for 1/3 Rule	20.50	**MWAT 2 24.4122**	MWAT method 2: 1/3 rule with Preferred Average
36	3 Avoided High for 1/3 Rule	no data	MWAT 3 no data	
37	4 Upper Optimum	no data	MWAT 4 no data	
38				
39	Notes: data not used			
40	1= acclimation too low- below 15			
41	2= acclimation too high- above 30 or higher than min CTM			
42	3= lifestage = embryo/larvae			
43	4= field study			

[1] The sample size refers to the number of observations from twenty fish tested in groups of three. The Preferred Average indicates the mean.

[2] Fish are from Clear Creek. The sample size is not clearly stated, but 25 fish were captured from each site.

[3] Fish are from Devils Icebox Spring Branch. The sample size is not clearly stated, but 25 fish were captured from each site.

[4] Fish are from Brier Creek. The CTM endpoint was the onset of muscle spasms.

[5] Fish are from Byrd's Mill Creek. The CTM endpoint was the loss of equilibrium.

[6] Fish are from Pennington Creek. The CTM endpoint was the loss of equilibrium.

[7] Fish are from Cummings Spring. The CTM endpoint was the loss of equilibrium.

[8] Fish are from Brier Creek. The CTM endpoint was the loss of equilibrium.
[9] Fish are from Pennington Creek. The CTM endpoint was the onset of muscle spasms.
[10] Fish are from Byrd's Mill Creek. The CTM endpoint was the onset of muscle spasms.
[11] Fish are from Cummings Spring. The CTM endpoint was the onset of muscle spasms.
[12] The temperature acclimation period is suspected to be long because fish were captured, maintained at 29°C (field temperature), and tested starting at field temperatures 2 hours after capture.

1	Common Name	Scientific Name	Life stage	Replicates/Sample Size	Acclimation Temperature	Avoid high	Avoid low	Pref high	Pref ave	Pref low	Lower Optimum	Optimum	Upper Optimum	UILT	UUILT	CTM	Rate of Increase (CTM)	Other Notes	Complete Reference	Lab (y/n)
2	Paiute Sculpin	Cottus beldingii										16.6	20.5					1	Huff et al. 2005	0
3																				
4					**minimum**															
5					**median**															
6					**maximum**															
7					**(n)**															
8																				
9					**Estimates of Factors**						**Calculation of Metrics**			**Notes on Calculation Methods**						
10											DM2MOS		2							
11					Median CTM's				no data		DM1MOS		2	MOS method 2: default = 2						
12				2	Median CTM's-conversion				no data		DM 2	no data								
13				1	Median UILT/UUILT				no data		DM 1	no data		Cannot calculate DM; no lethal data						
14				1	Optimum Temperature for 1/3 Rule				no data		MWAT 1	no data		Cannot calculate MWAT; no optimal data						
15				2	Pref Ave for 1/3 Rule				no data		MWAT 2	no data								
16				3	Avoided High for 1/3 Rule				no data		MWAT 3	no data								
17				4	Upper Optimum				no data		MWAT 4	no data								
18																				
19				Notes:	data not used															
20					1= acclimation too low- below 7															
21					2= acclimation too high- above 23 or higher than min CTM															
22					3= lifestage = embryo/larvae															
23					4= field study															

[1] This study calculated the realized thermal center (RNC) as 16.6°C and the upper limit of the realized thermal niche width (RNW) as 20.5°C.

	Common name	Scientific Name	Life stage	Replicates/Sample Size	Acclimation Temperature	Avoid high	Avoid low	Pref high	Pref ave	Pref low	Lower Optimum	Optimum	Upper Optimum	UILT	UUILT	CTM	Rate of Increase (CTM)	Other Notes	Complete Reference	Lab (y/n)
2	Plains Killifish	Fundulus zebrinus	adult		25											40.5	0.5 C/min	1	Ostrand and Wilde 2001	1
3	Plains Killifish	Fundulus zebrinus	adult		30											42	0.5 C/min	1	Ostrand and Wilde 2001	1
4																				
5					**minimum**											40.50				
6					**median**											**41.25**				
7					**maximum**											42.00				
8					**(n)**											2				
9																				
10																				
11					**Estimates of Factors**						**Calculation of Metrics**			**Notes on Calculation Methods**						
12											DM2MOS		**2**	MOS method 2: default = 2						
13					Median CTM's				41.25		DM1MOS		2							
14					2 Median CTM's-conversion				40.45		**DM 2**		**38.45**	DM method 2: Converted CTM - MOS						
15					1 Median UILT/UUILT				no data		DM 1		no data							
16					1 Optimum Temperature for 1/3 Rule				no data		MWAT 1		no data	Cannot calculate MWAT; no optimal data						
17					2 Pref Ave for 1/3 Rule				no data		MWAT 2		no data							
18					3 Avoided High for 1/3 Rule				no data		MWAT 3		no data							
19					4 Upper Optimum				no data		MWAT 4		no data							
20																				
21				Notes:	data not used															
22					1= acclimation too low- below 15															
23					2= acclimation too high- above 30 or higher than min CTM															
24					3= lifestage = embryo/larvae															
25					4= field study															

[1] Sample size was not specified. Fish were fasted for two days prior to tolerance tests. Other variables were included in the study but those results are not reported here.

1	Common Name	Scientific Name	Life stage	Replicates/Sample Size	Acclimation Temperature	Avoid high	Avoid low	Pref high	Pref ave	Pref low	Lower Optimum	Optimum	Upper Optimum	UILT	UUILT	CTM	Rate of Increase (CTM)	Other Notes	Complete Reference	Lab (y/n)
2	Plains Minnow	Hybognathus placitus		26	10											28.37	1 C/min		Lutterschmidt and Hutchinson 1997	1
3	Plains Minnow	Hybognathus placitus		26	10											31.75	1 C/min		Lutterschmidt and Hutchinson 1997	1
4	Plains Minnow	Hybognathus placitus	adult	N=100	21				30									1	Bryan et al. 1984	1
5	Plains Minnow	Hybognathus placitus	adult		25											37.9	0.5 C/min	2	Ostrand and Wile 2001	1
6	Plains Minnow	Hybognathus placitus	adult	n=2	25											39.95	1 C/min	3	Matthews and Maness 1979	1
7	Plains Minnow	Hybognathus placitus	adult		30											39.7	0.5 C/min	2	Ostrand and Wile 2001	1
8																				
9					**minimum**				30.00							37.90				
10					**median**				**30.00**							**39.70**				
11					**maximum**				30.00							39.95				
12					**(n)**				1							3				
13																				
14																				
15					**Estimates of Factors**						**Calculation of Metrics**			**Notes on Calculation Methods**						
16											DM2MOS	**1.78**		MOS method 1: 20% rule with converted CTM and Preferred Average						
17					Median CTM's				39.70		DM1MOS	no data								
18					2 Median CTM's-conversion				38.90		**DM 2**	**37.12**		DM method 2: Converted CTM - MOS						
19					1 Median UILT/UUILT				no data		DM 1	no data								
20					1 Optimum Temperature for 1/3 Rule				no data		MWAT 1	no data								
21					2 Pref Ave for 1/3 Rule				30.00		**MWAT 2**	**32.937**		MWAT method 2: 1/3 rule with Preferred Average						
22					3 Avoided High for 1/3 Rule				no data		MWAT 3	no data								
23					4 Upper Optimum				no data		MWAT 4	no data								
24																				
25				Notes:	data not used															
26					1= acclimation too low- below 15															
27					2= acclimation too high- above 30 or higher than min CTM															
28					3= lifestage = embryo/larvae															
29					4= field study															

[1] Temperature preference was reported for DO levels > 5 mg/L (range = 5-9mg/L); preferred temperature dropped at lower DO levels.

[2] Sample size was not specified. Fish were fasted for two days prior to tolerance tests. Other variables were included in the study but those results are not reported here.

[3] Sample size was small (*n* = 2). The rate of increase is assumed to be the same as that used by Hutchison (1961).

1	Common Name	Scientific Name	Life stage	Replicates/Sample Size	Acclimation Temperature	Avoid high	Avoid low	Pref high	Pref ave	Pref low	Lower Optimum	Optimum	Upper Optimum	UILT	UUILT	CTM	Rate of Increase (CTM)	Other Notes	Complete Reference	Lab (y/n)
2	Plains Topminnow	Fundulus sciadicus		3	26											37	2 C/hr		Smale and Rabeni 1995	1
3																				
4					**minimum**											37.00				
5					**median**											**37.00**				
6					**maximum**											37.00				
7					**(n)**											1				
8																				
9																				
10					**Estimates of Factors**						**Calculation of Metrics**			**Notes on Calculation Methods**						
11											DM2MOS		**2**	MOS method 2: default = 2						
12					Median CTM's				37.00		DM1MOS		no data							
13				2	Median CTM's-conversion				36.20		**DM 2**		**34.20**	DM method 2: Converted CTM - MOS						
14				1	Median UILT/UUILT				no data		DM 1		no data							
15				1	Optimum Temperature for 1/3 Rule				no data		MWAT 1		no data	Cannot calculate MWAT; no optimal data						
16				2	Pref Ave for 1/3 Rule				no data		MWAT 2		no data							
17				3	Avoided High for 1/3 Rule				no data		MWAT 3		no data							
18				4	Upper Optimum				no data		MWAT 4		no data							
19																				
20				Notes:	data not used															
21					1= acclimation too low- below 15															
22					2= acclimation too high- above 30 or higher than min CTM															
23					3= lifestage = embryo/larvae															
24					4= field study															

1	Common Name	Scientific Name	Life stage	Replicates/ Sample Size	Acclimation Temperature	Avoid high	Avoid low	Pref high	Pref ave	Pref low	Lower Optimum	Optimum	Upper Optimum	UILT	UUILT	CTM	Rate of Increase (CTM)	Other Notes	Complete Reference	Lab (y/n)
2	Pumpkinseed Sunfish	Lepomis gibbosus	juvenile	3/N=10	10									30				1	Hathaway 1928	1
3	Pumpkinseed Sunfish	Lepomis gibbosus	adult	24	10											30.07	0.3 C/min		Becker and Genoway 1979	1
4	Pumpkinseed Sunfish	Lepomis gibbosus	adult	24	10											29.53	0.1 C/min		Becker and Genoway 1979	1
5	Pumpkinseed Sunfish	Lepomis gibbosus	adult	24	10											30.37	0.5 C/min		Becker and Genoway 1979	1
6	Pumpkinseed Sunfish	Lepomis gibbosus	adult	32	10											31.55	0.02 C/mi		Becker and Genoway 1979	1
7	Pumpkinseed Sunfish	Lepomis gibbosus	adult	24	10											31.43	1 C/min		Becker and Genoway 1979	1
8	Pumpkinseed Sunfish	Lepomis gibbosus	adult	24	10											30.51	0.1 C/min		Becker and Genoway 1979	1
9	Pumpkinseed Sunfish	Lepomis gibbosus	adult	24	10											31.86	0.3 C/min		Becker and Genoway 1979	1
10	Pumpkinseed Sunfish	Lepomis gibbosus	adult	24	10											32.63	0.5 C/min		Becker and Genoway 1979	1
11	Pumpkinseed Sunfish	Lepomis gibbosus	adult	24	10											32.87	0.02 C/mi		Becker and Genoway 1979	1
12	Pumpkinseed Sunfish	Lepomis gibbosus	adult	32	10											34.61	1 C/min		Becker and Genoway 1979	1
13	Pumpkinseed Sunfish	Lepomis gibbosus		N=18/n=6	11									30.2					Black 1953	1
14	Pumpkinseed Sunfish	Lepomis gibbosus	adult	24	20											36.81	0.3 C/min		Becker and Genoway 1979	1
15	Pumpkinseed Sunfish	Lepomis gibbosus	adult	24	20											36.88	0.5 C/min		Becker and Genoway 1979	1
16	Pumpkinseed Sunfish	Lepomis gibbosus	adult	32	20											38.12	1 C/min		Becker and Genoway 1979	1
17	Pumpkinseed Sunfish	Lepomis gibbosus	adult	24	20											35.64	0.02 C/mi		Becker and Genoway 1979	1
18	Pumpkinseed Sunfish	Lepomis gibbosus	adult	32	20											36.56	1 C/min		Becker and Genoway 1979	1
19	Pumpkinseed Sunfish	Lepomis gibbosus	adult	24	20											36.03	0.1 C/min		Becker and Genoway 1979	1
20	Pumpkinseed Sunfish	Lepomis gibbosus	adult	24	20											35.06	0.3 C/min		Becker and Genoway 1979	1
21	Pumpkinseed Sunfish	Lepomis gibbosus	adult	24	20											35.08	0.1 C/min		Becker and Genoway 1979	1
22	Pumpkinseed Sunfish	Lepomis gibbosus	adult	24	20											35.3	0.02 C/mi		Becker and Genoway 1979	1
23	Pumpkinseed Sunfish	Lepomis gibbosus	adult	24	20											35.16	0.5 C/min		Becker and Genoway 1979	1
24	Pumpkinseed Sunfish	Lepomis gibbosus	juvenile	2/N=6	22.5									34				1	Hathaway 1928	1
25	Pumpkinseed Sunfish	Lepomis gibbosus	juvenile	(N=4/n=29)	25.5									34.5				2	Brett 1944	1
26	Pumpkinseed Sunfish	Lepomis gibbosus	juvenile	2/N=8	30									34.3				1	Hathaway 1928	1
27	Pumpkinseed Sunfish	Lepomis gibbosus	adult	N=6	not reported				26										Reynolds an Casterlin 1977	1
28	Pumpkinseed Sunfish	Lepomis gibbosus			18									28					Black 1953	1
29	Pumpkinseed Sunfish	Lepomis gibbosus			24									30.2					Black 1953	1
30	Pumpkinseed Sunfish	Lepomis gibbosus	adult		23.1				27.7							37.5		3	Reutter and Herdenorf 1976	1
31	Pumpkinseed Sunfish	Lepomis gibbosus							31.5										Ferguson 1958	1
32																				
33					**minimum**				26.00					28.00		35.06				
34					**median**				**27.70**					**34.00**		**36.03**				
35					**maximum**				31.50					34.50		38.12				
36					**(n)**				3					5		11				
37																				
38																				
39					**Estimates of Factors**						**Calculation of Metrics**			**Notes on Calculation Methods**						
40											DM2MOS	1.506								
41					Median CTM's				36.03		DM1MOS	**1.26**		MOS method 1: 20% rule with median UILT/UUILT and Preferred Average						
42				2	Median CTM's-conversion				35.23		DM 2	33.72								
43				1	Median UILT/UUILT				34.00		**DM 1**	**32.74**		DM method 1: Median UILT/UUILT - MOS						
44				1	Optimum Temperature for 1/3 Rule				no data		MWAT 1	no data								
45				2	Pref Ave for 1/3 Rule				27.70		**MWAT 2**	**29.779**		MWAT method 2: 1/3 rule with Preferred Average						
46				3	Avoided High for 1/3 Rule				no data		MWAT 3	no data								
47				4	Upper Optimum				no data		MWAT 4	no data								
48																				
49				Notes: data not used																
50					1= acclimation too low- below 15															
51					2= acclimation too high- above 30 or higher than min CTM															
52					3= lifestage = embryo/larvae															
53					4= field study															

[1] Early predecessor of UILT; tested 4 minute, 15 minute, 1 hour, 4 hour, and 24 hour tolerances. Author used weighted average for the lethal temperature.
[2] No laboratory acclimation; the acclimation temperature is the median of the range reported during the collection period (Aug 3) for Lake Opeongo (25-26°C).
[3] Preferred Average was tested in the summer.

1	Common Name	Scientific Name	Life stage	Replicates/ Sample Size	Acclimation Temperature	Avoid high	Avoid low	Pref high	Pref ave	Pref low	Lower Optimum	Optimum	Upper Optimum	UILT	UUILT	CTM	Rate of Increase (CTM)	Other Notes	Complete Reference	Lab (y/n)
2	Quillback	Carpiodes cyprinus	45-57 mm TL	6	see notes											38.8	0.5-0.8C/min	1	Mundahl 1990	1
3	Quillback	Carpiodes cyprinus	see notes	see notes														2	Yoder and Gammon 1976	0
4	Quillback	Carpiodes cyprinus	adult		23.3				22.1							37.2		3	Reutter and Herdendorf 1976	1
5																				
6					**minimum**				22.10							37.20				
7					**median**				**22.10**							**37.20**				
8					**maximum**				22.10							37.20				
9					**(n)**				22.1							37.2				
10																				
11					**Estimates of Factors**						**Calculation of Metrics**			**Notes on Calculation Methods**						
12											DM2MOS	**2.86**		MOS method 1: 20% rule with converted CTM and Preferred Average						
13					Median CTM's				37.20		DM1MOS	no data								
14					2 Median CTM's-conversion				36.40		**DM 2**	**33.54**		DM method 1: Median UILT/UUILT - MOS						
15					1 Median UILT/UUILT				no data		DM 1	no data								
16					1 Optimum Temperature for 1/3 Rule				no data		MWAT 1	no data								
17					2 Pref Ave for 1/3 Rule				22.10		**MWAT 2**	**26.819**		MWAT method 2: 1/3 rule with Preferred Average						
18					3 Avoided High for 1/3 Rule				no data		MWAT 3	no data								
19					4 Upper Optimum				no data		MWAT 4	no data								
20																				
21				Notes: data not used																
22					1= acclimation too low- below 15															
23					2= acclimation too high- above 30 or higher than min CTM															
24					3= lifestage = embryo/larvae															
25					4= field study															

[1] Nonstandard acclimation process: acclimation temperature refers to natural conditions in a pool during low water with disconnected pools (temperatures ranged from 32.5°C in submerged rock cavities to 39.5°C in full sun).

[2] Fish were captured in summer. Sample size was not given, but the sampling design and other plots suggest that they are high for most species. Winter data were also provided but not included in the database.

[3] Preferred average was tested in the fall.

1	Common Name	Scientific Name	Life stage	Replicates/Sample Size	Acclimation Temperature	Avoid high	Avoid low	Pref high	Pref ave	Pref low	Lower Optimum	Optimum	Upper Optimum	UILT	UUILT	CTM	Rate of Increase (CTM)	Other Notes	Complete Reference	Lab (y/n)
2	Rainbow Trout	Oncorhynchus mykiss	juvenile	6	5				11.8									1	McCauley et al. 1977	1
3	Rainbow Trout	Oncorhynchus mykiss	yoy	n=50	5									23.7				2	Kaya 1978	1
4	Rainbow Trout	Oncorhynchus mykiss	juvenile	n=50	5									25				3	Kaya 1978	1
5	Rainbow Trout	Oncorhynchus mykiss	fry	N=8	6	18												4	Stauffer et al. 1984	1
6	Rainbow Trout	Oncorhynchus mykiss	fry	2 reps (n=10 each per temp)	6									24.6				4	Stauffer et al. 1984	1
7	Rainbow Trout	Oncorhynchus mykiss	juvenile	2/n=8(N=16)	6				11.6									5	Cherry et al. 1975	1
8	Rainbow Trout	Oncorhynchus mykiss	see notes	4/n=2(N=8)	6	13	5											5	Cherry et al. 1975	1
9	Rainbow Trout	Oncorhynchus mykiss	juvenile	N=48	6	18												6	Stauffer et al. 1984	1
10	Rainbow Trout	Oncorhynchus mykiss	juvenile	N=48	6									24.6				6	Stauffer et al. 1984	1
11	Rainbow Trout	Oncorhynchus mykiss	juvenile	N=559	5 C				16									7	Garside and Tait 1958	1
12	Rainbow Trout	Oncorhynchus mykiss	juvenile	N=461	5 C				15									8	Garside and Tait 1958	1
13	Rainbow Trout	Oncorhynchus mykiss	fry	N=8	24	27												4	Stauffer et al. 1984	1
14	Rainbow Trout	Oncorhynchus mykiss	juvenile	2/n=8(N=16)	24				22									5	Cherry et al. 1975	1
15	Rainbow Trout	Oncorhynchus mykiss	see notes	4/n=2(N=8)	24	25	19											5	Cherry et al. 1975	1
16	Rainbow Trout	Oncorhynchus mykiss	juvenile	N=48	24	27												6	Stauffer et al. 1984	1
17	Rainbow Trout	Oncorhynchus mykiss	juvenile	N=48	24									26				6	Stauffer et al. 1984	1
18	Rainbow Trout	Oncorhynchus mykiss	juvenile	n=60	24.5									26.2				3	Kaya 1978	1
19	Rainbow Trout	Oncorhynchus mykiss	yoy	n=50	24.5									26.2				2	Kaya 1978	1
20	Rainbow Trout	Oncorhynchus mykiss	juvenile	n=60	24.5									26.2				9	Kaya 1978	1
21	Rainbow Trout	Oncorhynchus mykiss	yoy	n=50	24.5									26.2				2	Kaya 1978	1
22	Rainbow Trout	Oncorhynchus mykiss	juvenile	6	25				12									1	McCauley et al. 1977	1
23	Rainbow Trout	Oncorhynchus mykiss	juvenile	N=48	6, 12, 18, 24				14.7									6	Stauffer et al. 1984	1
24	Rainbow Trout	Oncorhynchus mykiss	juvenile	N=48	6,12,18,24										26			6	Stauffer et al. 1984	1
25	Rainbow Trout	Oncorhynchus mykiss	fry	N=8	see notes				14.7									4	Stauffer et al. 1984	1
26	Rainbow Trout	Oncorhynchus mykiss	juvenile	N=10	18									26.5				10	Alabaster and Welcomme 1962	0
27	Rainbow Trout	Oncorhynchus mykiss	adult	N=137	18.9 (mean river temp)													11	Baltz et al. 1987	0
28	Rainbow Trout	Oncorhynchus mykiss	adult	N=137	18.9 (mean river temp)													12	Baltz et al. 1987	0
29	Rainbow Trout	Oncorhynchus mykiss	adult	N=137	21.0 (mean river temp)													13	Baltz et al. 1987	0
30	Rainbow Trout	Oncorhynchus mykiss	juvenile adult	N=27	ambient stream											29.4	2 C/hr	14	Rodnick et al. 2004	0
31	Rainbow Trout	Oncorhynchus mykiss	adult	17														15	Baird and Krueger 2003	0
32	Rainbow Trout	Oncorhynchus mykiss	adult	N=137														16	Baltz et al. 1987	0
33	Rainbow Trout	Oncorhynchus mykiss	juvenile	2/n=8(N=16)	9				12.6									5	Cherry et al. 1975	1
34	Rainbow Trout	Oncorhynchus mykiss	see notes	4/n=2(N=8)	9	15	8											5	Cherry et al. 1975	1
35	Rainbow Trout	Oncorhynchus mykiss	yoy	n=70	9									24.2				2	Kaya 1978	1
36	Rainbow Trout	Oncorhynchus mykiss	juvenile	n=70	9									24.7				9	Kaya 1978	1
37	Rainbow Trout	Oncorhynchus mykiss	juvenile	n=50	9									25.2				3	Kaya 1978	1
38	Rainbow Trout	Oncorhynchus mykiss	juvenile	n=5 fish (many observations	10				16.7									17	McCauley et al. 1977	1
39	Rainbow Trout	Oncorhynchus mykiss	juvenile	5	10				12.7									1	McCauley et al. 1977	1
40	Rainbow Trout	Oncorhynchus mykiss	juvenile	3/n=5	10											28.45	0.2 C/min	18	Lee and Rinne 1980	1
41	Rainbow Trout	Oncorhynchus mykiss	juvenile	5 replicates/n=5-6/rep	10				15.8									19	Javaid and Anderson 1967a	1
42	Rainbow Trout	Oncorhynchus mykiss		N=40/n=10	11									24					Black 1953	1
43	Rainbow Trout	Oncorhynchus mykiss	fry	2 reps (n=10 each per temp)	12									25.9				4	Stauffer et al. 1984	1
44	Rainbow Trout	Oncorhynchus mykiss	juvenile	2/n=8(N=16)	12				14.4									5	Cherry et al. 1975	1
45	Rainbow Trout	Oncorhynchus mykiss	see notes	4/n=2(N=8)	12	17	11											5	Cherry et al. 1975	1
46	Rainbow Trout	Oncorhynchus mykiss	juvenile	N=48	12									25.9				6	Stauffer et al. 1984	1
47	Rainbow Trout	Oncorhynchus mykiss	juvenile	6 replicates/n=5	12.1				14.7									20	Peterson et al. 1979	1
48	Rainbow Trout	Oncorhynchus mykiss	fry	6 replicates/n=5	12.7				14.3									21	Peterson et al. 1979	1
49	Rainbow Trout	Oncorhynchus mykiss	yoy	n=60	13									25.2				2	Kaya 1978	1
50	Rainbow Trout	Oncorhynchus mykiss	juvenile	n=60	13									24.7				9	Kaya 1978	1
51	Rainbow Trout	Oncorhynchus mykiss	juvenile	n=50	13									25.2				3	Kaya 1978	1
52	Rainbow Trout	Oncorhynchus mykiss	fry	19	15											29.6	5 C/hr	22	Ineno et al. 2005	1
53	Rainbow Trout	Oncorhynchus mykiss	fry	19	15											30.1	5 C/hr	22	Ineno et al. 2005	1
54	Rainbow Trout	Oncorhynchus mykiss	juvenile	6	15				10.4									1	McCauley et al. 1977	1
55	Rainbow Trout	Oncorhynchus mykiss	juvenile	2/n=8(N=16)	15				16.9									5	Cherry et al. 1975	1
56	Rainbow Trout	Oncorhynchus mykiss	see notes	4/n=2(N=8)	15	19	13											5	Cherry et al. 1975	1
57	Rainbow Trout	Oncorhynchus mykiss	juvenile	30	15											28.7	2 C/day	23	Galbreath et al. 2004	1
58	Rainbow Trout	Oncorhynchus mykiss	juvenile	29	15											28.8	4 C/day	23	Galbreath et al. 2004	1
59	Rainbow Trout	Oncorhynchus mykiss	juvenile	30	15											28.8	8 C/day	23	Galbreath et al. 2004	1
60	Rainbow Trout	Oncorhynchus mykiss	juvenile	30	15											28.4	24 C/day	24	Galbreath et al. 2004	1
61	Rainbow Trout	Oncorhynchus mykiss	juvenile	30	15											28.6	24 C/day	25	Galbreath et al. 2004	1
62	Rainbow Trout	Oncorhynchus mykiss	juvenile	5 replicates/n=5-6/rep	15				17.5									26	Javaid and Anderson 1967a	1

1	Common Name	Scientific Name	Life stage	Replicates/Sample Size	Acclimation Temperature	Avoid high	Avoid low	Pref high	Pref ave	Pref low	Lower Optimum	Optimum	Upper Optimum	UILT	UUILT	CTM	Rate of Increase (CTM)	Other Notes	Complete Reference	Lab (y/n)
63	Rainbow Trout	Oncorhynchus mykiss	juvenile	N=30 (n=30 per treatment)	16									25.6				27	Hokanson et al. 1977	1
64	Rainbow Trout	Oncorhynchus mykiss	yoy	n=60	17									25.7				2	Kaya 1978	1
65	Rainbow Trout	Oncorhynchus mykiss	juvenile	n=70	17									25.2				9	Kaya 1978	1
66	Rainbow Trout	Oncorhynchus mykiss	juvenile	n=50	17									25.7				3	Kaya 1978	1
67	Rainbow Trout	Oncorhynchus mykiss	fry	N=8	18	24												4	Stauffer et al. 1984	1
68	Rainbow Trout	Oncorhynchus mykiss	fry	2 reps (n=10 each per temp)	18									26.7				4	Stauffer et al. 1984	1
69	Rainbow Trout	Oncorhynchus mykiss	juvenile	2/n=8(N=16)	18				18.1									5	Cherry et al. 1975	1
70	Rainbow Trout	Oncorhynchus mykiss	see notes	4/n=2(N=8)	18	19	13											5	Cherry et al. 1975	1
71	Rainbow Trout	Oncorhynchus mykiss	juvenile	n=11	18	16.3	15.6		16.1									28	Schurman et al. 1991	1
72	Rainbow Trout	Oncorhynchus mykiss	juvenile	N=48	18	24												6	Stauffer et al. 1984	1
73	Rainbow Trout	Oncorhynchus mykiss	juvenile	N=48	18									26.7				6	Stauffer et al. 1984	1
74	Rainbow Trout	Oncorhynchus mykiss	fry	22	20											30.4	5 C/hr	22	Ineno et al. 2005	1
75	Rainbow Trout	Oncorhynchus mykiss	fry	22	20											30.6	5 C/hr	22	Ineno et al. 2005	1
76	Rainbow Trout	Oncorhynchus mykiss	fry	16	20											29.9	5 C/hr	29	Ineno et al. 2005	1
77	Rainbow Trout	Oncorhynchus mykiss	fry	16	20											30.2	5 C/hr	29	Ineno et al. 2005	1
78	Rainbow Trout	Oncorhynchus mykiss	juvenile	6	20				9.8									1	McCauley et al. 1977	1
79	Rainbow Trout	Oncorhynchus mykiss	juvenile	3/n=5	20											29.35	0.2 C/min	18	Lee and Rinne 1980	1
80	Rainbow Trout	Oncorhynchus mykiss	juvenile	5 replicates/n=5-6/rep	20				22									30	Javaid and Anderson 1967a	1
81	Rainbow Trout	Oncorhynchus mykiss	juvenile	5 replicates/n=5-6/rep	20				18.5									31	Javaid and Anderson 1967a	1
82	Rainbow Trout	Oncorhynchus mykiss	juvenile	5 replicates/n=5-6/rep	20				21.5									31	Javaid and Anderson 1967a	1
83	Rainbow Trout	Oncorhynchus mykiss	juvenile	2/n=8(N=16)	21				20.1									5	Cherry et al. 1975	1
84	Rainbow Trout	Oncorhynchus mykiss	see notes	4/n=2(N=8)	21	23	16											5	Cherry et al. 1975	1
85	Rainbow Trout	Oncorhynchus mykiss	yoy	n=50	21									26.2				2	Kaya 1978	1
86	Rainbow Trout	Oncorhynchus mykiss	juvenile	n=60	21									25.7				9	Kaya 1978	1
87	Rainbow Trout	Oncorhynchus mykiss	juvenile	n=60	21									26.2				3	Kaya 1978	1
88	Rainbow Trout	Oncorhynchus mykiss	juvenile	N=551	10				15									37	Garside and Tait 1958	1
89	Rainbow Trout	Oncorhynchus mykiss	juvenile	N=565	15				13									33	Garside and Tait 1958	1
90	Rainbow Trout	Oncorhynchus mykiss	juvenile	N=495	20				11									34	Garside and Tait 1958	1
91	Rainbow Trout	Oncorhynchus mykiss	juvenile	N=532	20				12									35	Garside and Tait 1958	1
92	Rainbow Trout	Oncorhynchus mykiss	juvenile	2/N=7	see notes				18									36	McCauley et al. 1977	1
93	Rainbow Trout	Oncorhynchus mykiss	juvenile	2/N=7	see notes				19									36	McCauley et al. 1977	1
94	Rainbow Trout	Oncorhynchus mykiss	juvenile	3/ n=50 per tank											24.3			37	Bear 2005	1
95	Rainbow Trout	Oncorhynchus mykiss	juvenile	3/ n=50 per tank											26			37	Bear 2005	1
96	Rainbow Trout	Oncorhynchus mykiss	juvenile								6.8	13.1	18.2					38	Bear 2005	1
97	Rainbow Trout	Oncorhynchus mykiss	juvenile	N=522 (n=85)								15.5						39	Hokanson et al. 1977	1
98	Rainbow Trout	Oncorhynchus mykiss	juvenile	N=522 (n=85)								17.2						40	Hokanson et al. 1977	1
99	Rainbow Trout	Oncorhynchus mykiss	juvenile	N=370(n=74)								17							Papoutsoglou and Papaparaskeva-Papoutsoglou 1978	1
100	Rainbow Trout	Oncorhynchus mykiss	juvenile	n=12	10											28	0.3 C/min		Currie et al. 2004	1
101	Rainbow Trout	Oncorhynchus mykiss	juvenile	n=12	15											29.1	0.3 C/min		Currie et al. 2004	1
102	Rainbow Trout	Oncorhynchus mykiss	juvenile	n=12	20											29.8	0.3 C/min		Currie et al. 2004	1
103	Rainbow Trout	Oncorhynchus mykiss	juvenile	n=12	10-20 (diel cycling)											28.8	0.3 C/min		Currie et al. 2004	1
104	Rainbow Trout	Oncorhynchus mykiss	juvenile	n=23	12-17 C											28.14	2 C/day	41	Galbreath et al. 2006	1
105	Rainbow Trout	Oncorhynchus mykiss	juvenile	n=23	12-17 C											27.93	2 C/day	42	Galbreath et al. 2006	1
106	Rainbow Trout	Oncorhynchus mykiss	juvenile	n=40	12-17 C											28	2 C/day	43	Galbreath et al. 2006	1
107	Rainbow Trout	Oncorhynchus mykiss	juvenile	n=36	12-17 C											27.73	2 C/day	44	Galbreath et al. 2006	1
108	Rainbow Trout	Oncorhynchus mykiss	juvenile	n=30	12-17 C											27.76	2 C/day	45	Galbreath et al. 2006	1
109	Rainbow Trout	Oncorhynchus mykiss	juvenile	n=33	12-17 C											28.19	2 C/day	46	Galbreath et al. 2006	1
110	Rainbow Trout	Oncorhynchus mykiss	juvenile	10 replicates/n=5	10											30.7	0.8 C/min	47	Patra et al. 2007	1
111	Rainbow Trout	Oncorhynchus mykiss							13.6										Ferguson 1958	1
112																				
113					**minimum**	15.00	8.00		9.80		6.80	13.10	18.20	24.00	24.30	27.73				
114					**median**	**19.00**	**13.00**		**15.40**		**6.80**	**16.25**	**18.20**	**25.65**	**25.15**	**28.80**				
115					**maximum**	24.00	16.00		22.00		6.80	17.20	18.20	26.70	26.00	30.70				
116					**(n)**	8	6		24		1	4	1	18	2	24				

119		Estimates of Factors			Calculation of Metrics		Notes on Calculation Methods
120					DM2MOS	2.35	MOS method 1: 20% rule with converted CTM and Preferred Average
121		Median CTM's		28.80	DM1MOS	**1.88**	
122	2	Median CTM's-conversion		28.00	DM 2	25.65	DM method 1: Median UILT/UUILT - MOS
123	1	Median UILT/UUILT		25.65	**DM 1**	**23.77**	
124	1	Optimum Temperature for 1/3 Rule		16.25	**MWAT 1**	**19.352**	MWAT method 1: 1/3 rule with Optimum Temperature
125	2	Pref Ave for 1/3 Rule		15.40	MWAT 2	18.7825	
126	3	Avoided High for 1/3 Rule		19.00	MWAT 3	21.1945	19 was chosen as Avoided High because the acclimation temperature (15) was closest to the
127	4	Upper Optimum		18.20	MWAT 4	18.20	other optimal temperature metrics
128							
129	Notes: data not used						
130		1= acclimation too low- below 7					
131		2= acclimation too high- above 23 or higher than min CTM					
132		3= lifestage = embryo/larvae					
133		4= field study					

[1] Preferences are derived from measured water temperatures. Fish body temperatures are also reported in the paper, and are within 0.4°C in all cases.

[2] Ennis trout from hatchery.

[3] Firehole River.

[4] Acclimation temperature varied (6°C, 9°C, 12°C, 15°C, 18°C, 24°C), but the preference was calculated as the mean of all groups because there was not a detectable relationship between the acclimation and preferred temperatures.

[5] Fish were assumed to be adults. Fish were fasted for 2.5-3 days prior to being tested.

[6] Final Thermal Preference is calculated from all pooled data, as there was no difference found among acclimation treatments in preference.

[7] December test. The sample size is the number of observations on eight fish over roughly two hours, taken 1.5 hours after the fish were introduced to the tank.

[8] August test. The sample size is the number of observations on seven fish over roughly two hours, taken 1.5 hours after the fish were introduced to the tank.

[9] Winthrop Hatchery.

[10] The UILT was estimated from the median survival times plotted in Figure 1 for a 24-hour study duration.

[11] August 1983 data. The mean stream temperatures were higher, so these results may represent the coldest available temperature.

[12] July 1984 data. The mean stream temperatures were higher, so these results may represent the coldest available temperature.

[13] September 1983 data. The mean stream temperatures were higher, so these results may represent the coldest available temperature.

[14] Fish were captured and maintained in steam enclosures for three days before CTM tests were conducted in field. Data from four field streams are pooled due to similarity of sites and small sample size at individual sites.

[15] June through September. Observations were recorded when the main river flow temperature was < 20°C; the Preferred Average is within the optimum growth range for Rainbow Trout reported elsewhere.

[16] September 1984 data. The mean stream temperatures were higher, so these results may represent the coldest available temperature.

[17] The Preferred Average is the mean of five fish included in Table 1.

[18] Modified CTM was also studied, based on gradual rise in diurnally fluctuating temperature regime. These results are not include in the database.

[19] The Preferred Average is the mean of the modes for the groups tested (range = 15-17°C).

[20] Fish were hatched in the laboratory. Study used a vertical gradient design. The acclimation period is presumed long; fish were brought to acclimation temperature at rate of 2°C/month after incubation at 7-8°C.
[21] Fish were hatched in the laboratory. Study used a horizontal gradient design. The acclimation period is presumed long; fish were brought to acclimation temperature at rate of 2°C/month after incubation at 7-8°C.
[22] Nagano Strain; an additional thermally selected strain was reported but not included in database.
[23] Troutlodge X Wytheville strains.
[24] Troutlodge X Wytheville strains; trial 1 at this rate of change.
[25] Troutlodge X Wytheville strains; trial 2 at this rate of change.

[26] The Preferred Average is the mean of the modes for the groups tested (range = 17-19°C).
[27] Fish were fasted for 24 hours before tests; the 24 hour TL50 was 25.7°C.
[28] Preferred and avoidance temperatures are the mean of the medians for the sample of fish. Only the temperature preference of fish under normoxic conditions was included in the database. Hypoxic conditions were also used in the study but not included in the database.
[29] Donaldson Strain; an additional thermally selected strain was reported but not included in database.
[30] The Preferred Average is the mean of the modes for the groups tested (range = 21-23°C).
[31] Fish were fasted; thermal preference was measured daily (repeated measures) over 15 days and preferences were similar throughout fasting period, so a combined average is estimated to the nearest half degree from Figure 1 and reported here.
[32] December test. The sample size is the number of observations on eight fish over roughly two hours, taken 1.5 hours after the fish were introduced to the tank.
[33] October test. The sample size is the number of observations on eight fish over roughly two hours, taken 1.5 hours after the fish were introduced to the tank.
[34] December test. The sample size is the number of observations on seven fish over roughly two hours, taken 1.5 hours after the fish were introduced to the tank.
[35] September test. The sample size is the number of observations on seven fish over roughly two hours, taken 1.5 hours after the fish were introduced to the tank.
[36] Acclimation process: fish were reared at 15-20°C in a hatchery and held at 18°C for one day in the laboratory before being tested. The sample size is the number of fish, and there were 20 observations per fish per run.
[37] Nonstandard UUILT method: some disease occurred and was treated, which is a common occurrence in warm treatments of longer lab studies, where disease rates can increase with thermal stress.
[38] The optimum range was based on a lack of significant difference of the minimum and maximum from the 95% confidence interval of the regression line at the optimum temperature.
[39] The study was conducted under diel fluctuating temperature regimes. The optimum is the nominal temperature of the treatment at which maximum growth occurred.

[40] The study was conducted under a constant temperature regime. The optimum is the nominal temperature of the treatment at which maximum growth occurred.
[41] From rainbow trout #1a test with diploid fish only.
[42] From rainbow trout #1b test with diploid fish only.
[43] From rainbow trout #2 test with diploid fish only.
[44] From rainbow trout #3a test with diploid fish only.
[45] From rainbow trout #3a test with diploid fish that received thermal shock as eggs to induce triploidy but did not become triploid.
[46] From rainbow trout #3b test with diploid fish only.
[47] Only data from the control group (untreated with other chemicals) are included here. No specific CTM method was cited, but a history of CTM development was reviewed in the introduction that cited most of the relevant procedures used by other researchers.

1	Common Name	Scientific Name	Life stage	Replicates/Sample Size	Acclimation Temperature	Avoid high	Avoid low	Pref high	Pref ave	Pref low	Lower Optimum	Optimum	Upper Optimum	UILT	UUILT	CTM	Rate of Increase (CTM)	Other Notes	Complete Reference	Lab (y/n)
2	Red Shiner	Cyprinella lutrensis		20	10											34.04	1 C/min		Lutterschmidt and Hutchinson 1997	1
3	Red Shiner	Cyprinella lutrensis		20	10											30.7	1 C/min		Lutterschmidt and Hutchinson 1997	1
4	Red Shiner	Cyprinella lutrensis	adult	82	15											32	1 C/min	1	Maness and Hutchinson 1980	1
5	Red Shiner	Cyprinella lutrensis	adult	10	15											31.4	1 C/min	2	Maness and Hutchinson 1980	1
6	Red Shiner	Cyprinella lutrensis	adult	10	15											33.5	1 C/min	2	Maness and Hutchinson 1980	1
7	Red Shiner	Cyprinella lutrensis	adult	12	22											36.18	0.3 C/min	3	Takle et al. 1983	1
8	Red Shiner	Cyprinella lutrensis		N=9	23											34.5	1 C/min	3	Messaad and Young 2000	1
9	Red Shiner	Cyprinella lutrensis	adult	3/n=4	25											37.6	0.3 C/min	4	Carveth et al. 2006	1
10	Red Shiner	Cyprinella lutrensis	adult	3/n=4	25											39.5	0.3 C/min	4	Carveth et al. 2006	1
11	Red Shiner	Cyprinella lutrensis	adult	n=10	25											38.99	1 C/min	5	Matthews and Maness 1979	1
12	Red Shiner	Cyprinella lutrensis	adult	NS by group (273 total)	25											37.8	0.3 C/min	6	King et al. 1985	1
13	Red Shiner	Cyprinella lutrensis	adult	NS by group (273 total)	25											37.81	0.3 C/min	7	King et al. 1985	1
14	Red Shiner	Cyprinella lutrensis	adult	NS by group (273 total)	25											37.99	0.3 C/min	8	King et al. 1985	1
15	Red Shiner	Cyprinella lutrensis	adult	NS by group (273 total)	25											36.47	0.3 C/min	9	King et al. 1985	1
16	Red Shiner	Cyprinella lutrensis	adult	NS by group (273 total)	25											37.15	0.3 C/min	10	King et al. 1985	1
17	Red Shiner	Cyprinella lutrensis		11	26											38.1	2 C/hr		Smale and Rabeni 1995	1
18	Red Shiner	Cyprinella lutrensis	adult	3/n=4	30											39.7	0.3 C/min	4	Carveth et al. 2006	1
19	Red Shiner	Cyprinella lutrensis	adult	3/n=4	30											40.9	0.3 C/min	4	Carveth et al. 2006	1
20	Red Shiner	Cyprinella lutrensis		N=9	30											35	1 C/min	3	Messaad and Young 2000	1
21	Red Shiner	Cyprinella lutrensis	adult	10	30											39.61	0.3 C/min	11	Rutledge and Beitinger 1989	1
22	Red Shiner	Cyprinella lutrensis	adult	10	30											39.65	0.3 C/min	11	Rutledge and Beitinger 1989	1
23																				
24					**minimum**											31.40				
25					**median**											**37.80**				
26					**maximum**											40.90				
27					**(n)**											19				
29																				
30					**Estimates of Factors**						**Calculation of Metrics**			**Notes on Calculation Methods**						
31											DM2MOS		2	MOS method 2: default = 2						
32					Median CTM's				37.80		DM1MOS	no data								
33					2 Median CTM's-conversion				37.00		**DM 2**	**35.00**		DM method 2: Converted CTM - MOS						
34					1 Median UILT/UUILT				no data		DM 1	no data								
35					1 Optimum Temperature for 1/3 Rule				no data		MWAT 1	no data		Cannot calculate MWAT; no optimal data						
36					2 Pref Ave for 1/3 Rule				no data		MWAT 2	no data								
37					3 Avoided High for 1/3 Rule				no data		MWAT 3	no data								
38					4 Upper Optimum				no data		MWAT 4	no data								
39																				
40				Notes: data not used																
41					1= acclimation too low- below 15															
42					2= acclimation too high- above 30 or higher than min CTM															
43					3= lifestage = embryo/larvae															
44					4= field study															

[1] Fish were fasted for one day prior to being tested. CTM values were estimated from Figure 2 for only the fish that were not previously exposed to CTM testing. Data were collected in October.

[2] Fish were fasted for one day prior to being tested. CTM values were estimated from Figure 2 for only the fish that were not previously exposed to CTM testing. Data were collected in May. Sample size may have been higher than reported.

[3] Results are from the control group in study on effects of toxicity on CTM.

[4] Fish were 38-60 mm in length. Recorded replicates and sample size are the minimum for all species tested.

[1] Fish we[5] The rate of increase is assumed to be the same as that used by Hutchison (1961).
[6] Regulated site 57 km downstream from dam.
[7] Unregulated site 121 km downstream from dam.
[8] Unregulated site labeled “Upstream.”
[9] Regulated site 1 km downstream from dam.
[10] Regulated site 30 km downstream from dam.
[11] Fish are from the normoxic group and had no access to the water surface during testing. Data from the hypoxic and hyperoxic groups are excluded from the database.

1	Common Name	Scientific Name	Life stage	Replicates/Sample Size	Acclimation Temperature	Avoid high	Avoid low	Pref high	Pref ave	Pref low	Lower Optimum	Optimum	Upper Optimum	UILT	UUILT	CTM	Rate of Increase (CTM)	Other Notes	Complete Reference	Lab (y/n)
2	Redside Shiner	Richardsonius balteatus			9-11									25					Black 1953	1
3	Redside Shiner	Richardsonius balteatus			14									27.6					Black 1953	1
4	Redside Shiner	Richardsonius balteatus										21.1	23.7					1	Huff et al. 2005	0
5																				
6					**minimum**															
7					**median**															
8					**maximum**															
9					**(n)**															
10																				
11																				
12					**Estimates of Factors**						**Calculation of Metrics**			**Notes on Calculation Methods**						
13											DM2MOS	2		MOS method 2: default = 2						
14					Median CTM's				no data		DM1MOS	no data								
15				2	Median CTM's-conversion				no data		DM 2	no data								
16				1	Median UILT/UUILT				no data		DM 1	no data		Cannot calculate DM; no lethal data						
17				1	Optimum Temperature for 1/3 Rule				no data		MWAT 1	no data		Cannot calculate MWAT; no optimal data						
18				2	Pref Ave for 1/3 Rule				no data		MWAT 2	no data								
19				3	Avoided High for 1/3 Rule				no data		MWAT 3	no data								
20				4	Upper Optimum				no data		MWAT 4	no data								
21																				
22				Notes:	data not used															
23					1= acclimation too low- below 15															
24					2= acclimation too high- above 30 or higher than min CTM															
25					3= lifestage = embryo/larvae															
26					4= field study															

[1] This study calculated the realized thermal center (RNC) as 21.1°C and the upper limit of the realized thermal niche width (RNW) as 23.7°C.

1	Common Name	Scientific Name	Life stage	Replicates/Sample Size	Acclimation Temperature	Avoid high	Avoid low	Pref high	Pref ave	Pref low	Lower Optimum	Optimum	Upper Optimum	UILT	UUILT	CTM	Rate of Increase (CTM)	Other Notes	Complete Reference	Lab (y/n)
2	River Carpsucker	Carpiodes carpio																Summer	Yoder and Gammon 1976	0
3	River Carpsucker	Carpiodes carpio																Fall	Yoder and Gammon 1976	0
4																				
5					**minimum**															
6					**median**															
7					**maximum**															
8					**(n)**															
9																				
10																				
11					**Estimates of Factors**						**Calculation of Metrics**			**Notes on Calculation Methods**						
12											DM2MOS		2	MOS method 2: default = 2						
13					Median CTM's				no data		DM1MOS	no data								
14				2	Median CTM's-conversion				no data		DM 2	no data								
15				1	Median UILT/UUILT				no data		DM 1	no data		Cannot calculate DM; no lethal data						
16				1	Optimum Temperature for 1/3 Rule				no data		MWAT 1	no data		Cannot calculate MWAT; no optimal data						
17				2	Pref Ave for 1/3 Rule				no data		MWAT 2	no data								
18				3	Avoided High for 1/3 Rule				no data		MWAT 3	no data								
19				4	Upper Optimum				no data		MWAT 4	no data								
20																				
21				Notes:	data not used															
22					1= acclimation too low- below 15															
23					2= acclimation too high- above 30 or higher than min CTM															
24					3= lifestage = embryo/larvae															
25					4= field study															

1	Common Name	Scientific Name	Life stage	Replicates/Sample Size	Acclimation Temperature	Avoid high	Avoid low	Pref high	Pref ave	Pref low	Lower Optimum	Optimum	Upper Optimum	UILT	UUILT	CTM	Rate of Increase (CTM)	Spawning Info	Other Notes	Complete Reference	Lab (y/n)
2	Rock Bass	Ambloplites rupestris							21.3											Coutant 1977	1
3	Rock Bass	Ambloplites rupestris							20.7											Coutant 1977	1
4	Rock Bass	Ambloplites rupestris							27.4										Daytime	Coutant 1977	1
5	Rock Bass	Ambloplites rupestris							27.55										Nighttime	Coutant 1977	1
6	Rock Bass	Ambloplites rupestris	adult						27.5											Brown 1974	1
7	Rock Bass	Ambloplites rupestris							27.4											Brown 1974	1
8	Rock Bass	Ambloplites rupestris				30.5	27												Nighttime	Carlander 1969	1
9	Rock Bass	Ambloplites rupestris									8.5								Growth limit	Carlander 1969	1
10	Rock Bass	Ambloplites rupestris	adult		23.5				20.2							36			Summer	Reutter and Herdendorf 1976	1
11	Rock Bass	Ambloplites rupestris	adult						18.7										Summer	Reutter and Herdendorf 1976	1
12	Rock Bass	Ambloplites rupestris							28											Neill and Magnuson 1974	1
13	Rock Bass	Ambloplites rupestris		6	20-22	29	25.5												Daytime	Neill and Magnuson 1974	1
14	Rock Bass	Ambloplites rupestris		6	20-22	29.5	26												Nighttime	Neill and Magnuson 1974	1
15	Rock Bass	Ambloplites rupestris							29					36						Cherry et al. 1977	1
16	Rock Bass	Ambloplites rupestris	"small"						26.2										Daytime	Countant 1977	1
17	Rock Bass	Ambloplites rupestris	"small"						28.8										Nighttime	Countant 1977	1
18	Rock Bass	Ambloplites rupestris	adult						21.6										Winter	Countant 1977	1
19	Rock Bass	Ambloplites rupestris	adult						20.5										Spring	Countant 1977	1
20	Rock Bass	Ambloplites rupestris	adult						22.8										Fall	Countant 1977	1
21	Rock Bass	Ambloplites rupestris	<1 yr						30.6										Summer	Cherry et al. 1977	1
22	Rock Bass	Ambloplites rupestris	50-100mm "fork length"		18	27	15												Summer	Cherry et al. 1977	1
23	Rock Bass	Ambloplites rupestris	50-100mm "fork length"		21	30	18												Summer	Cherry et al. 1977	1
24	Rock Bass	Ambloplites rupestris	50-100mm "fork length"		24	33	21												Summer	Cherry et al. 1977	1
25	Rock Bass	Ambloplites rupestris	50-100mm "fork length"		27	33	24												Summer	Cherry et al. 1977	1
26	Rock Bass	Ambloplites rupestris	50-100mm "fork length"		33	33	24												Summer	Cherry et al. 1977	1
27	Rock Bass	Ambloplites rupestris	50-100mm "fork length"		33	35	27												Summer	Cherry et al. 1977	1
28	Rock Bass	Ambloplites rupestris	juvenile						27.3											Brown 1974	1
29	Rock Bass	Ambloplites rupestris		8					30.2											Stauffer et al. 1984	1
30	Rock Bass	Ambloplites rupestris		8 groups	18	27														Stauffer et al. 1984	1
31	Rock Bass	Ambloplites rupestris		8 groups	21	27														Stauffer et al. 1984	1
32	Rock Bass	Ambloplites rupestris		8 groups	24	30														Stauffer et al. 1984	1
33	Rock Bass	Ambloplites rupestris		8 groups	27	33														Stauffer et al. 1984	1
34	Rock Bass	Ambloplites rupestris		8 groups	30	33														Stauffer et al. 1984	1
35	Rock Bass	Ambloplites rupestris	adult	10 fish. tested individually					30											Reynolds and Casterlin 1978c	1
37					**minimum**	27.00	15.00		18.70		8.50			36.00		36.00					
38					**median**	**30.25**	**24.00**		**27.40**		**8.50**			**36.00**		**36.00**					
39					**maximum**	35.00	27.00		30.60		8.50			36.00		36.00					
40					**(n)**	14	9		19		1			1		1					
41																					
42																					
43					**Estimates of Factors**						**Calculation of Metrics**			**Notes on Calculation Methods**							
44											DM2MOS	1.56									
45					Median CTM's				36.00		DM1MOS	**1.72**		MOS method 1: 20% rule with median UILT/UUILT and Preferred Average							
46					2 Median CTM's-conversion				35.20		DM 2	33.64									
47					1 Median UILT/UUILT				36.00		**DM 1**	**34.28**		DM method 1: Median UILT/UUILT - MOS							
48					1 Optimum Temperature for 1/3 Rule				no data		MWAT 1	no data									
49					2 Pref Ave for 1/3 Rule				27.40		**MWAT 2**	**30.238**		MWAT method 2: 1/3 rule with Preferred Average							
50					3 Avoided High for 1/3 Rule				33.00		MWAT 3	33.99		33 was chosen as Avoided High because the acclimation temperature (27) was closest to the other							
51					4 Upper Optimum				no data		MWAT 4	no data		optimal temperature metrics							
52																					
53				Notes: data not used																	
54					1= acclimation too low- below 15																
55					2= acclimation too high- above 30 or higher than min CTM																
56					3= lifestage = embryo/larvae																
57					4= field study																

1	Common Name	Scientific Name	Life stage	Replicates/Sample Size	Acclimation Temperature	Avoid high	Avoid low	Pref high	Pref ave	Pref low	Lower Optimum	Optimum	Upper Optimum	UILT	UUILT	CTM	Rate of Increase (CTM)	Other Notes	Complete Reference	Lab (y/n)
2	Roundtail Chub	Gila robusta	juvenile	3/n=4	25											36.6	0.3 C/min	1	Carveth et al. 2006	1
3	Roundtail Chub	Gila robusta	juvenile	3/n=4	25											38	0.3 C/min	1	Carveth et al. 2006	1
4																				
5					**minimum**											36.60				
6					**median**											**37.30**				
7					**maximum**											38.00				
8					**(n)**											2				
9																				
10																				
11					**Estimates of Factors**						**Calculation of Metrics**			**Notes on Calculation Methods**						
12											DM2MOS	**2**		MOS method 2: default = 2						
13					Median CTM's				37.30		DM1MOS	2								
14				2	Median CTM's-conversion				36.50		**DM 2**	**34.50**		DM method 2: Converted CTM - MOS						
15				1	Median UILT/UUILT				no data		DM 1	no data								
16				1	Optimum Temperature for 1/3 Rule				no data		MWAT 1	no data		Cannot calculate MWAT; no optimal data						
17				2	Pref Ave for 1/3 Rule				no data		MWAT 2	no data								
18				3	Avoided High for 1/3 Rule				no data		MWAT 3	no data								
19				4	Upper Optimum				no data		MWAT 4	no data								
20																				
21				Notes:	data not used															
22					1= acclimation too low- below 15															
23					2= acclimation too high- above 30 or higher than min CTM															
24					3= lifestage = embryo/larvae															
25					4= field study															

[1] Fish were 34-51 mm in length. Recorded replicates and sample size are the minimum for all species tested.

1	Common Name	Scientific Name	Life stage	Replicates/Sample Size	Acclimation Temperature	Avoid high	Avoid low	Pref high	Pref ave	Pref low	Lower Optimum	Optimum	Upper Optimum	UILT	UUILT	CTM	Rate of Increase (CTM)	Other Notes	Complete Reference	Lab (y/n)
2	Sand Shiner	Notropis stramineus	adult	10	15											33	1 C/min	March	Kowalski et al. 1978	1
3	Sand Shiner	Notropis stramineus	adult	18	15											33.1	1 C/min	March	Kowalski et al. 1978	1
4	Sand Shiner	Notropis stramineus	adult	10	15											32.3	1 C/min	December	Kowalski et al. 1978	1
5	Sand Shiner	Notropis stramineus	adult	13	15											32.3	1 C/min	January	Kowalski et al. 1978	1
6	Sand Shiner	Notropis stramineus		6	26											37	2 C/hr		Smale and Rabeni 1995	1
7																				
8					**minimum**											32.30				
9					**median**											**33.00**				
10					**maximum**											37.00				
11					**(n)**											5				
12																				
13																				
14					**Estimates of Factors**						**Calculation of Metrics**			**Notes on Calculation Methods**						
15											DM2MOS	**2**		MOS method 2: default = 2						
16					Median CTM's				33.00		DM1MOS	2								
17				2	Median CTM's-conversion				32.20		**DM 2**	**30.20**		DM method 2: Converted CTM - MOS						
18				1	Median UILT/UUILT				no data		DM 1	no data								
19				1	Optimum Temperature for 1/3 Rule				no data		MWAT 1	no data		Cannot calculate MWAT; no optimal data						
20				2	Pref Ave for 1/3 Rule				no data		MWAT 2	no data								
21				3	Avoided High for 1/3 Rule				no data		MWAT 3	no data								
22				4	Upper Optimum				no data		MWAT 4	no data								
23																				
24				Notes:	data not used															
25					1= acclimation too low- below 15															
26					2= acclimation too high- above 30 or higher than min CTM															
27					3= lifestage = embryo/larvae															
28					4= field study															

1	Common Name	Scientific Name	Life stage	Replicates/Sample Size	Acclimation Temperature	Avoid high	Avoid low	Pref high	Pref ave	Pref low	Lower Optimum	Optimum	Upper Optimum	UILT	UUILT	CTM	Rate of Increase (CTM)	Other Notes	Complete Reference	Lab (y/n)
2	Sauger	Sander canadense																Fall	Yoder and Gammon 1976	0
3	Sauger	Sander canadense	juvenile									22						Growth	Koenst and Smith 1976	1
4																				
5					**minimum**							22.00								
6					**median**							**22.00**								
7					**maximum**							22.00								
8					**(n)**							1								
9																				
10																				
11					**Estimates of Factors**						**Calculation of Metrics**			**Notes on Calculation Methods**						
12											DM2MOS	2								
13					Median CTM's				no data		DM1MOS	2		MOS method 2: default = 2						
14				2	Median CTM's-conversion				no data		DM 2	no data								
15				1	Median UILT/UUILT				no data		DM 1	no data		Cannot calculate DM; no lethal data						
16				1	Optimum Temperature for 1/3 Rule				22.00		MWAT 1	no data		Cannot calculate MWAT; no lethal data or Upper Optimum						
17				2	Pref Ave for 1/3 Rule				no data		MWAT 2	no data								
18				3	Avoided High for 1/3 Rule				no data		MWAT 3	no data								
19				4	Upper Optimum				no data		MWAT 4	no data								
20																				
21				Notes:	data not used															
22					1= acclimation too low- below 15															
23					2= acclimation too high- above 30 or higher than min CTM															
24					3= lifestage = embryo/larvae															
25					4= field study															

1	Common Name	Scientific Name	Life stage	Replicates/Sample Size	Acclimation Temperature	Avoid high	Avoid low	Pref high	Pref ave	Pref low	Lower Optimum	Optimum	Upper Optimum	UILT	UUILT	CTM	Rate of Increase (CTM)	Other Notes	Complete Reference	Lab (y/n)
2	Shorthead Redhorse	Moxostoma macrolepidotum							26.75										Yoder and Gammon 1976	0
3	Shorthead Redhorse	Moxostoma macrolepidotum				26	22												Coutant 1977	0
4	Shorthead Redhorse	Moxostoma macrolepidotum	large juveniles; small adults	N=2/n=10-12	20.6-23.8										33.3		1C/day	1	Reash et al. 2000	1
5	Shorthead Redhorse	Moxostoma macrolepidotum	large juveniles; small adults	10-12 fish	20.6-23.8											35.1	3-5C/hr	2	Reash et al. 2000	1
6																				
7					**minimum**	26.00	22.00								33.30	35.10				
8					**median**	**26.00**	**22.00**								**33.30**	**35.10**				
9					**maximum**	26.00	22.00								33.30	35.10				
10					**(n)**	1	1								1	1				
11																				
12																				
13					**Estimates of Factors**						**Calculation of Metrics**			**Notes on Calculation Methods**						
14											DM2MOS	1.66								
15					Median CTM's				35.10		DM1MOS	**1.46**		MOS method 1: 20% method with median UILT/UUILT and Avoided High						
16					2 Median CTM's-conversion				34.30		DM 2	32.64								
17					1 Median UILT/UUILT				33.30		**DM 1**	**31.84**		DM method 1: Median UILT/UUILT - MOS						
18					1 Optimum Temperature for 1/3 Rule				no data		MWAT 1	no data								
19					2 Pref Ave for 1/3 Rule				no data		MWAT 2	no data								
20					3 Avoided High for 1/3 Rule				26.00		**MWAT 3**	**28.409**		MWAT method 3: 1/3 rule with Avoided High						
21					4 Upper Optimum				no data		MWAT 4	no data		26 was chosen as the Avoided High because there were no recorded						
22															acclimation temperatures					
23				Notes: data not used																
24					1= acclimation too low- below 15															
25					2= acclimation too high- above 30 or higher than min CTM															
26					3= lifestage = embryo/larvae															
27					4= field study															

[1] UUILT was conducted with a slow heating method for UUILT.

[2] CTM endpoint was death.

1	Common Name	Scientific Name	Life stage	Replicates/Sample Size	Acclimation Temperature	Avoid high	Avoid low	Pref high	Pref ave	Pref low	Lower Optimum	Optimum	Upper Optimum	UILT	UUILT	CTM	Rate of Increase (CTM)	Other Notes	Complete Reference	Lab (y/n)
2	Shovelnose Sturgeon	Scaphirhynchus platorynchus	embryo											28				1	Kappenman et al. 2009	1
3	Shovelnose Sturgeon	Scaphirhynchus platorynchus	embryo								12		24					2	Kappenman et al. 2009	1
4	Shovelnose Sturgeon	Scaphirhynchus platorynchus	embryo									17.5						3	Kappenman et al. 2009	1
5	Shovelnose Sturgeon	Scaphirhynchus platorynchus	juvenile		18							22.4						4	Kappenman et al. 2009	1
6	Shovelnose Sturgeon	Scaphirhynchus platorynchus	juvenile		18						10							5	Kappenman et al. 2009	1
7																				
8					**minimum**						10.00	22.40								
9					**median**						**10.00**	**22.40**								
10					**maximum**						10.00	22.40								
11					**(n)**						1	1								
12																				
13																				
14					**Estimates of Factors**						**Calculation of Metrics**			**Notes on Calculation Methods**						
15											DM2MOS	2								
16					Median CTM's				no data		DM1MOS	2		MOS method 2: default = 2						
17				2	Median CTM's-conversion				no data		DM 2	no data								
18				1	Median UILT/UUILT				no data		DM 1	no data		Cannot calculate DM; no lethal data						
19				1	Optimum Temperature for 1/3 Rule				22.40		MWAT 1	no data		Cannot calculate MWAT; no lethal data or Upper Optimum						
20				2	Pref Ave for 1/3 Rule				no data		MWAT 2	no data								
21				3	Avoided High for 1/3 Rule				no data		MWAT 3	no data								
22				4	Upper Optimum				no data		MWAT 4	no data								
23																				
24				Notes:	data not used															
25					1= acclimation too low- below 15															
26					2= acclimation too high- above 30 or higher than min CTM															
27					3= lifestage = embryo/larvae															
28					4= field study															

[1] UILT indicates the upper temperature with 100% embryo mortality.

[2] Lower and Upper optima indicate the approximate thermal niche for embryos.

[3] Optimum temperature for embryo survival.

[4] Growth optimum.

[5] Minimum temperature needed for growth.

1	Common Name	Scientific Name	Life stage	Replicates/Sample Size	Acclimation Temperature	Avoid high	Avoid low	Pref high	Pref ave	Pref low	Lower Optimum	Optimum	Upper Optimum	UILT	UUILT	CTM	Rate of Increase (CTM)	Other Notes	Complete Reference	Lab (y/n)
2	Smallmouth Bass	Micropterus dolomieui	adult	n=13	2				26									1	Barans and Tubb 1973	1
3	Smallmouth Bass	Micropterus dolomieui	juvenile	2/n=8(N=16)	15				20.2									2	Cherry et al. 1975	1
4	Smallmouth Bass	Micropterus dolomieui	juvenile	4/n=2(N=8)	15	26	13											2	Cherry et al. 1975	1
5	Smallmouth Bass	Micropterus dolomieui	juvenile	2/n=8(N=16)	18				22.9									2	Cherry et al. 1975	1
6	Smallmouth Bass	Micropterus dolomieui	juvenile	4/n=2(N=8)	18	27	17											2	Cherry et al. 1975	1
7	Smallmouth Bass	Micropterus dolomieui	adult	5	20				25.5									3	Bevelhimer 1996	1
8	Smallmouth Bass	Micropterus dolomieui	juvenile	2/n=8(N=16)	21				26.5									2	Cherry et al. 1975	1
9	Smallmouth Bass	Micropterus dolomieui	juvenile	4/n=2(N=8)	21	30	20											2	Cherry et al. 1975	1
10	Smallmouth Bass	Micropterus dolomieui	juvenile adult	N=20	22			34.4	31.1	26.7								4	Reynolds and Casterlin 1976	1
11	Smallmouth Bass	Micropterus dolomieui	juvenile adult	N=20	22			33.9	29.4	25.6								5	Reynolds and Casterlin 1976	1
12	Smallmouth Bass	Micropterus dolomieui		N=12	22			30.1	28.4	26.6								6	Reynolds and Casterlin 1976	1
13	Smallmouth Bass	Micropterus dolomieui	yoy	n=20	23				30									1	Barans and Tubb 1973	1
14	Smallmouth Bass	Micropterus dolomieui	juvenile	2/n=8(N=16)	24				29.8									2	Cherry et al. 1975	1
15	Smallmouth Bass	Micropterus dolomieui	juvenile	4/n=2(N=8)	24	31	22											2	Cherry et al. 1975	1
16	Smallmouth Bass	Micropterus dolomieui		8	26											36.9	2 C/hr		Smale and Rabeni 1995	1
17	Smallmouth Bass	Micropterus dolomieui	juvenile	2/n=8(N=16)	27				30.1									2	Cherry et al. 1975	1
18	Smallmouth Bass	Micropterus dolomieui	juvenile	4/n=2(N=8)	27	31	24											2	Cherry et al. 1975	1
19	Smallmouth Bass	Micropterus dolomieui	juvenile	2/n=8(N=16)	30				31.3									2	Cherry et al. 1975	1
20	Smallmouth Bass	Micropterus dolomieui	juvenile	4/n=2(N=8)	30	33	26											2	Cherry et al. 1975	1
21	Smallmouth Bass	Micropterus dolomieui	juvenile	N=360								24						7	Horning and Pearson 1973	1
22	Smallmouth Bass	Micropterus dolomieui	fry	N=220								25.5							Coutant and DeAngelis 1983	1
23	Smallmouth Bass	Micropterus dolomieui	fry	N=490								30						8	Larimore and Duever 1968	1
24	Smallmouth Bass	Micropterus dolomieui	adult	1 fish per test	23.3				26.6							36.3		9	Reutter and Herdendorf 1976	1
25	Smallmouth Bass	Micropterus dolomieui	yoy						31									10	Reutter and Herdendorf 1976	1
26	Smallmouth Bass	Micropterus dolomieui	adult						30									10	Reutter and Herdendorf 1976	1
27	Smallmouth Bass	Micropterus dolomieui							28										Ferguson 1958	1
28																				
29					**minimum**	26.00	13.00	30.10	20.20	25.60		24.00				36.30				
30					**median**	**30.50**	**21.00**	**33.90**	**29.40**	**26.60**		**25.50**				**36.60**				
31					**maximum**	33.00	26.00	34.40	31.30	26.70		30.00				36.90				
32					**(n)**	6	6	3	15	3		3				2				

35	**Estimates of Factors**		**Calculation of Metrics**	**Notes on Calculation Methods**
36			DM2MOS **2.06**	MOS method 1: 20% rule with converted CTM and Optimum Temperature
37	Median CTM's	36.60	DM1MOS no data	
38	2 Median CTM's-conversion	35.80	**DM 2 33.74**	DM method 2: Converted CTM - MOS
39	1 Median UILT/UUILT	no data	DM 1 no data	
40	1 Optimum Temperature for 1/3 Rule	25.50	**MWAT 1 28.899**	MWAT method 1: 1/3 rule with Optimum Temperature
41	2 Pref Ave for 1/3 Rule	29.40	MWAT 2 31.512	
42	3 Avoided High for 1/3 Rule	33.00	MWAT 3 33.924	33 was chosen as the Avoided High because the acclimation temperature (29) was
43	4 Upper Optimum	no data	MWAT 4 no data	closest to the other optimal metrics

45	Notes: data not used
46	1= acclimation too low- below 15
47	2= acclimation too high- above 30 or higher than min CTM
48	3= lifestage = embryo/larvae
49	4= field study

[1] Winter conditions. Average preferences indicate the modal preference; preferred temperatures, gradient temperatures, and acclimation temperatures are approximated from Figure 1.

[2] Fish were assumed to be adults. Fish were fasted for 2.5-3 days prior to being tested.

[3] Low and high ration groups were pooled, and the temperature at the mean preferred position in the gradient tank is reported as the Preferred Average.

[1] Winter condition[4] Daytime preference. Acclimation temperature indicates the median of the range reported (20-24°C). Sample size refers to the number of fish, and several measurements were taken from each over time.
[5] Nighttime preference. Acclimation temperature indicates the median of the range reported (20-24°C). Sample size refers to the number of fish, and several measurements were taken from each over time.
[6] Preferred average indicates the median of the minimum and maximum preferred temperatures recorded during the 24-hour study period (reported as Lower and Upper preferred temperatures).
[7] A 3°C gap may affect the precision of the optima estimate, but this value is generally consistent with others and was the peak growth temperature among those tested in this study.
[8] Optimum for swimming performance. A 5°C gap between treatments means that precision may be poor.
[9] Fall.
[10] Summer.

1	Common Name	Scientific Name	Life stage	Replicates/Sample Size	Acclimation Temperature	Avoid high	Avoid low	Pref high	Pref ave	Pref low	Lower Optimum	Optimum	Upper Optimum	UILT	UUILT	CTM	Rate of Increase (CTM)	Other Notes	Complete Reference	Lab (y/n)
2	Speckled Dace	Rhinichthys osculus	adult	10/n=5	20											32.4	0.3 C/min		Castleberry and Cech 1992	1
3	Speckled Dace	Rhinichthys osculus	adult	14	24											34.54	0.45 C/mi	1	Kaya et al. 1992	1
4	Speckled Dace	Rhinichthys osculus	adult	14	24											33.86	0.45 C/mi	2	Kaya et al. 1992	1
5	Speckled Dace	Rhinichthys osculus	juvenile adult	3/n=4	25											34.4	0.3 C/min	3	Carveth et al. 2006	1
6	Speckled Dace	Rhinichthys osculus	juvenile adult	3/n=4	25											36	0.3 C/min	3	Carveth et al. 2006	1
7	Speckled Dace	Rhinichthys osculus	adult	14	27											34.62	0.45 C/mi	1	Kaya et al. 1992	1
8	Speckled Dace	Rhinichthys osculus	adult	14	27											34.9	0.45 C/mi	2	Kaya et al. 1992	1
9	Speckled Dace	Rhinichthys osculus	juvenile adult	3/n=4	30											35.8	0.3 C/min	3	Carveth et al. 2006	1
10	Speckled Dace	Rhinichthys osculus	juvenile adult	3/n=4	30											36.9	0.3 C/min	3	Carveth et al. 2006	1
11																				
12					**minimum**											32.40				
13					**median**											**34.62**				
14					**maximum**											36.90				
15					**(n)**											9				
16																				
17																				
18					**Estimates of Factors**						**Calculation of Metrics**			**Notes on Calculation Methods**						
19											DM2MOS	2		MOS method 2: default = 2						
20					Median CTM's				34.62		DM1MOS	2								
21				2	Median CTM's-conversion				33.82		**DM 2**	**31.82**		DM method 2: Converted CTM - MOS						
22				1	Median UILT/UUILT				no data		DM 1	no data								
23				1	Optimum Temperature for 1/3 Rule				no data		MWAT 1	no data		Cannot calculate MWAT; no optimal data						
24				2	Pref Ave for 1/3 Rule				no data		MWAT 2	no data								
25				3	Avoided High for 1/3 Rule				no data		MWAT 3	no data								
26				4	Upper Optimum				no data		MWAT 4	no data								
27																				
28				Notes:	data not used															
29					1= acclimation too low- below 15															
30					2= acclimation too high- above 30 or higher than min CTM															
31					3= lifestage = embryo/larvae															
32					4= field study															

[1] Kendall Warm Springs strain.

[2] Green River strain.

[3] Fish were 37-68 mm in length. Recorded replicates and sample size are the minimum for all species tested.

1	Common Name	Scientific Name	Life stage	Replicates /Sample Size	Acclimation Temperature	Avoid high	Avoid low	Pref high	Pref ave	Pref low	Lower Optimum	Optimum	Upper Optimum	UILT	UUILT	CTM	Rate of Increase (CTM)	Other Notes	Complete Reference	Lab (y/n)
2	Spottail Shiner	Notropis hudsonius	juvenile	N=40	6				8									1	Stauffer et al. 1984	1
3	Spottail Shiner	Notropis hudsonius	juvenile	N=40	6									26.9				1	Stauffer et al. 1984	1
4	Spottail Shiner	Notropis hudsonius	juvenile	N=40	12				20									1	Stauffer et al. 1984	1
5	Spottail Shiner	Notropis hudsonius	juvenile	N=40	12	27												1	Stauffer et al. 1984	1
6	Spottail Shiner	Notropis hudsonius	juvenile	N=40	12									27				1	Stauffer et al. 1984	1
7	Spottail Shiner	Notropis hudsonius	fry	N=8	18	21												2	Stauffer et al. 1984	1
8	Spottail Shiner	Notropis hudsonius	juvenile	N=40	18				27									1	Stauffer et al. 1984	1
9	Spottail Shiner	Notropis hudsonius	juvenile	N=40	18	31												1	Stauffer et al. 1984	1
10	Spottail Shiner	Notropis hudsonius	juvenile	N=40	18									26.7				1	Stauffer et al. 1984	1
11	Spottail Shiner	Notropis hudsonius	juvenile	N=40	24				29.5									1	Stauffer et al. 1984	1
12	Spottail Shiner	Notropis hudsonius	juvenile	N=40	24	33												1	Stauffer et al. 1984	1
13	Spottail Shiner	Notropis hudsonius	juvenile	N=40	24									33.1				1	Stauffer et al. 1984	1
14	Spottail Shiner	Notropis hudsonius	adult	N=2/n=17	25			32	29	25									Kellogg and Gift 1983	1
15	Spottail Shiner	Notropis hudsonius	juvenile	N=40	30				26									1	Stauffer et al. 1984	1
16	Spottail Shiner	Notropis hudsonius	juvenile	N=40	30	36												1	Stauffer et al. 1984	1
17	Spottail Shiner	Notropis hudsonius	juvenile	N=40	30									33.1	33.1			1	Stauffer et al. 1984	1
18	Spottail Shiner	Notropis hudsonius	adult	N=7/n=20							25	27.3	32.2					3	Kellogg and Gift 1983	1
19	Spottail Shiner	Notropis hudsonius	adult		21.7				14.3							32.8		4	Reutter and Herdendorf 1976	1
20	Spottail Shiner	Notropis hudsonius							14										Meldrim and Gift 1971	1
21																				
22					**minimum**	21.00		32.00	14.00	25.00	25.00	27.30	32.20	26.70	33.10	32.80				
23					**median**	**32.00**		**32.00**	**26.50**	**25.00**	**25.00**	**27.30**	**32.20**	**33.10**	**33.10**	**32.80**				
24					**maximum**	36.00		32.00	29.50	25.00	25.00	27.30	32.20	33.10	33.10	32.80				
25					**(n)**	4		1	6	1	1	1	1	3	1	1				
27																				
28					**Estimates of Factors**						**Calculation of Metrics**			**Notes on Calculation Methods**						
29											DM2MOS	0.94								
30					Median CTM's				32.80		DM1MOS	**1.16**		MOS method 1: 20% rule with median UILT/UUILT and Optimum Temperature						
31					2 Median CTM's-conversion				32.00		DM 2	31.06								
32					1 Median UILT/UUILT				33.10		**DM 1**	**31.94**		DM method 1: Median UILT/UUILT - MOS						
33					1 Optimum Temperature for 1/3 Rule				27.30		**MWAT 1**	**29.214**		MWAT method 1: 1/3 rule with Optimum Temperature						
34					2 Pref Ave for 1/3 Rule				26.50		MWAT 2	28.678								
35					3 Avoided High for 1/3 Rule				33.00		MWAT 3	33.033		33 was chosen as the Avoided High because the acclimation temperature (24) was						
36					4 Upper Optimum				32.20		MWAT 4	32.20		closest to the other optimal metrics						
37																				
38				Notes: data not used																
39					1= acclimation too low- below 15															
40					2= acclimation too high- above 30 or higher than min CTM															
41					3= lifestage = embryo/larvae															
42					4= field study															

[1] Final Thermal Preference was pooled for all data because no difference was found among acclimation treatments in preference.

[2] Acclimation temperature varied (6°C, 9°C, 12°C, 15°C, 18°C, 24°C), but the Preferred Average was calculated as the mean of all the groups because there was not a detectable relationship between the acclimation and preferred temperatures.

[3] The Lower and Upper growth optimum are minimum and maximum temperatures that are statistically indistinguishable from the maximum growth temperature.

[4] Preferred average in the spring.

	Common Name	Scientific Name	Life stage	Replicates/Sample Size	Acclimation Temperature	Avoid high	Avoid low	Pref high	Pref ave	Pref low	Lower Optimum	Optimum	Upper Optimum	UILT	UUILT	CTM	Rate of Increase (CTM)	Other Notes	Complete Reference	Lab (y/n)
2	Stonecat	Noturus flavus	adult		1.6				25.1							29		Fall	Reutter and Herdendorf 1976	1
3																				
4					**minimum**															
5					**median**															
6					**maximum**															
7					**(n)**															
8																				
9																				
10					**Estimates of Factors**						**Calculation of Metrics**			**Notes on Calculation Methods**						
11											DM2MOS		2							
12					Median CTM's				no data		DM1MOS		2	MOS method 2: default = 2						
13				2	Median CTM's-conversion				no data		DM 2	no data								
14				1	Median UILT/UUILT				no data		DM 1	no data		Cannot calculate DM; no lethal data						
15				1	Optimum Temperature for 1/3 Rule				no data		MWAT 1	no data		Cannot calculate MWAT; no optimal data						
16				2	Pref Ave for 1/3 Rule				no data		MWAT 2	no data								
17				3	Avoided High for 1/3 Rule				no data		MWAT 3	no data								
18				4	Upper Optimum				no data		MWAT 4	no data								
19																				
20				Notes:	data not used															
21					1= acclimation too low- below 15															
22					2= acclimation too high- above 30 or higher than min CTM															
23					3= lifestage = embryo/larvae															
24					4= field study															

	Common Name	Scientific Name	Life stage	Replicates/Sample Size	Acclimation Temperature	Avoid high	Avoid low	Pref high	Pref ave	Pref low	Lower Optimum	Optimum	Upper Optimum	UILT	UUILT	CTM	Rate of Increase (CTM)	Other Notes	Complete Reference	Lab (y/n)
2	Sturgeon Chub	Macrhybopsis gelida																		
3																				
4					**minimum**															
5					**median**															
6					**maximum**															
7					**(n)**															
8																				
9																				
10					**Estimates of Factors**						**Calculation of Metrics**			**Notes on Calculation Methods**						
11											DM2MOS	2								
12					Median CTM's				no data		DM1MOS	2		MOS method 2: default = 2						
13				2	Median CTM's-conversion				no data		DM 2	no data								
14				1	Median UILT/UUILT				no data		DM 1	no data		Cannot calculate DM; no lethal data						
15				1	Optimum Temperature for 1/3 Rule				no data		MWAT 1	no data		Cannot calculate MWAT; no optimal data						
16				2	Pref Ave for 1/3 Rule				no data		MWAT 2	no data								
17				3	Avoided High for 1/3 Rule				no data		MWAT 3	no data								
18				4	Upper Optimum				no data		MWAT 4	no data								
19																				
20				Notes:	data not used															
21					1= acclimation too low- below 15															
22					2= acclimation too high- above 30 or higher than min CTM															
23					3= lifestage = embryo/larvae															
24					4= field study															

1	Common Name	Scientific Name	Life stage	Replicates/Sample Size	Acclimation Temperature	Avoid high	Avoid low	Pref high	Pref ave	Pref low	Lower Optimum	Optimum	Upper Optimum	UILT	UUILT	CTM	Rate of Increase (CTM)	Spawning info	Other Notes	Complete Reference	Lab (y/n)
2	Suckermouth Minnow	Phenacobius mirabilis		2	10											33.4	1C/min		1	Lutterschmidt and Hutchinson 1997	1
3	Suckermouth Minnow	Phenacobius mirabilis		2	10											30.4	1C/min		2	Lutterschmidt and Hutchinson 1997	1
4	Suckermouth Minnow	Phenacobius mirabilis																23	3	Bestgen and Compton 2007	1
5																					
6					**minimum**																
7					**median**																
8					**maximum**																
9					**(n)**																
10																					
11																					
12					**Estimates of Factors**						**Calculation of Metrics**			**Notes on Calculation Methods**							
13											DM2MOS	2									
14					Median CTM's				no data		DM1MOS	2		MOS method 2: default = 2							
15				2	Median CTM's-conversion				no data		DM 2	no data									
16				1	Median UILT/UUILT				no data		DM 1	no data		Cannot calculate DM; no lethal data							
17				1	Optimum Temperature for 1/3 Rule				no data		MWAT 1	no data		Cannot calculate MWAT; no optimal data							
18				2	Pref Ave for 1/3 Rule				no data		MWAT 2	no data									
19				3	Avoided High for 1/3 Rule				no data		MWAT 3	no data									
20				4	Upper Optimum				no data		MWAT 4	no data									
21																					
22				Notes: data not used																	
23					1= acclimation too low- below 15																
24					2= acclimation too high- above 30 or higher than min CTM																
25					3= lifestage = embryo/larvae																
26					4= field study																

[1] CTM endpoint is the onset of muscle spasms.

[2] CTM endpoint is the loss of righting response.

[3] The development and growth of larvae was faster at 23°C than at 17°C and 19°C.

1	Common Name	Scientific Name	Life stage	Replicates/Sample Size	Acclimation Temperature	Avoid high	Avoid low	Pref high	Pref ave	Pref low	Lower Optimum	Optimum	Upper Optimum	UILT	UUILT	CTM	Rate of Increase (CTM)	Other Notes	Complete Reference	Lab (y/n)
2	Tiger Muskellunge	Esox lucius x Esox masquinongy	juvenile	N=130	27.5									32				1	Scott 1964	1
3	Tiger Muskellunge	Esox lucius x Esox masquinongy	juvenile	N=130	30									33				1	Scott 1964	1
4																				
5					**minimum**									32.00						
6					**median**									**32.50**						
7					**maximum**									33.00						
8					**(n)**									2						
9																				
10																				
11					**Estimates of Factors**						**Calculation of Metrics**			**Notes on Calculation Methods**						
12											DM2MOS	2								
13					Median CTM's				no data		DM1MOS	**2**		MOS method 2: default = 2						
14				2	Median CTM's-conversion				no data		DM 2	no data								
15				1	Median UILT/UUILT				32.50		**DM 1**	**30.50**		DM method 1: Median UILT/UUILT - MOS						
16				1	Optimum Temperature for 1/3 Rule				no data		MWAT 1	no data		Cannot calculate MWAT; no optimal data						
17				2	Pref Ave for 1/3 Rule				no data		MWAT 2	no data								
18				3	Avoided High for 1/3 Rule				no data		MWAT 3	no data								
19				4	Upper Optimum				no data		MWAT 4	no data								
20																				
21				Notes:	data not used															
22					1= acclimation too low- below 15															
23					2= acclimation too high- above 30 or higher than min CTM															
24					3= lifestage = embryo/larvae															
25					4= field study															

[1] The UILT is estimated from the plot of mean survival time after fish were transferred to a range of lethal temperatures. Only values from a study period of 24-hours or more were included.

1	Common Name	Scientific Name	Life stage	Replicates/Sample Size	Acclimation Temperature	Avoid high	Avoid low	Pref high	Pref ave	Pref low	Lower Optimum	Optimum	Upper Optimum	UILT	UUILT	CTM	Rate of Increase (CTM)	Spawning info	Other Notes	Complete Reference	Lab (y/n)
2	Utah Chub	Gila atraria																14	1	Valdez 2007	1
3	Utah Chub	Gila atraria																20	2	Valdez 2007	1
4	Utah Chub	Gila atraria																18	3	Valdez 2007	1
5	Utah Chub	Gila atraria									16								4	Valdez 2007	1
6	Utah Chub	Gila atraria		207 fish total, 25-29 fish per test temp								22							5	Petersen and Paukert 2005	1
7	Utah Chub	Gila atraria											30						6	Valdez 2007	1
8	Utah Chub	Gila atraria										23							7	Valdez 2007	1
9	Utah Chub	Gila atraria														35			8	Valdez 2007	1
10																					
11					**minimum**						16.00	22.00	30.00			35.00					
12					**median**						**16.00**	**22.50**	**30.00**			**35.00**					
13					**maximum**						16.00	23.00	30.00			35.00					
14					**(n)**						1	2	1			1					
15																					
16																					
17					**Estimates of Factors**						**Calculation of Metrics**			**Notes on Calculation Methods**							
18											DM2MOS	**2.34**		MOS method 1: 20% rule with converted CTM and Optimum Temperature							
19					Median CTM's				35.00		DM1MOS	no data									
20				2	Median CTM's-conversion				34.20		**DM 2**	**31.86**		DM method 2: Converted CTM - MOS							
21				1	Median UILT/UUILT				no data		DM 1	no data									
22				1	Optimum Temperature for 1/3 Rule				22.50		**MWAT 1**	**26.361**		Cannot calculate MWAT; no optimal data							
23				2	Pref Ave for 1/3 Rule				no data		MWAT 2	no data									
24				3	Avoided High for 1/3 Rule				no data		MWAT 3	no data									
25				4	Upper Optimum				30.00		MWAT 4	30.00									
26																					
27				Notes: data not used																	
28					1= acclimation too low- below 15																
29					2= acclimation too high- above 30 or higher than min CTM																
30					3= lifestage = embryo/larvae																
31					4= field study																

[1] Minimum incubation temperature.

[2] Maximum incubation temperature.

[3] Optimum incubation temperature.

[4] Minimum growth temperature.

[5] Optimal temperature for respiration. The study only tested temperatures of 6°C, 9°C, 12°C, 18°C, and 22°C.

[6] Maximum growth temperature.

[7] Optimum growth temperature.

[8] Upper lethal temperature.

	Common Name	Scientific Name	Life stage	Replicates/Sample Size	Acclimation Temperature	Avoid high	Avoid low	Pref high	Pref ave	Pref low	Lower Optimum	Optimum	Upper Optimum	UILT	UUILT	CTM	Rate of Increase (CTM)	Other Notes	Complete Reference	Lab (y/n)
2	Utah Sucker	Catostomus ardens																		
3																				
4					**minimum**															
5					**median**															
6					**maximum**															
7					**(n)**															
8																				
9																				
10																				
11					**Estimates of Factors**						**Calculation of Metrics**			**Notes on Calculation Methods**						
12											DM2MOS		2							
13					Median CTM's				no data		DM1MOS		2	MOS method 2: default = 2						
14				2	Median CTM's-conversion				no data		DM 2	no data								
15				1	Median UILT/UUILT				no data		DM 1	no data		Cannot calculate DM; no lethal data						
16				1	Optimum Temperature for 1/3 Rule				no data		MWAT 1	no data		Cannot calculate MWAT; no optimal data						
17				2	Pref Ave for 1/3 Rule				no data		MWAT 2	no data								
18				3	Avoided High for 1/3 Rule				no data		MWAT 3	no data								
19				4	Upper Optimum				no data		MWAT 4	no data								
20																				
21				Notes:	data not used															
22					1= acclimation too low- below 15															
23					2= acclimation too high- above 30 or higher than min CTM															
24					3= lifestage = embryo/larvae															
25					4= field study															

	Common Name	Scientific Name	Life stage	Replicates/Sample Size	Acclimation Temperature	Avoid high	Avoid low	Pref high	Pref ave	Pref low	Lower Optimum	Optimum	Upper Optimum	UILT	UUILT	CTM	Rate of Increase (CTM)	Other Notes	Complete Reference	Lab (y/n)
2	Walleye	Sander vitreus	juvenile	3 replicates/n=20	14-23 C									31.6				1	Wilson and Nagler 2006	1
3	Walleye	Sander vitreus	juvenile		8-26 C									27.0-31.6					Koenst and Smith 1976	1
4	Walleye	Sander vitreus	juvenile	see notes								26						2	Hokanson and Koenst 1986	1
5	Walleye	Sander vitreus	juvenile	see notes	22.1									33			0.5 C/day	2	Hokanson and Koenst 1986	1
6	Walleye	Sander vitreus	juvenile	see notes	26									34.1			0.5 C/day	2	Hokanson and Koenst 1986	1
7	Walleye	Sander vitreus	juvenile	see notes	28									34.1	34.1		0.5 C/day	2	Hokanson and Koenst 1986	1
8	Walleye	Sander vitreus	juvenile	see notes	25.8									31.6				2	Hokanson and Koenst 1986	1
9	Walleye	Sander vitreus	juvenile	2 replicates/n=20	15-22 C									34.1				3	Wilson and Nagler 2006	1
10	Walleye	Sander vitreus	juvenile									22						4	Koenst and Smith 1976	1
11	Walleye	Sander vitreus							20										Kelso 1972	1
12	Walleye	Sander vitreus	fingerlings	25 fish per aquarium								22						5	Huh et al. 1976	2
13																				
14					**minimum**				20.00			22.00		31.60	34.10					
15					**median**				**20.00**			**22.00**		**34.10**	**34.10**					
16					**maximum**				20.00			26.00		34.10	34.10					
17					**(n)**				1			3		5	1					
18																				
19																				
20					**Estimates of Factors**						**Calculation of Metrics**			**Notes on Calculation Methods**						
21											DM2MOS	2								
22					Median CTM's				no data		DM1MOS	**2.42**		MOS method 1: 20% rule with median UILT/UUILT and Optimum Temperature						
23					2 Median CTM's-conversion				no data		DM 2	no data								
24					1 Median UILT/UUILT				34.10		**DM 1**	**31.68**		DM method 1: Median UILT/UUILT - MOS						
25					1 Optimum Temperature for 1/3 Rule				22.00		**MWAT 1**	**25.993**		MWAT method 1: 1/3 rule with Optimum Temperature						
26					2 Pref Ave for 1/3 Rule				20.00		MWAT 2	24.653								
27					3 Avoided High for 1/3 Rule				no data		MWAT 3	no data								
28					4 Upper Optimum				no data		MWAT 4	no data								
29																				
30				Notes: data not used																
31					1= acclimation too low- below 15															
32					2= acclimation too high- above 30 or higher than min CTM															
33					3= lifestage = embryo/larvae															
34					4= field study															

[1] Yearling juveniles. The study used a nonstandard UUILT method: started fish at acclimation temperature, rather than transferring groups of fish to new temperatures, and increased temperature slowly (1°C/day), allowing acclimation along the way. Survival was tracked, and temperature at 50% mortality was considered the UUILT. Acclimation was ambient and spanned seasons.

[2] The sample size was not specified.

[3] Sub-yearling juveniles. The study used a nonstandard UUILT method: started fish at acclimation temperature, rather than transferring groups of fish to new temperatures, and increased temperature slowly (1°C/day), allowing acclimation along the way. Survival was tracked, and temperature at 50% mortality was considered the UUILT. Acclimation was ambient and spanned seasons.

[4] Optimum for juvenile growth.

[5] Optimum for growth.

1	Common Name	Scientific Name	Life stage	Replicates/Sample Size	Acclimation Temperature	Avoid high	Avoid low	Pref high	Pref ave	Pref low	Lower Optimum	Optimum	Upper Optimum	UILT	UUILT	CTM	Rate of Increase (CTM)	Other Notes	Complete Reference	Lab (y/n)
2	Western Mosquitofish	Gambusia affinis	adult female	N=10	5											33.7	0.3 C/min	1	Otto 1973	1
3	Western Mosquitofish	Gambusia affinis	adult female	N=10	5											32	0.3 C/min	2	Otto 1973	1
4	Western Mosquitofish	Gambusia affinis	adult female	n=10	5									32.75			0.3 C/min	3	Otto 1973	1
5	Western Mosquitofish	Gambusia affinis	adult female	n=10	5									29.5			0.3 C/min	4	Otto 1973	1
6	Western Mosquitofish	Gambusia affinis	adult	8 replicates/N=4 each	6				24.4										Cherry et al. 1976	1
7	Western Mosquitofish	Gambusia affinis	adult	8 replicates/N=1 each	6				23.9										Cherry et al. 1976	1
8	Western Mosquitofish	Gambusia affinis		20	10											38.47	1 C/min		Lutterschmidt and Hutchinson 1997	1
9	Western Mosquitofish	Gambusia affinis		20	10											36.88	1 C/min		Lutterschmidt and Hutchinson 1997	1
10	Western Mosquitofish	Gambusia affinis	adult female	N=10	10											35	0.3 C/min	5	Otto 1973	1
11	Western Mosquitofish	Gambusia affinis	adult female	N=10	10											33.5	0.3 C/min	6	Otto 1973	1
12	Western Mosquitofish	Gambusia affinis	adult female	n=10	10									32.75			0.3 C/min	3	Otto 1973	1
13	Western Mosquitofish	Gambusia affinis	adult female	n=10	10									31			0.3 C/min	7	Otto 1973	1
14	Western Mosquitofish	Gambusia affinis	adult	8 replicates/N=4 each	12				27.9										Cherry et al. 1976	1
15	Western Mosquitofish	Gambusia affinis	adult	8 replicates/N=1 each	12				26.8										Cherry et al. 1976	1
16	Western Mosquitofish	Gambusia affinis	adult	8 replicates/N=1 each	12	30	9												Cherry et al. 1976	1
17	Western Mosquitofish	Gambusia affinis	adult	90	35									37.5				8	Otto 1973	1
18	Western Mosquitofish	Gambusia affinis	adult	10	35											42.3	0.3 C/min	9	Otto 1973	1
19	Western Mosquitofish	Gambusia affinis	adult	10	35											43.3	0.3 C/min	10	Otto 1973	1
20	Western Mosquitofish	Gambusia affinis	adult	10	35											43.3	0.3 C/min	10	Otto 1973	1
21	Western Mosquitofish	Gambusia affinis	adult	10	35											43.3	0.3 C/min	11	Otto 1973	1
22	Western Mosquitofish	Gambusia affinis	adult	10	35											43.7	0.3 C/min	12	Otto 1973	1
23	Western Mosquitofish	Gambusia affinis	adult female	N=10	35											43.2	0.3 C/min	1	Otto 1973	1
24	Western Mosquitofish	Gambusia affinis	adult female	N=10	35											42	0.3 C/min	2	Otto 1973	1
25	Western Mosquitofish	Gambusia affinis	adult	8 replicates/N=4 each	36				33.6										Cherry et al. 1976	1
26	Western Mosquitofish	Gambusia affinis	adult	8 replicates/N=1 each	36				33.4										Cherry et al. 1976	1
27	Western Mosquitofish	Gambusia affinis	adult	8 replicates/N=1 each	36	39	27												Cherry et al. 1976	1
28	Western Mosquitofish	Gambusia affinis	adult female	N=10	15											35.5	0.3 C/min	5	Otto 1973	1
29	Western Mosquitofish	Gambusia affinis	adult female	N=10	15											34.5	0.3 C/min	6	Otto 1973	1
30	Western Mosquitofish	Gambusia affinis	adult female	n=10	15									33.5			0.3 C/min	13	Otto 1973	1
31	Western Mosquitofish	Gambusia affinis	adult female	n=10	15									35			0.3 C/min	7	Otto 1973	1
32	Western Mosquitofish	Gambusia affinis	adult	8 replicates/N=4 each	18				30.9										Cherry et al. 1976	1
33	Western Mosquitofish	Gambusia affinis	adult	8 replicates/N=1 each	18				30.4										Cherry et al. 1976	1
34	Western Mosquitofish	Gambusia affinis	adult	8 replicates/N=1 each	18	33	12												Cherry et al. 1976	1
35	Western Mosquitofish	Gambusia affinis	adult	45	18.5											33.7	0.3 C/min	14	Johnon 1976	1
36	Western Mosquitofish	Gambusia affinis	adult	103	18.5											33.2	0.3 C/min	15	Johnon 1976	1
37	Western Mosquitofish	Gambusia affinis	adult	86	18.5											34.4	0.3 C/min	16	Johnon 1976	1
38	Western Mosquitofish	Gambusia affinis	adult	43	18.5											35	0.3 C/min	17	Johnon 1976	1
39	Western Mosquitofish	Gambusia affinis	adult	32	18.5											35.5	0.3 C/min	18	Johnon 1976	1
40	Western Mosquitofish	Gambusia affinis	adult	48	18.5											36.6	0.3 C/min	19	Johnon 1976	1
41	Western Mosquitofish	Gambusia affinis	adult	56	18.5											35.6	0.3 C/min	20	Johnon 1976	1
42	Western Mosquitofish	Gambusia affinis	adult	48	18.5											35.7	0.3 C/min	21	Johnon 1976	1
43	Western Mosquitofish	Gambusia affinis	adult	53	18.5											34.6	0.3 C/min	22	Johnon 1976	1
44	Western Mosquitofish	Gambusia affinis	adult	35	18.5											34.6	0.3 C/min	23	Johnon 1976	1
45	Western Mosquitofish	Gambusia affinis	adult	51	18.5											34.1	0.3 C/min	24	Johnon 1976	1
46	Western Mosquitofish	Gambusia affinis	adult	40	18.5											33.8	0.3 C/min	25	Johnon 1976	1
47	Western Mosquitofish	Gambusia affinis	adult	36	18.5											35.1	0.3 C/min	26	Johnon 1976	1
48	Western Mosquitofish	Gambusia affinis	adult	35	18.5											35.2	0.3 C/min	27	Johnon 1976	1
49	Western Mosquitofish	Gambusia affinis	adult	39	18.5											35.6	0.3 C/min	28	Johnon 1976	1
50	Western Mosquitofish	Gambusia affinis	adult	36	18.5											35.5	0.3 C/min	29	Johnon 1976	1
51	Western Mosquitofish	Gambusia affinis	adult	34	18.5											36.1	0.3 C/min	30	Johnon 1976	1
52	Western Mosquitofish	Gambusia affinis	adult	41	18.5											36.5	0.3 C/min	31	Johnon 1976	1
53	Western Mosquitofish	Gambusia affinis	adult	45	18.5											36.9	0.3 C/min	32	Johnon 1976	1
54	Western Mosquitofish	Gambusia affinis	adult	45	18.5											36.6	0.3 C/min	33	Johnon 1976	1
55	Western Mosquitofish	Gambusia affinis	adult	37	18.5											36.3	0.3 C/min	34	Johnon 1976	1
56	Western Mosquitofish	Gambusia affinis	adult	34	18.5											35.6	0.3 C/min	35	Johnon 1976	1
57	Western Mosquitofish	Gambusia affinis	adult	37	18.5											35.4	0.3 C/min	36	Johnon 1976	1
58	Western Mosquitofish	Gambusia affinis	adult	32	18.5											34.9	0.3 C/min	37	Johnon 1976	1
59	Western Mosquitofish	Gambusia affinis	adult	45	18.5											35.2	0.3 C/min	14	Johnon 1976	1
60	Western Mosquitofish	Gambusia affinis	adult	103	18.5											34.5	0.3 C/min	15	Johnon 1976	1
61	Western Mosquitofish	Gambusia affinis	adult	86	18.5											35.4	0.3 C/min	16	Johnon 1976	1

1	Common Name	Scientific Name	Life stage	Replicates/Sample Size	Acclimation Temperature	Avoid high	Avoid low	Pref high	Pref ave	Pref low	Lower Optimum	Optimum	Upper Optimum	UILT	UUILT	CTM	Rate of Increase (CTM)	Other Notes	Complete Reference	Lab (y/n)
62	Western Mosquitofish	Gambusia affinis	adult	43	18.5											36.5	0.3 C/min	17	Johnon 1976	1
63	Western Mosquitofish	Gambusia affinis	adult	32	18.5											36.3	0.3 C/min	18	Johnon 1976	1
64	Western Mosquitofish	Gambusia affinis	adult	48	18.5											37.4	0.3 C/min	19	Johnon 1976	1
65	Western Mosquitofish	Gambusia affinis	adult	56	18.5											37	0.3 C/min	20	Johnon 1976	1
66	Western Mosquitofish	Gambusia affinis	adult	48	18.5											36.8	0.3 C/min	21	Johnon 1976	1
67	Western Mosquitofish	Gambusia affinis	adult	53	18.5											35.7	0.3 C/min	22	Johnon 1976	1
68	Western Mosquitofish	Gambusia affinis	adult	35	18.5											35.6	0.3 C/min	23	Johnon 1976	1
69	Western Mosquitofish	Gambusia affinis	adult	51	18.5											35.2	0.3 C/min	24	Johnon 1976	1
70	Western Mosquitofish	Gambusia affinis	adult	40	18.5											35.3	0.3 C/min	25	Johnon 1976	1
71	Western Mosquitofish	Gambusia affinis	adult	36	18.5											35.7	0.3 C/min	26	Johnon 1976	1
72	Western Mosquitofish	Gambusia affinis	adult	35	18.5											36.1	0.3 C/min	27	Johnon 1976	1
73	Western Mosquitofish	Gambusia affinis	adult	39	18.5											36.6	0.3 C/min	28	Johnon 1976	1
74	Western Mosquitofish	Gambusia affinis	adult	36	18.5											36.3	0.3 C/min	29	Johnon 1976	1
75	Western Mosquitofish	Gambusia affinis	adult	34	18.5											36.6	0.3 C/min	30	Johnon 1976	1
76	Western Mosquitofish	Gambusia affinis	adult	41	18.5											37.7	0.3 C/min	31	Johnon 1976	1
77	Western Mosquitofish	Gambusia affinis	adult	45	18.5											38	0.3 C/min	32	Johnon 1976	1
78	Western Mosquitofish	Gambusia affinis	adult	45	18.5											37.4	0.3 C/min	33	Johnon 1976	1
79	Western Mosquitofish	Gambusia affinis	adult	37	18.5											36.8	0.3 C/min	34	Johnon 1976	1
80	Western Mosquitofish	Gambusia affinis	adult	34	18.5											36.4	0.3 C/min	35	Johnon 1976	1
81	Western Mosquitofish	Gambusia affinis	adult	37	18.5											36.4	0.3 C/min	36	Johnon 1976	1
82	Western Mosquitofish	Gambusia affinis	adult	32	18.5											36.6	0.3 C/min	37	Johnon 1976	1
83	Western Mosquitofish	Gambusia affinis	adult	45	18.5											36.1	0.3 C/min	14	Johnon 1976	1
84	Western Mosquitofish	Gambusia affinis	adult	103	18.5											35.3	0.3 C/min	15	Johnon 1976	1
85	Western Mosquitofish	Gambusia affinis	adult	86	18.5											35.8	0.3 C/min	16	Johnon 1976	1
86	Western Mosquitofish	Gambusia affinis	adult	43	18.5											36.7	0.3 C/min	17	Johnon 1976	1
87	Western Mosquitofish	Gambusia affinis	adult	32	18.5											36.9	0.3 C/min	18	Johnon 1976	1
88	Western Mosquitofish	Gambusia affinis	adult	48	18.5											38.3	0.3 C/min	19	Johnon 1976	1
89	Western Mosquitofish	Gambusia affinis	adult	56	18.5											38.1	0.3 C/min	20	Johnon 1976	1
90	Western Mosquitofish	Gambusia affinis	adult	48	18.5											37.5	0.3 C/min	21	Johnon 1976	1
91	Western Mosquitofish	Gambusia affinis	adult	53	18.5											36.4	0.3 C/min	22	Johnon 1976	1
92	Western Mosquitofish	Gambusia affinis	adult	35	18.5											36.2	0.3 C/min	23	Johnon 1976	1
93	Western Mosquitofish	Gambusia affinis	adult	51	18.5											36	0.3 C/min	24	Johnon 1976	1
94	Western Mosquitofish	Gambusia affinis	adult	40	18.5											35.9	0.3 C/min	25	Johnon 1976	1
95	Western Mosquitofish	Gambusia affinis	adult	36	18.5											36.3	0.3 C/min	26	Johnon 1976	1
96	Western Mosquitofish	Gambusia affinis	adult	35	18.5											36.5	0.3 C/min	27	Johnon 1976	1
97	Western Mosquitofish	Gambusia affinis	adult	39	18.5											37.1	0.3 C/min	28	Johnon 1976	1
98	Western Mosquitofish	Gambusia affinis	adult	36	18.5											36.8	0.3 C/min	29	Johnon 1976	1
99	Western Mosquitofish	Gambusia affinis	adult	34	18.5											37.2	0.3 C/min	30	Johnon 1976	1
100	Western Mosquitofish	Gambusia affinis	adult	41	18.5											38.2	0.3 C/min	31	Johnon 1976	1
101	Western Mosquitofish	Gambusia affinis	adult	45	18.5											38.5	0.3 C/min	32	Johnon 1976	1
102	Western Mosquitofish	Gambusia affinis	adult	45	18.5											37.9	0.3 C/min	33	Johnon 1976	1
103	Western Mosquitofish	Gambusia affinis	adult	37	18.5											37.5	0.3 C/min	34	Johnon 1976	1
104	Western Mosquitofish	Gambusia affinis	adult	34	18.5											36.9	0.3 C/min	35	Johnon 1976	1
105	Western Mosquitofish	Gambusia affinis	adult	37	18.5											36.8	0.3 C/min	36	Johnon 1976	1
106	Western Mosquitofish	Gambusia affinis	adult	32	18.5											36.7	0.3 C/min	37	Johnon 1976	1
107	Western Mosquitofish	Gambusia affinis	adult female	N=10	20											37	0.3 C/min	5	Otto 1973	1
108	Western Mosquitofish	Gambusia affinis	adult female	N=10	20											37	0.3 C/min	6	Otto 1973	1
109	Western Mosquitofish	Gambusia affinis	adult female	n=10	20									37			0.3 C/min	13	Otto 1973	1
110	Western Mosquitofish	Gambusia affinis	adult female	n=10	20									35.5			0.3 C/min	38	Otto 1973	1
111	Western Mosquitofish	Gambusia affinis	adult	N=17	20				25.5									39	Bacon et al. 1967	1
112	Western Mosquitofish	Gambusia affinis	adult	N=64	20				26									39	Bacon et al. 1967	1
113	Western Mosquitofish	Gambusia affinis	adult	8 replicates/N=4 each	24				32										Cherry et al. 1976	1
114	Western Mosquitofish	Gambusia affinis	adult	8 replicates/N=1 each	24				31.3										Cherry et al. 1976	1
115	Western Mosquitofish	Gambusia affinis	adult	8 replicates/N=1 each	24	36	18												Cherry et al. 1976	1
116	Western Mosquitofish	Gambusia affinis	adult	3/n=4	25											40.7	0.3 C/min	40	Carveth et al. 2006	1
117	Western Mosquitofish	Gambusia affinis	adult	3/n=4	25											39.5	0.3 C/min	40	Carveth et al. 2006	1
118	Western Mosquitofish	Gambusia affinis	adult	10	25											38	0.3 C/min	9	Otto 1973	1
119	Western Mosquitofish	Gambusia affinis	adult	10	25											39.4	0.3 C/min	41	Otto 1973	1
120	Western Mosquitofish	Gambusia affinis	adult	10	25											39.6	0.3 C/min	42	Otto 1973	1
121	Western Mosquitofish	Gambusia affinis	adult	10	25											39.6	0.3 C/min	43	Otto 1973	1

1	Common Name	Scientific Name	Life stage	Replicates/Sample Size	Acclimation Temperature	Avoid high	Avoid low	Pref high	Pref ave	Pref low	Lower Optimum	Optimum	Upper Optimum	UILT	UUILT	CTM	Rate of Increase (CTM)	Other Notes	Complete Reference	Lab (y/n)
122	Western Mosquitofish	Gambusia affinis	adult	10	25											40.2	0.3 C/min	44	Otto 1973	1
123	Western Mosquitofish	Gambusia affinis	adult	90	25									35.5				8	Otto 1973	1
124	Western Mosquitofish	Gambusia affinis	adult	10	25											41.6	0.3 C/min	45	Otto 1973	1
125	Western Mosquitofish	Gambusia affinis	adult	10	25											40.6	0.3 C/min	46	Otto 1973	1
126	Western Mosquitofish	Gambusia affinis	adult	10	25											41.4	0.3 C/min	47	Otto 1973	1
127	Western Mosquitofish	Gambusia affinis	adult	10	25											40.1	0.3 C/min	48	Otto 1973	1
128	Western Mosquitofish	Gambusia affinis	adult female	N=10	25											39.5	0.3 C/min	5	Otto 1973	1
129	Western Mosquitofish	Gambusia affinis	adult female	N=10	25											38	0.3 C/min	6	Otto 1973	1
130	Western Mosquitofish	Gambusia affinis	adult female	n=10	25									37.75			0.3 C/min	49	Otto 1973	1
131	Western Mosquitofish	Gambusia affinis	adult female	n=10	25									37.75			0.3 C/min	49	Otto 1973	1
132	Western Mosquitofish	Gambusia affinis	adult female	n=10	25									37.75	37.75		0.3 C/min	49	Otto 1973	1
133	Western Mosquitofish	Gambusia affinis	adult female	n=10	25									36			0.3 C/min	7	Otto 1973	1
134	Western Mosquitofish	Gambusia affinis	adult female	n=10	25									37.25			0.3 C/min	50	Otto 1973	1
135	Western Mosquitofish	Gambusia affinis	adult female	n=10	25									37.25	37.25		0.3 C/min	50	Otto 1973	1
136	Western Mosquitofish	Gambusia affinis	adult	3/n=4	30											41.4	0.3 C/min	40	Carveth et al. 2006	1
137	Western Mosquitofish	Gambusia affinis	adult	3/n=4	30											42.1	0.3 C/min	40	Carveth et al. 2006	1
138	Western Mosquitofish	Gambusia affinis	adult	8 replicates/N=4 each	30				35.3										Cherry et al. 1976	1
139	Western Mosquitofish	Gambusia affinis	adult	8 replicates/N=1 each	30				34.8										Cherry et al. 1976	1
140	Western Mosquitofish	Gambusia affinis	adult	8 replicates/N=1 each	30	39	24												Cherry et al. 1976	1
141	Western Mosquitofish	Gambusia affinis	adult	10	30											41	0.3 C/min	9	Otto 1973	1
142	Western Mosquitofish	Gambusia affinis	adult female	N=10	30											42	0.3 C/min	5	Otto 1973	1
143	Western Mosquitofish	Gambusia affinis	adult female	N=10	30											31.5	0.3 C/min	6	Otto 1973	1
144	Western Mosquitofish	Gambusia affinis	adult	N=22	14-21 C ambient spring				31									51	Winkler 1979	1
145	Western Mosquitofish	Gambusia affinis	adult	N=22	20-33 C ambient spring				31									52	Winkler 1979	1
146	Western Mosquitofish	Gambusia affinis	juvenile	n=200								25						53	Wurtsbaugh and Cech 1983	1
147																				
148					**minimum**	33.00	12.00		25.50			25.00		33.50	37.25	31.50				
149					**median**	**36.00**	**18.00**		**31.00**			**25.00**		**37.00**	**37.50**	**36.55**				
150					**maximum**	39.00	24.00		35.30			25.00		37.75	37.75	42.10				
151					**(n)**	3	3		10			1		11	2	94				
153																				
154					**Estimates of Factors**						**Calculation of Metrics**			**Notes on Calculation Methods**						
155											DM2MOS	2.15								
156					Median CTM's				36.55		DM1MOS	**2.45**		MOS method 1: 20% rule with median UILT/UUILT and Optimum Temperature						
157					2 Median CTM's-conversion				35.75		DM 2	33.60								
158					1 Median UILT/UUILT				37.25		**DM 1**	**34.80**		DM method 1: Median UILT/UUILT - MOS						
159					1 Optimum Temperature for 1/3 Rule				25.00		**MWAT 1**	**29.0425**		MWAT method 1: 1/3 rule with Optimum Temperature						
160					2 Pref Ave for 1/3 Rule				31.00		MWAT 2	33.0625								
161					3 Avoided High for 1/3 Rule				39.00		MWAT 3	38.4225		39 was chosen as the Avoided High because the acclimation temperature (30) is closest to						
162					4 Upper Optimum				no data		MWAT 4	no data		the other optimal metrics						
163																				
164				Notes: data not used																
165					1= acclimation too low- below 15															
166					2= acclimation too high- above 30 or higher than min CTM															
167					3= lifestage = embryo/larvae															
168					4= field study															

[1] Warm-adapted Arizona population; CTM is reported in text.

[2] Cold-adapted Utah population; CTM is reported in text.

[3] Warm-adapted Arizona population; UILT is the median of the range bracketing 32.5°C and 33.0°C.

[4] Cold-adapted Arizona population; UILT is the median of the range bracketing 29.0°C and 30.0°C.

[5] Warm-adapted Arizona population; CTM was determined using a ruler from Figure 1.

[6] Cold-adapted Utah population; CTM was determined using a ruler from Figure 1.

[7] Cold-adapted Arizona population; UILT is the temperature closest to 50% survival compared to other treatment temps.
[8] Fish were held at a 24-hour photoperiod.
[9] Fish underwent a stable temperature acclimation.
[10] Fish underwent a cyclic temperature acclimation (Cycle F) with a peak amplitude of 40.0 for 30 minutes (peak was above UILT) after a 0.3°C/minute increase from the base acclimation temperature.
[11] Fish underwent a cyclic temperature acclimation (Cycle F") with a peak amplitude of 40.0 for 120 minutes (peak was above UILT) after a 0.3°C/minute increase from the base acclimation temperature.
[12] Fish underwent a cyclic temperature acclimation (Cycle G) with a peak amplitude of 41.5 for 30 minutes (peak was above UILT) after a 0.3°C/minute increase from the base acclimation temperature.
[13] Warm-adapted Arizona population; UILT is the temperature at which mortality is almost exactly 50% during test period.
[14] Males only. Time of day = 0:00 - 1:59 hours. The acclimation temperature is the median of the reported range (18-19°C).
[15] Males only. Time of day = 2:00 - 3:59 hours. The acclimation temperature is the median of the reported range (18-19°C).
[16] Males only. Time of day = 4:00 - 5:59 hours. The acclimation temperature is the median of the reported range (18-19°C).
[17] Males only. Time of day = 6:00 - 7:59 hours. The acclimation temperature is the median of the reported range (18-19°C).
[18] Males only. Time of day = 8:00 - 9:59 hours. The acclimation temperature is the median of the reported range (18-19°C).
[19] Males only. Time of day = 10:00 - 11:59 hours. The acclimation temperature is the median of the reported range (18-19°C).
[20] Males only. Time of day = 12:00 - 13:59 hours. The acclimation temperature is the median of the reported range (18-19°C).
[21] Males only. Time of day = 14:00 - 15:59 hours. The acclimation temperature is the median of the reported range (18-19°C).
[22] Males only. Time of day = 16:00 - 17:59 hours. The acclimation temperature is the median of the reported range (18-19°C).
[23] Males only. Time of day = 18:00 - 19:59 hours. The acclimation temperature is the median of the reported range (18-19°C).
[24] Males only. Time of day = 20:00 - 21:59 hours. The acclimation temperature is the median of the reported range (18-19°C).
[25] Males only. Time of day = 22:00 - 23:59 hours. The acclimation temperature is the median of the reported range (18-19°C).
[26] Females only. Time of day = 0:00 - 1:59 hours. The acclimation temperature is the median of the reported range (18-19°C).
[27] Females only. Time of day = 2:00 - 3:59 hours. The acclimation temperature is the median of the reported range (18-19°C).
[28] Females only. Time of day = 4:00 - 5:59 hours. The acclimation temperature is the median of the reported range (18-19°C).
[29] Females only. Time of day = 6:00 - 7:59 hours. The acclimation temperature is the median of the reported range (18-19°C).
[30] Females only. Time of day = 8:00 - 9:59 hours. The acclimation temperature is the median of the reported range (18-19°C).
[31] Females only. Time of day = 10:00 - 11:59 hours. The acclimation temperature is the median of the reported range (18-19°C).
[32] Females only. Time of day = 12:00 - 13:59 hours. The acclimation temperature is the median of the reported range (18-19°C).
[33] Females only. Time of day = 14:00 - 15:59 hours. The acclimation temperature is the median of the reported range (18-19°C).
[34] Females only. Time of day = 16:00 - 17:59 hours. The acclimation temperature is the median of the reported range (18-19°C).
[35] Females only. Time of day = 18:00 - 19:59 hours. The acclimation temperature is the median of the reported range (18-19°C).
[36] Females only. Time of day = 20:00 - 21:59 hours. The acclimation temperature is the median of the reported range (18-19°C).
[37] Females only. Time of day = 22:00 - 23:59 hours. The acclimation temperature is the median of the reported range (18-19°C).

[38] Cold-adapted Arizona population; UILT is the median of the range bracketing 35.0°C and 36.0°C.
[39] Male Fish. The acclimation temperature is the room temp (18-22°C). Fish were fasted for 24 hours before being tested. Survival results were also reported, but were not sufficient for a UILT estimation. The Preferred Average is the median of the two most common temperatures selected.
[40] Fish were 26-46 mm in length. Recorded replicates and sample size are the minimum for all species tested.
[41] Fish underwent a cyclic temperature acclimation (Cycle A) with a peak amplitude of 30.0 for 30 minutes (peak was above UILT) after a 0.3°C/minute increase from the base acclimation temperature.
[42] Fish underwent a cyclic temperature acclimation (Cycle B) with a peak amplitude of 34.0 for 30 minutes (peak was above UILT) after a 0.3°C/minute increase from the base acclimation temperature.
[43] Fish underwent a cyclic temperature acclimation (Cycle B') with a peak amplitude of 34.0 for 60 minutes (peak was above UILT) after a 0.3°C/minute increase from the base acclimation temperature.
[44] Fish underwent a cyclic temperature acclimation (Cycle C) with a peak amplitude of 36.5 for 30 minutes (peak was above UILT) after a 0.3°C/minute increase from the base acclimation temperature.
[45] Fish underwent a cyclic temperature acclimation (Cycle C") with a peak amplitude of 36.5 for 360 minutes (peak was above UILT) after a 0.3°C/minute increase from the base acclimation temperature.
[46] Fish underwent a cyclic temperature acclimation (Cycle D) with a peak amplitude of 39.0 for 30 minutes (peak was above UILT) after a 0.3°C/minute increase from the base acclimation temperature.
[47] Fish underwent a cyclic temperature acclimation (Cycle E) with a peak amplitude of 40.5 for 30 minutes (peak was above UILT) after a 0.3°C/minute increase from the base acclimation temperature.
[48] Fish underwent a cyclic temperature acclimation (Cycle C') with a peak amplitude of 36.5 for 60 minutes (peak was above UILT) after a 0.3°C/minute increase from the base acclimation temperature.
[49] Warm-adapted Arizona population; UILT is the median of the range bracketing 37.5°C and 38.0°C.
[50] Cold-adapted Arizona population; UILT is the median of the range bracketing 37.0°C and 37.5°C.
[51] Acclimation temperature indicates the range of ambient spring temperatures in the mountain lake where fish were collected.
[52] Acclimation temperature indicates the range of ambient spring temperatures in the geothermal warm spring where fish were collected.
[53] Temperature treatments are not close enough together for high precision in estimating optima.

1	Common Name	Scientific Name	Life stage	Replicates/Sample Size	Acclimation Temperature	Avoid high	Avoid low	Pref high	Pref ave	Pref low	Lower Optimum	Optimum	Upper Optimum	UILT	UUILT	CTM	Rate of Increase (CTM)	Other Notes	Complete Reference	Lab (y/n)
2	Western Silvery Minnow	Hybognathus argyritis																		
3																				
4					**minimum**															
5					**median**															
6					**maximum**															
7					**(n)**															
8																				
9																				
10					**Estimates of Factors**						**Calculation of Metrics**			**Notes on Calculation Methods**						
11											DM2MOS	2								
12					Median CTM's				no data		DM1MOS	2		MOS method 2: default = 2						
13				2	Median CTM's-conversion				no data		DM 2	no data								
14				1	Median UILT/UUILT				no data		DM 1	no data		Cannot calculate DM; no lethal dat						
15				1	Optimum Temperature for 1/3 Rule				no data		MWAT 1	no data		Cannot calculate MWAT; no optimal data						
16				2	Pref Ave for 1/3 Rule				no data		MWAT 2	no data								
17				3	Avoided High for 1/3 Rule				no data		MWAT 3	no data								
18				4	Upper Optimum				no data		MWAT 4	no data								
19																				
20				Notes:	data not used															
21					1= acclimation too low- below 15															
22					2= acclimation too high- above 30 or higher than min CTM															
23					3= lifestage = embryo/larvae															
24					4= field study															

1	Common Name	Scientific Name	Life stage	Replicates/Sample Size	Acclimation Temperature	Avoid high	Avoid low	Pref high	Pref ave	Pref low	Lower Optimum	Optimum	Upper Optimum	UILT	UUILT	CTM	Rate of Increase (CTM)	Other Notes	Complete Reference	Lab (y/n)
2	White Crappie	Pomoxis annularis																Summer	Yoder and Gammon 1976	0
3	White Crappie	Pomoxis annularis																Fall	Yoder and Gammon 1976	0
4	White Crappie	Pomoxis annularis	adult		24.4				19.4							>32.8		Summer	Reutter and Herdendorf 1976	1
5																				
6					**minimum**				19.40							0.00				
7					**median**				**19.40**							**32.80**				
8					**maximum**				19.40							0.00				
9					**(n)**				1							1				
10																				
11																				
12					**Estimates of Factors**						**Calculation of Metrics**			**Notes on Calculation Methods**						
13											DM2MOS	**2.52**								
14					Median CTM's				32.80		DM1MOS	no data		MOS method 1: 20% rule with median UILT/UUILT and Optimum Temperature						
15					2 Median CTM's-conversion				32.00		**DM 2**	**29.48**		DM method 2: Converted CTM - MOS						
16					1 Median UILT/UUILT				no data		DM 1	no data								
17					1 Optimum Temperature for 1/3 Rule				no data		MWAT 1	no data								
18					2 Pref Ave for 1/3 Rule				19.40		**MWAT 2**	**23.558**		MWAT method 2: 1/3 rule with Preferred Average						
19					3 Avoided High for 1/3 Rule				no data		MWAT 3	no data								
20					4 Upper Optimum				no data		MWAT 4	no data								
21																				
22				Notes:	data not used															
23					1= acclimation too low- below 15															
24					2= acclimation too high- above 30 or higher than min CTM															
25					3= lifestage = embryo/larvae															
26					4= field study															

	Common Name	Scientific Name	Life stage	Replicates/Sample Size	Acclimation Temperature	Avoid high	Avoid low	Pref high	Pref ave	Pref low	Lower Optimum	Optimum	Upper Optimum	UILT	UUILT	CTM	Rate of Increase (CTM)	Other Notes	Complete Reference	Lab (y/n)
1																				
2	White Sucker	Catastomus commersoni	juvenile adult	5	5									26.3					Hart 1947	1
3	White Sucker	Catastomus commersoni	juvenile adult	5	10									27.7					Hart 1947	1
4	White Sucker	Catastomus commersoni	embryo	n=80-100+								15.2							McCormick et al. 1977	1
5	White Sucker	Catastomus commersoni	see notes	see notes														1	Yoder and Gammon 1976	0
6	White Sucker	Catastomus commersoni	see notes	see notes														2	Yoder and Gammon 1976	0
7	White Sucker	Catastomus commersoni	see notes	500 (est. see notes)														3	Michaud 1981	0
8	White Sucker	Catastomus commersoni	juvenile adult	5	15									29.3					Hart 1947	1
9	White Sucker	Catastomus commersoni	juvenile adult	5	20									29.3					Hart 1947	1
10	White Sucker	Catastomus commersoni		N=11	23			26.1	24.5	22.8								4	Reynolds and Casterlin 1978b	1
11	White Sucker	Catastomus commersoni	juvenile adult	5	25									29.3	29.3				Hart 1947	1
12	White Sucker	Catastomus commersoni	juvenile	(N=30 in 4 groups)	25.5									31.2				5	Brett 1944	1
13	White Sucker	Catastomus commersoni		5	26											34.9	2 C/hr		Smale and Rabeni 1995	1
14	White Sucker	Catastomus commersoni	larva-juvenile	n=80								26.9						6	McCormick et al. 1977	1
15	White Sucker	Catastomus commersoni	adult		19				22.4							31.6		7	Reutter and Herdendorf 1976	1
16																				
17					**minimum**			26.10	22.40	22.80		26.90		29.30	29.30	31.60				
18					**median**			**26.10**	**23.45**	**22.80**		**26.90**		**29.30**	**29.30**	**33.25**				
19					**maximum**			26.10	24.50	22.80		26.90		31.20	29.30	34.90				
20					**(n)**			1	2	1		1		4	1	2				
21																				
22																				
23					**Estimates of Factors**						**Calculation of Metrics**			**Notes on Calculation Methods**						
24											DM2MOS	**1.11**								
25					Median CTM's				33.25		DM1MOS	**0.48**		MOS method 1: 20% rule with median UILT/UUILT and Optimum Temperature						
26					2 Median CTM's-conversion				32.45		DM 2	31.34								
27					1 Median UILT/UUILT				29.30		**DM 1**	**28.82**		DM method 1: Median UILT/UUILT - MOS						
28					1 Optimum Temperature for 1/3 Rule				26.90		**MWAT 1**	**27.692**		MWAT method 1: 1/3 rule with Optimal Temperature						
29					2 Pref Ave for 1/3 Rule				23.45		MWAT 2	25.3805								
30					3 Avoided High for 1/3 Rule				no data		MWAT 3	no data								
31					4 Upper Optimum				no data		MWAT 4	no data								
32																				
33				Notes: data not used																
34					1= acclimation too low- below 15															
35					2= acclimation too high- above 30 or higher than min CTM															
36					3= lifestage = embryo/larvae															
37					4= field study															

[1] Summer. The sample size not given, but sampling design and other plots suggest that they are high for most species. Winter data are also provided but not included in database.

[2] Fall. The sample size not given, but sampling design and other plots suggest that they are high for most species. Winter data are also provided but not included in database.

[3] The sample size is estimated from the temperature-frequency histogram. The temperature measurement method is not confirmed. There is no clear modal preference identifiable.

[4] The Preferred Average is the median of the daytime and nighttime modes reported for the same 11 fish (daytime mean = 24.0°C; nighttime mean = 24.2°C).

[5] No lab acclimation; the acclimation temperature is the median of the range reported during the collection period (Aug 1) for Lake Opeongo (25-26°C).

[6] Testing at 20.8°C and 23.9°C also resulted in high growth and biomass gain.

[7] Preferred Average is from fall.

1	Common Name	Scientific Name	Life stage	Replicates/Sample Size	Acclimation Temperature	Avoid high	Avoid low	Pref high	Pref ave	Pref low	Lower Optimum	Optimum	Upper Optimum	UILT	UUILT	CTM	Rate of Increase (CTM)	Other Notes	Complete Reference	Lab (y/n)
2	Yellow Perch	Perca flavescens	yoy	n=25	1				13									1	Barans and Tubb 1973	1
3	Yellow Perch	Perca flavescens	adult	n=12	1				15									1	Barans and Tubb 1973	1
4	Yellow Perch	Perca flavescens	adult	n=27	5				10									2	Barans and Tubb 1973	1
5	Yellow Perch	Perca flavescens	yoy	n=21	5				24									2	Barans and Tubb 1973	1
6	Yellow Perch	Perca flavescens	juvenile adult	5	5									21.3					Hart 1947	1
7	Yellow Perch	Perca flavescens	juvenile	N=10-12	8				17.5									3	Ferguson 1958	1
8	Yellow Perch	Perca flavescens	juvenile	2/N=10	10									29				4	Hathaway 1928	1
9	Yellow Perch	Perca flavescens	juvenile	2/N=16	10									29				4	Hathaway 1928	1
10	Yellow Perch	Perca flavescens	juvenile	N=10-12	10				20.6									5	Ferguson 1958	1
11	Yellow Perch	Perca flavescens	juvenile adult	5	10									25					Hart 1947	1
12	Yellow Perch	Perca flavescens		N=70/n=10	11									29.2					Black 1953	1
13	Yellow Perch	Perca flavescens	juvenile	N=10-12	15				24.5									6	Ferguson 1958	1
14	Yellow Perch	Perca flavescens	juvenile adult	5	15									27.7					Hart 1947	1
15	Yellow Perch	Perca flavescens	yoy	n=28	16				25									1	Barans and Tubb 1973	1
16	Yellow Perch	Perca flavescens	adult	n=38	16				17									1	Barans and Tubb 1973	1
17	Yellow Perch	Perca flavescens	juvenile	N=10-12	20				21.5									7	Ferguson 1958	1
18	Yellow Perch	Perca flavescens	juvenile	N=10	20			23	20.2	17								8	Reynolds and Casterlin 1979b	1
19	Yellow Perch	Perca flavescens	juvenile	2/N=8	22.5									29.6				4	Hathaway 1928	1
20	Yellow Perch	Perca flavescens	yoy	n=27	23				29									9	Barans and Tubb 1973	1
21	Yellow Perch	Perca flavescens	adult	n=17	23				25									9	Barans and Tubb 1973	1
22	Yellow Perch	Perca flavescens	juvenile	N=8	24				23									10	McCauley and Read 1973	1
23	Yellow Perch	Perca flavescens	adult	N=8	24				18									10	McCauley and Read 1973	1
24	Yellow Perch	Perca flavescens	juvenile	N=8	24				20									11	McCauley and Read 1973	1
25	Yellow Perch	Perca flavescens	adult	N=8	24				17									11	McCauley and Read 1973	1
26	Yellow Perch	Perca flavescens	juvenile	N=8	24				24									12	McCauley and Read 1973	1
27	Yellow Perch	Perca flavescens	adult	N=8	24				20									12	McCauley and Read 1973	1
28	Yellow Perch	Perca flavescens	juvenile	N=10-12	25				24									13	Ferguson 1958	1
29	Yellow Perch	Perca flavescens	juvenile adult	5	25									29.7					Hart 1947	1
30	Yellow Perch	Perca flavescens	juvenile	(N=33 in 4 groups)	25.5									30.9				14	Brett 1944	1
31	Yellow Perch	Perca flavescens	juvenile	2/N=8	30									30.3				4	Hathaway 1928	1
32	Yellow Perch	Perca flavescens	juvenile	N=10-12	30				26.5									15	Ferguson 1958	1
33	Yellow Perch	Perca flavescens			18									26.5					Black 1953	1
34	Yellow Perch	Perca flavescens			22-24									29.2					Black 1953	1
35	Yellow Perch	Perca flavescens	adult		22				20.9							35		16	Reutter and Herdendorf 1956	1
36	Yellow Perch	Perca flavescens	yoy						26									16	Reutter and Herdendorf 1956	1
37	Yellow Perch	Perca flavescens	adult						27									16	Reutter and Herdendorf 1956	1
38	Yellow Perch	Perca flavescens							22.5									17	Meldrim and Gift 1971	1
39	Yellow Perch	Perca flavescens							23.4									17	Neill 1971	1
40	Yellow Perch	Perca flavescens	juvenile		24				21.65										McCauley and Read 1973	1
41	Yellow Perch	Perca flavescens	adult						18.85										McCauley and Read 1973	1
42																				
43					**minimum**			23.00	17.00	17.00				26.50		35.00				
44					**median**			**23.00**	**22.75**	**17.00**				**29.60**		**35.00**				
45					**maximum**			23.00	29.00	17.00				30.90		35.00				
46					**(n)**			1	22	1				7		1				

49			Estimates of Factors		Calculation of Metrics		Notes on Calculation Methods
50					DM2MOS	2.29	
51			Median CTM's	35.00	DM1MOS	**1.37**	MOS method 1: 20% rule with median UILT/UUILT and Preferred Average
52		2	Median CTM's-conversion	34.20	DM 2	31.91	
53		1	Median UILT/UUILT	29.60	**DM 1**	**28.23**	DM method 1: Median UILT/UUILT - MOS
54		1	Optimum Temperature for 1/3 Rule	no data	MWAT 1	no data	
55		2	Pref Ave for 1/3 Rule	22.75	**MWAT 2**	**25.0105**	MWAT method 2: 1/3 rule with Preferred Average
56		3	Avoided High for 1/3 Rule	no data	MWAT 3	no data	
57		4	Upper Optimum	no data	MWAT 4	no data	
58							
59		Notes: data not used					
60			1= acclimation too low- below 15				
61			2= acclimation too high- above 30 or higher than min CTM				
62			3= lifestage = embryo/larvae				
63			4= field study				

[1] Winter conditions. Preferred Average indicates the modal preference; preferred temperature, gradient temperatures, and acclimation temperature are approximated from Figure 1.

[2] Spring conditions. Preferred Average indicates the modal preference; preferred temperature, gradient temperatures, and acclimation temperature are approximated from Figure 1.

[3] The acclimation period is not specified. The modal Preferred Average is included here; the arithmetic mean is reported but not included in the database (18.6°C).

[4] Study is an early predecessor of UILT; tested 4 minute, 15 minute, 1 hour, 4 hour, and 24 hour tolerances. Author used weighted average for lethal temperature.

[5] The acclimation period is not specified. The modal Preferred Average is included here; the arithmetic mean is reported but not included in the database (19.3°C).

[6] The acclimation period is not specified. The modal Preferred Average is included here; the arithmetic mean is reported but not included in the database (23.0°C).

[7] The acclimation period is not specified. The modal Preferred Average is included here; the arithmetic mean is reported but not included in the database (23.1°C).

[8] Preferred Low and High temperatures are the lowest and highest hourly preferred temperatures measured during three days from each fish. The Preferred Average is the mean of the daily mode for ten fish over three days.

[9] Summer conditions. Preferred Average indicates the modal preference; preferred temperature, gradient temperatures, and acclimation temperature are approximated from Figure 1.

[10] Lake St. Claire fish, October Sample. The sample size refers to the number of fish, and many observations on each fish were recorded and used to establish modal preference (mean preference = 23.3°C).

[11] Lake St. Claire fish, November Sample. The sample size refers to the number of fish, and many observations on each fish were recorded and used to establish modal preference (mean preference = 20.0°C).

[12] Grand River fish, June Sample. The sample size refers to the number of fish, and many observations on each fish were recorded and used to establish modal preference (mean preference = 23.3°C).
[13] The acclimation period is not specified. The modal preferred temperature is included here, and the arithmetic mean is also reported in reference (24.5°C).
[14] No laboratory acclimation; the acclimation temperature is the median of the range reported during the collection period (Jul 23) for Lake Opeongo (25-26°C).
[15] The acclimation period is not specified. The modal preferred temperature is included here, and the arithmetic mean is also reported in reference (26.7°C).
[16] Summer.
[17] Spring.

Appendix A References

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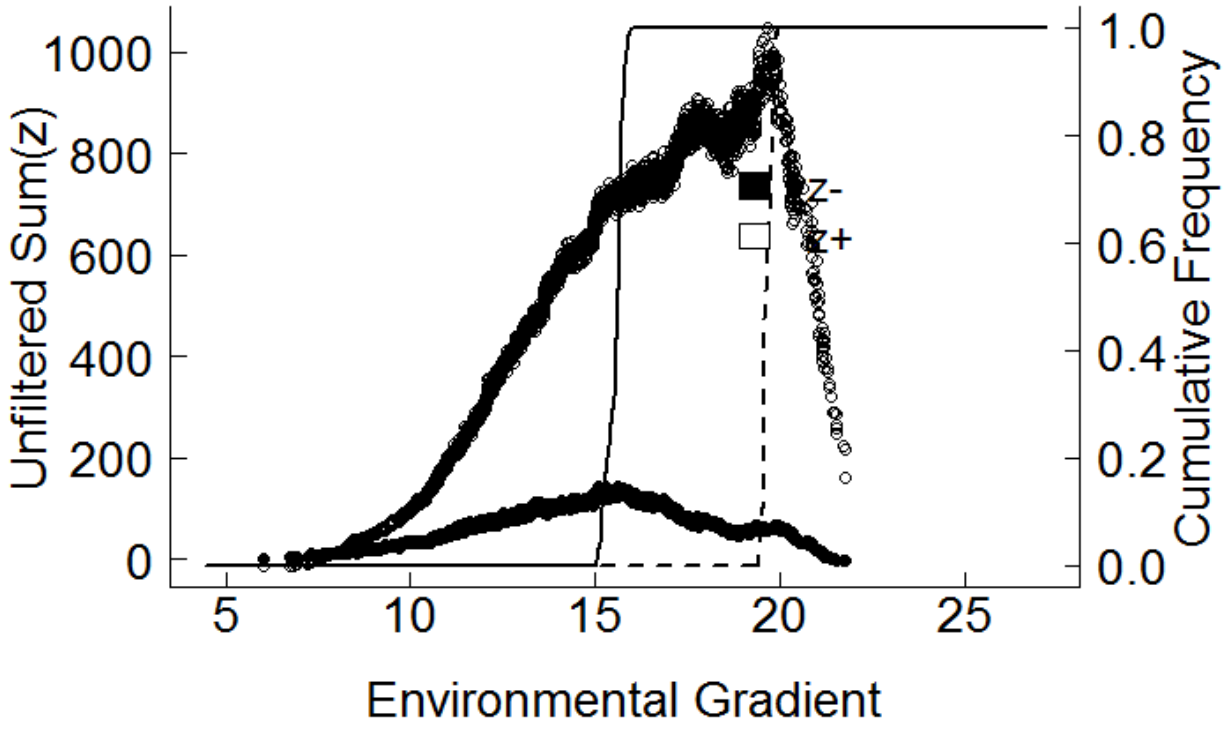
APPENDIX B:

TITAN diagnostic figures



Appendix Figure B-1. TITAN diagnostic output (Baker and King 2015). The x-axis represents the environmental gradient of modeled mean August temperature in °C. There are 1761 values along the x-axis for which there are two plotted points. These 1761 values along the x-axis indicate all of the candidate change points iteratively tested by TITAN analysis. At each candidate change point, one of the two plotted points indicates the summed z- score and the other indicates the summed z+ score.

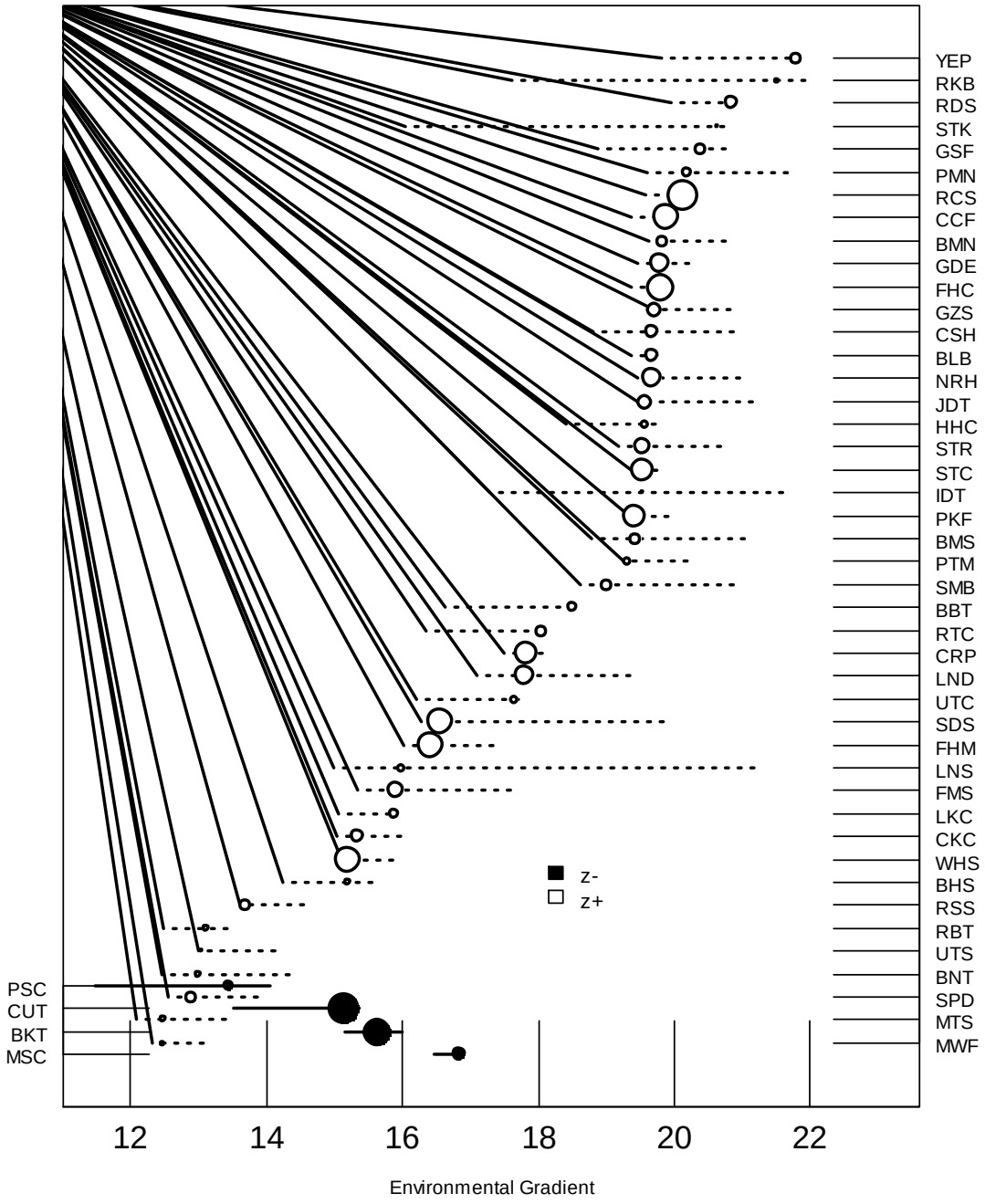
The filled circles (these make up the lower curve, which peaks at the solid line) indicate summed z- scores. The value of z- scores is defined by the left axis. For each change point, these

values represent the summed strengths of association of all species that, at this particular change point, were associated with the colder end of the thermal gradient. The greatest summed z- score is used to define the lower community-level threshold.

The open circles (these make up the upper curve, which peaks at the dashed line) indicate summed z+ scores. The value of the z+ scores is also defined by the left axis. For each change point, these values represent the summed strengths of association of all species that, at this particular change point, were associated with the warmer end of the thermal gradient. The greatest summed z+ score is used to define the upper community-level threshold.

The lines indicate the results of the 500 bootstrap replicates used to define the confidence intervals around the community-level thresholds identified by TITAN. Through this replication, the maximum summed z- and maximum summed z+ scores were calculated 500 times. The cumulative frequency of the results of these 500 replicates for the summed z- score (solid line) and summed z+ score (dashed line) is indicated on the right axis. For example, zero of the 500 replicates resulted in a maximum summed z- score at candidate change points lower than 15°C, all 500 replicates produce values between approximately 15°C and 16°C, and after 16°C there were no additional maximum summed z- scores produced by any of the replicates.

The angle of the cumulative frequency lines is a useful diagnostic tool. A sharply vertical increase, as seen here, is indicative of a true community-level threshold (Baker and King 2010).



Appendix Figure B-2. TITAN output (Baker and King 2015). The circles indicate the species-specific change points of each species in the TITAN analysis. The strengths of association at these change points were summed to determine the synchronous change points used to define the community-level thresholds. Filled circles represent species more associated with the colder side of the partition at their species-specific change point and open circles represent species more

associated with the warmer side of the partition. The size of the circle indicates strength of association with their particular side of the partition at their change point. Dotted lines represent the interval between the 5th and 95th confidence intervals of the species-specific change points, determined with 250 replicates (Baker and King 2010).

Appendix B References

Baker, M.E., and R.S. King. 2010. A new method for detecting and interpreting biodiversity and ecological community thresholds. Methods in Ecology and Evolution 1(1):25-37.

Baker, M.E., R.S. King, and D. Kahle. 2015. TITAN2: Threshold Indicator Taxa Analysis. R package version 2.1. http://CRAN.R-project.org/package=TITAN2.

APPENDIX C:

Thermal tier classification process step-by-step results

Pre-Step One: Results of TITAN and Indicator Value analysis. Species are classified into site-groups or combinations of site-groups based on the results of TITAN and Indicator Value analysis.

SITE-GROUP: COLD

Species	MWAT	DM
Cutthroat Trout	18.1	22.31
Brook Trout	18.34	21.68
Mottled Sculpin		27.85
Utah Sucker		
Paiute Sculpin		

SITE-GROUP: COLD-COOL

Species	MWAT	DM
Speckled Dace		31.82
Brown Trout	19.32	24.92
Rainbow Trout	19.35	23.77
Mountain Whitefish		
Mountain Sucker	21.95	29

SITE-GROUP: COOL

Species	MWAT	DM
Flannelmouth Sucker	26.22	31.15
Redside Shiner		
Roundtail Chub		34.5
Bluehead Sucker	25	
Utah Chub	26.01	31.86
Burbot	19.59	25.42
Northern Leatherside Chub	23.79	27.76

SITE-GROUP: COOL-WARM

Species	MWAT	DM
White Sucker	27.69	28.82
Lake Chub		

SITE-GROUP: WARM

Species	MWAT	DM
Sand Shiner		30.2
Flathead Chub		
River Carpsucker		
Channel Catfish	32.38	35.76
Longnose Dace		28.6
Fathead Minnow	28.78	31.88
Plains Killifish		38.45
Common Carp	29.84	33.88
Stonecat		
Shorthead Redhorse	26	31.3
Goldeye		
Johnny Darter	25.37	29.04
Central Stoneroller	27.82	
Common Shiner	24.2	28.97
Plains Topminnow		34.2
Brook Stickleback		28.6
Iowa Darter		
Bigmouth Shiner		33.8
Red Shiner		35
Gizzard Shad	30.3	30.72
Green Sunfish	31.05	35.12
Creek Chub		28.6
Brassy Minnow		
Smallmouth Bass	28.9	33.74
Yellow Perch	25.01	28.23
Plains Minnow	32.94	37.12
Hornyhead Chub		32.8
Longnose Sucker		24.8
Black Bullhead		35.30
Quillback	26.82	33.54
Sturgeon Chub		
Largemouth Bass	31.38	34.06
Rock Bass	30.24	34.28

Step One: Consolidation of site groups. Site groups are consolidated into candidate thermal tiers using the three following steps:

A. Eliminate any site-group with three or fewer species.
B. Reclassify its species into the least sensitive adjacent site-group.
C. Consolidated site-groups are now referred to as candidate thermal tiers.

Species that are affected by this step are highlighted in yellow.

CANDIDATE TIER 1

Species	MWAT	DM
Cutthroat Trout	18.1	22.31
Brook Trout	18.34	21.68
Mottled Sculpin		27.85
Utah Sucker		
Paiute Sculpin		

CANDIDATE TIER 2

Species	MWAT	DM
Speckled Dace		31.82
Brown Trout	19.32	24.92
Rainbow Trout	19.35	23.77
Mountain Whitefish		
Mountain Sucker	21.95	29

CANDIDATE TIER 3

Species	MWAT	DM
Flannelmouth Sucker	26.22	31.15
Redside Shiner		
Roundtail Chub		34.5
Bluehead Sucker	25	
Utah Chub	26.01	31.86
Burbot	19.59	25.42
Northern Leatherside Chub	23.79	27.76

CANDIDATE TIER 4

Species	MWAT	DM
Sand Shiner		30.2
Flathead Chub		
River Carpsucker		
Channel Catfish	32.38	35.76
Longnose Dace		28.6
Fathead Minnow	28.78	31.88
Plains Killifish		38.45
Common Carp	29.84	33.88
Stonecat		
Shorthead Redhorse	26	31.3
Goldeye		
Johnny Darter	25.37	29.04
Central Stoneroller	27.82	
Common Shiner	24.2	28.97
Plains Topminnow		34.2
Brook Stickleback		28.6
Iowa Darter		
Bigmouth Shiner		33.8
Red Shiner		35
Gizzard Shad	30.3	30.72
Green Sunfish	31.05	35.12
Creek Chub		28.6
Brassy Minnow		
Smallmouth Bass	28.9	33.74
Yellow Perch	25.01	28.23
Plains Minnow	32.94	37.12
Hornyhead Chub		32.8
Longnose Sucker		24.8
Black Bullhead		35.30
Quillback	26.82	33.54
Sturgeon Chub		
Largemouth Bass	31.38	34.06
Rock Bass	30.24	34.28
White Sucker	27.69	28.82
Lake Chub		

Step Two: Reclassification of species. Species whose species-specific criteria differ substantially from those of their candidate thermal tier are reclassified from their initial candidate tiers into a different candidate tier that is more closely aligned with their species-specific criteria. This is accomplished using the following steps:

A. Calculate the mean MWAT and mean DM for each candidate tier.

B. Calculate the thermal distance between each pair of adjacent tiers' mean MWAT and mean DM values.

C. If a species has an MWAT or DM that is 50% or more of the thermal distance between its own and another candidate tier, reclassify it into the other tier.

D. If a species has an MWAT or DM that is lower than the average MWAT or DM of a tier that is two tiers lower than its own, then reclassify it into the lower tier. If both MWAT and DM are available for this species, then both must qualify for this type of reclassification.

The following sub-steps provide a framework for decision making in cases where it is unclear whether a species meets the criteria for reclassification:

Step 2a. MWAT is prioritized: if a species' MWAT makes it a candidate for reclassification but its DM does not, it is moved. If a species' DM makes it a candidate for reclassification but its MWAT does not, it is not moved.

Step 2b. There is one exception to the prioritization of MWAT: if prioritizing MWAT would cause a species to have the lowest MWAT or DM in its candidate tier, then prioritize DM.

Species that have been reclassified from a colder candidate tier into a warmer candidate tier are highlighted in blue. Species that have been reclassified from a warmer candidate tier into a colder candidate tier are highlighted in red. All species except Longnose Sucker are reclassified from an adjacent candidate tier; Longnose Sucker was reclassified from Candidate Tier IV to Candidate Tier II, and is noted in Appendix C with a darker red highlight.

CANDIDATE TIER 1

Species	MWAT	DM
Cutthroat Trout	18.1	22.31
Brook Trout	18.34	21.68
Utah Sucker		
Paiute Sculpin		

CANDIDATE TIER 2

Species	MWAT	DM
Brown Trout	19.32	24.92
Rainbow Trout	19.35	23.77
Mountain Whitefish		
Mountain Sucker	21.95	29
Mottled Sculpin		27.85
Burbot	19.59	25.42
Longnose Sucker		24.8

CANDIDATE TIER 3

Species	MWAT	DM
Flannelmouth Sucker	26.22	31.15
Redside Shiner		
Bluehead Sucker	25	
Utah Chub	26.01	31.86
Northern Leatherside Chub	23.79	27.76
Speckled Dace		31.82
Sand Shiner		30.2
Longnose Dace		28.6
Shorthead Redhorse	26	31.3
Johnny Darter	25.37	29.04
Common Shiner	24.2	28.97
Brook Stickleback		28.6
Creek Chub		28.6
Yellow Perch	25.01	28.23
White Sucker	27.69	28.82

CANDIDATE TIER 4

Species	MWAT	DM
Flathead Chub		
River Carpsucker		
Channel Catfish	32.38	35.76
Fathead Minnow	28.78	31.88
Plains Killifish		38.45
Common Carp	29.84	33.88
Stonecat		
Goldeye		
Central Stoneroller	27.82	
Plains Topminnow		34.2
Iowa Darter		
Bigmouth Shiner		33.8
Red Shiner		35
Gizzard Shad	30.3	30.72
Green Sunfish	31.05	35.12
Brassy Minnow		
Smallmouth Bass	28.9	33.74
Plains Minnow	32.94	37.12
Hornyhead Chub		32.8
Black Bullhead		35.30
Quillback	26.82	33.54
Sturgeon Chub		
Largemouth Bass	31.38	34.06
Rock Bass	30.24	34.28
Lake Chub		
Roundtail Chub		34.5

Step Three: Placement of species not classified by TITAN. The initial candidate tiers were formed using the results of TITAN and Indicator Value analysis, which could only include the 52 species with more than three observations in the species assemblage database. 21 additional species are expected to be found in Wyoming streams but were observed three or fewer times. These species were classified into candidate thermal tiers based on their species-specific MWAT and DM criteria. This was accomplished using the following steps:

A. Recalculate the mean MWAT and mean DM for each candidate tier.

B. Classify all species not classified by TITAN into the candidate tier with the most similar MWAT and DM

The following sub-steps provide a framework for decision making in cases where a species' classification is unclear.

Step 3a. MWAT is again prioritized, unless doing so would cause a species to have the lowest MWAT or DM in its candidate tier.

Step 3b. Any species not placed by TITAN that have no species-specific criteria should be classified into a candidate tier containing species of the same genus if possible, or the most ecologically similar species if there are no species of the same genus.

Newly classified species are highlighted in yellow.

CANDIDATE TIER 1

Species	MWAT	DM
Cutthroat Trout	18.1	22.31
Brook Trout	18.34	21.68
Utah Sucker		
Paiute Sculpin		

CANDIDATE TIER 2

Species	MWAT	DM
Brown Trout	19.32	24.92
Rainbow Trout	19.35	23.77
Mountain Whitefish		
Mountain Sucker	21.95	29
Mottled Sculpin		27.85
Burbot	19.59	25.42
Longnose Sucker		24.8

CANDIDATE TIER 3

Species	MWAT	DM
Flannelmouth Sucker	26.22	31.15
Redside Shiner		
Bluehead Sucker	25	
Utah Chub	26.01	31.86
Northern Leatherside Chub	23.79	27.76
Speckled Dace		31.82
Sand Shiner		30.2
Longnose Dace		28.6
Shorthead Redhorse	26	31.3
Johnny Darter	25.37	29.04
Common Shiner	24.2	28.97
Brook Stickleback		28.6
Creek Chub		28.6
Yellow Perch	25.01	28.23
White Sucker	27.69	28.82
Walleye	25.99	31.68
Northern Pike		30
Orangethroat Darter	24.41	29.98
Finescale Dace		30
White Crappie	23.56	29.48
Black Crappie	26.56	32.1
Shovelnose Sturgeon		
Northern Pearl Dace		
Sauger		
Golden Shiner	27.71	31.56

CANDIDATE TIER 4

Species	MWAT	DM
Flathead Chub		
River Carpsucker		
Channel Catfish	32.38	35.76
Fathead Minnow	28.78	31.88
Plains Killifish		38.45
Common Carp	29.84	33.88
Stonecat		
Goldeye		
Central Stoneroller	27.82	
Plains Topminnow		34.2
Iowa Darter		
Bigmouth Shiner		33.8
Red Shiner		35
Gizzard Shad	30.3	30.72
Green Sunfish	31.05	35.12
Brassy Minnow		
Smallmouth Bass	28.9	33.74
Plains Minnow	32.94	37.12
Hornyhead Chub		32.8
Black Bullhead		35.30
Quillback	26.82	33.54
Sturgeon Chub		
Largemouth Bass	31.38	34.06
Rock Bass	30.24	34.28
Lake Chub		
Roundtail Chub		34.5
Emerald Shiner	28.86	30.34
Freshwater Drum	30.19	32.02
Grass Carp	29.96	35.95
Spottail Shiner	29.21	31.94
Bluegill	31.59	33.14
Kendall Warm Springs Dace		31.75
Pumpkinseed Sunfish	29.78	32.74
Suckermouth Minnow		
Flathead Catfish		
Western Silvery Minnow		
Western Mosquitofish		

Step Four: Reclassification of some species classified by TITAN with no species-specific thermal criteria. The fourth step acknowledges that there may be some species that require a similar reclassification to the reclassified species in Step Two, but that do not have any species-specific criteria to justify reclassification as described in Step Two. These species may be reclassified according to the following step:

A. Any species that were placed by TITAN but have no species-specific criteria may be transferred into the CT of a closely related species, at expert discretion.

Species that have been reclassified from a colder candidate tier into a warmer candidate tier are highlighted in blue. Paiute Sculpin, which was classified from Candidate Tier I into Candidate Tier II, is highlighted in light blue. Utah Sucker, which was classified from Candidate Tier I into Candidate Tier III, is highlighted in darker blue. There were no species reclassified from a warmer tier into a colder tier.

CANDIDATE TIER 1

Species	MWAT	DM
Cutthroat Trout	18.1	22.31
Brook Trout	18.34	21.68

CANDIDATE TIER 2

Species	MWAT	DM
Brown Trout	19.32	24.92
Rainbow Trout	19.35	23.77
Mountain Whitefish		
Mountain Sucker	21.95	29
Mottled Sculpin		27.85
Burbot	19.59	25.42
Longnose Sucker		24.8
Paiute Sculpin		

CANDIDATE TIER 3

Species	MWAT	DM
Flannelmouth Sucker	26.22	31.15
Redside Shiner		
Bluehead Sucker	25	
Utah Chub	26.01	31.86
Northern Leatherside Chub	23.79	27.76
Speckled Dace		31.82
Sand Shiner		30.2
Longnose Dace		28.6
Shorthead Redhorse	26	31.3
Johnny Darter	25.37	29.04
Common Shiner	24.2	28.97
Brook Stickleback		28.6
Creek Chub		28.6
Yellow Perch	25.01	28.23
White Sucker	27.69	28.82
Walleye	25.99	31.68
Northern Pike		30
Orangethroat Darter	24.41	29.98
Finescale Dace		30
White Crappie	23.56	29.48
Black Crappie	26.56	32.1
Shovelnose Sturgeon		
Northern Pearl Dace		
Sauger		
Golden Shiner	27.71	31.56
Utah Sucker		

CANDIDATE TIER 4

Species	MWAT	DM
Flathead Chub		
River Carpsucker		
Channel Catfish	32.38	35.76
Fathead Minnow	28.78	31.88
Plains Killifish		38.45
Common Carp	29.84	33.88
Stonecat		
Goldeye		
Central Stoneroller	27.82	
Plains Topminnow		34.2
Iowa Darter		
Bigmouth Shiner		33.8
Red Shiner		35
Gizzard Shad	30.3	30.72
Green Sunfish	31.05	35.12
Brassy Minnow		
Smallmouth Bass	28.9	33.74
Plains Minnow	32.94	37.12
Hornyhead Chub		32.8
Black Bullhead		35.30
Quillback	26.82	33.54
Sturgeon Chub		
Largemouth Bass	31.38	34.06
Rock Bass	30.24	34.28
Lake Chub		
Roundtail Chub		34.5
Emerald Shiner	28.86	30.34
Freshwater Drum	30.19	32.02
Grass Carp	29.96	35.95
Spottail Shiner	29.21	31.94
Bluegill	31.59	33.14
Kendall Warm Springs Dace		31.75
Pumpkinseed Sunfish	29.78	32.74
Suckermouth Minnow		
Flathead Catfish		
Western Silvery Minnow		
Western Mosquitofish		

Step Five: Expansion of candidate tiers. In order to classify species into more than four tiers to allow for more precise thermal regulation, candidate thermal tiers were divided according to the following steps:

A. Recalculate the mean MWAT and mean DM for each candidate tier.

B. Divide each candidate tier containing four or more species in half to produce two candidate tiers, one containing species with MWAT and DM values below the mean, and one with MWAT and DM values above the mean.

The following sub-steps provide a framework to clarify the process of dividing tiers:

Step 5a. Apply the same conditions regarding prioritization of MWAT.

Step 5b. For species with no available MWAT or DM, place them in the new candidate tier containing the most ecologically similar species.

CANDIDATE TIER 1

Species	MWAT	DM
Cutthroat Trout	18.1	22.31
Brook Trout	18.34	21.68

CANDIDATE TIER 2A

Species	MWAT	DM
Brown Trout	19.32	24.92
Rainbow Trout	19.35	23.77
Burbot	19.59	25.42
Longnose Sucker		24.8

CANDIDATE TIER 2B

Species	MWAT	DM
Mountain Whitefish		
Mountain Sucker	21.95	29
Mottled Sculpin		27.85
Paiute Sculpin		

CANDIDATE TIER 3A

Species	MWAT	DM
Bluehead Sucker	25	
Northern Leatherside Chub	23.79	27.76
Longnose Dace		28.6
Common Shiner	24.2	28.97
Brook Stickleback		28.6
Creek Chub		28.6
Yellow Perch	25.01	28.23
Orangethroat Darter	24.41	29.98
White Crappie	23.56	29.48
Northern Pearl Dace		
Johnny Darter	25.37	29.04
White Sucker	27.69	28.82

CANDIDATE TIER 3B

Species	MWAT	DM
Flannelmouth Sucker	26.22	31.15
Utah Chub	26.01	31.86
Speckled Dace		31.82
Sand Shiner		30.2
Shorthead Redhorse	26	31.3
Walleye	25.99	31.68
Northern Pike		30
Finescale Dace		30
Black Crappie	26.56	32.1
Sauger		
Utah Sucker		
Shovelnose Sturgeon		
Redside Shiner		
Golden Shiner	27.71	31.56

CANDIDATE TIER 4A

Species	MWAT	DM
Fathead Minnow	28.78	31.88
Central Stoneroller	27.82	
Smallmouth Bass	28.9	33.74
Hornyhead Chub		32.8
Quillback	26.82	33.54
Emerald Shiner	28.86	30.34
Spottail Shiner	29.21	31.94
Kendall Warm Springs Dace		31.75
Pumpkinseed Sunfish	29.78	32.74
Flathead Chub		
Lake Chub		
Common Carp	29.84	33.88
Grass Carp	29.96	35.95

CANDIDATE TIER 4B

Species	MWAT	DM
River Carpsucker		
Channel Catfish	32.38	35.76
Plains Killifish		38.45
Stonecat		
Goldeye		
Plains Topminnow		34.2
Iowa Darter		
Bigmouth Shiner		33.8
Red Shiner		35
Gizzard Shad	30.3	30.72
Green Sunfish	31.05	35.12
Brassy Minnow		
Plains Minnow	32.94	37.12
Black Bullhead		35.30
Sturgeon Chub		
Largemouth Bass	31.38	34.06
Rock Bass	30.24	34.28
Roundtail Chub		34.5
Freshwater Drum	30.19	32.02
Bluegill	31.59	33.14
Suckermouth Minnow		
Flathead Catfish		
Western Silvery Minnow		
Western Mosquitofish		

Step Six: Consolidation of tiers. Because the expansion of candidate tiers in Step Five has increased the resolution of the tiers to a degree that tiers were no longer meaningfully different from one another, Step Six was required to reduce this resolution by consolidating the tiers according to the follow steps:

A. For all candidate tiers that were divided in Step 5, the resulting upper sub-tier is merged with the lower sub-tier of the next-warmest divided candidate tier.

The following sub-step provides a framework to clarify the process of consolidating tiers:

Step 6a. If the adjacent candidate tier was not divided in Step 5, the sub-tier adjacent to this undivided tier is not consolidated.

The resulting candidate tiers contain the final species classifications proposed for implementation in Wyoming's thermal standard.

TIER I (COLD)

Species	MWAT	DM
Cutthroat Trout	18.1	22.3
Brook Trout	18.34	21.7

TIER II (COLD-COOL)

Species	MWAT	DM
Brown Trout	19.32	24.9
Rainbow Trout	19.35	23.8
Burbot	19.59	25.4
Longnose Sucker		24.8

TIER III (COOL)

Species	MWAT	DM
Mountain Whitefish		
Mountain Sucker	21.95	29
Mottled Sculpin		27.85
Paiute Sculpin		
Bluehead Sucker	25	
Northern Leatherside Chub	23.79	27.76
Longnose Dace		28.6
Common Shiner	24.2	28.97
Brook Stickleback		28.6
Creek Chub		28.6
Yellow Perch	25.01	28.23
Orangethroat Darter	24.41	29.98
White Crappie	23.56	29.48
Northern Pearl Dace		
Johnny Darter	25.37	29.04
White Sucker	27.69	28.82

TIER IV (COOL-WARM)

Species	MWAT	DM
Flannelmouth Sucker	26.22	31.15
Utah Chub	26.01	31.86
Speckled Dace		31.82
Sand Shiner		30.2
Shorthead Redhorse	26	31.3
Common Carp	29.84	33.88
Walleye	25.99	31.68
Northern Pike		30
Finescale Dace		30
Black Crappie	26.56	32.1
Sauger		
Utah Sucker		
Shovelnose Sturgeon		
Redside Shiner		
Fathead Minnow	28.78	31.88
Central Stoneroller	27.82	
Smallmouth Bass	28.9	33.74
Hornyhead Chub		32.8
Quillback	26.82	33.54
Grass Carp	29.96	35.95
Emerald Shiner	28.86	30.34
Spottail Shiner	29.21	31.94
Golden Shiner	27.71	31.56
Kendall Warm Springs Dace		31.75
Pumpkinseed Sunfish	29.78	32.74
Flathead Chub		
Lake Chub		

TIER V (WARM)

Species	MWAT	DM
River Carpsucker		
Channel Catfish	32.38	35.76
Plains Killifish		38.45
Stonecat		
Goldeye		
Plains Topminnow		34.2
Iowa Darter		
Bigmouth Shiner		33.8
Red Shiner		35
Gizzard Shad	30.3	30.72
Green Sunfish	31.05	35.12
Brassy Minnow		
Plains Minnow	32.94	37.12
Black Bullhead		35.30
Sturgeon Chub		
Largemouth Bass	31.38	34.06
Rock Bass	30.24	34.28
Roundtail Chub		34.5
Freshwater Drum	30.19	32.02
Bluegill	31.59	33.14
Suckermouth Minnow		
Flathead Catfish		
Western Silvery Minnow		
Western Mosquitofish		

APPENDIX D:

Evaluation database

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	Site ID	Longitude	Latitude	Location	Elevation (m)	Fish Survey Source	Thermoraph Source	BKT	CUT	BBT	BNT	LNS	RBT	MSC	MTS
2								1	1	2	2	2	2	3	3
3	1	-110.2712579	41.0065	Henry's Fork	2553	WGFD	Chandler et al. 2016	0	25	0	0	0	0	138	18
4	2	-110.5474053	41.0985	Blacks Fork	2477	WGFD	Chandler et al. 2016	16	1	0	2	0	1	442	1
5	3	-110.6134016	41.2179	Muddy Creek	2152	WGFD	Chandler et al. 2016	0	0	0	0	0	0	0	0
6	4	-106.9704313	41.0632	Harrison Creek	2768	WGFD	Chandler et al. 2016	0	2	0	0	0	0	0	0
7	5	-106.9699783	41.0594	Harrison Creek	2724	WGFD	Chandler et al. 2016	0	2	0	0	0	0	0	0
8	6	-107.356042	41.1373	Savery Creek	2081	WGFD	Chandler et al. 2016	0	2	0	0	0	2	210	3
9	7	-110.2046162	41.376	Smiths Fork	1968	WGFD	Chandler et al. 2016	0	0	0	0	0	0	0	0
10	8	-108.5335874	41.5062	Bitter Creek	2056	WGFD	Chandler et al. 2016	0	0	0	0	0	0	0	80
11	9	-110.5675399	41.5861	Little Muddy Creek	2001	WGFD	Chandler et al. 2016	0	0	0	0	0	0	0	16
12	10	-110.5335386	41.7507	Hams Fork	2089	WGFD	Chandler et al. 2016	0	0	0	2	0	0	0	3
13	11	-109.7856029	41.857	Big Sandy River	1910	WGFD	Chandler et al. 2016	0	0	0	0	0	0	0	0
14	12	-109.590082	42.0028	Big Sandy River	1968	WGFD	Chandler et al. 2016	0	2	0	1	0	1	0	0
15	13	-109.3004018	42.2847	Little Sandy Creek	2080	WGFD	Chandler et al. 2016	0	0	0	0	0	0	5	11
16	14	-109.508398	42.3673	Big Sandy River	2085	WGFD	Chandler et al. 2016	0	0	0	0	1	0	35	2
17	15	-109.2077662	42.5306	Little Sandy Creek	2430	WGFD	Chandler et al. 2016	54	0	0	13	0	0	111	0
18	16	-109.3240233	42.5667	Big Sandy River	2267	WGFD	Chandler et al. 2016	3	0	0	2	0	1	4	3
19	17	-107.14249	42.4874	Sweetwater River	1800	WGFD	Chandler et al. 2016	0	0	0	0	4	0	0	0
20	18	-106.8351253	44.9814	Prairie Dog Creek	1058	WGFD	Chandler et al. 2016	0	0	0	0	1	0	0	5
21	19	-106.2283943	44.4764	Crazy Woman Creek	1174	WGFD	Chandler et al. 2016	0	0	0	0	0	0	0	1
22	20	-106.425879	44.2644	Crazy Woman Creek	1281	WGFD	Chandler et al. 2016	0	0	0	0	1	0	0	6
23	21	-106.0820595	44.8722	Cabin Creek	1074	WGFD	Chandler et al. 2016	0	0	0	0	0	0	0	0
24	22	-106.0843687	44.8158	Powder River	1081	WGFD	Chandler et al. 2016	0	0	0	0	0	0	0	0
25	23	-106.1491891	44.4215	Powder River	1155	WGFD	Chandler et al. 2016	0	0	0	0	0	0	0	0
26	24	-106.1717027	43.9164	Powder River	1281	WGFD	Chandler et al. 2016	0	0	0	0	0	0	0	7
27	25	-106.2997675	43.6981	Powder River	1336	WGFD	Chandler et al. 2016	0	0	0	0	0	0	0	0
28	26	-108.047208	44.5111	Big Horn River	1155	WGFD	Chandler et al. 2016	0	0	0	0	8	0	0	10
29	27	-107.3776256	43.6469	Nowood River	1542	WGFD	Chandler et al. 2016	0	0	0	25	1	1	0	0
30	28	-107.9605948	44.2763	Nowood River	1187	WGFD	Chandler et al. 2016	0	0	0	0	1	0	0	0
31	29	-105.78	42.74	Box Elder Creek	1842	Hickerson	Hickerson	0	0	0	17	0	11	0	0
32	30	-106.029	42.712	Deer Creek	1722	Hickerson	Hickerson	0	0	0	58	5	6	0	0
33	31	-105.439	41.926	Laramie River	1982	Hickerson	Hickerson	0	0	0	0	9	0	0	0
34	32	-110.375	42.465	South Beaver Creek	2343	Girard	Girard	0	2	0	0	0	0	21	0
35	33	-110.393	42.442	South Beaver Creek	2475	Girard	Girard	0	16	0	0	0	0	0	0
36	34	-110.381	42.433	Pine Grove Creek	2444	Girard	Girard	0	0	0	0	0	0	0	11
37	35	-110.304	42.41	Fogarty Creek	2265	Girard	Girard	0	0	0	0	0	0	0	8
38	36	-110.296	42.361	Dry Piney Creek	2246	Girard	Girard	0	0	0	0	0	0	0	2
39	37	-110.408	42.46	Mini Beaver Creek	2440	Girard	Girard	0	1	0	0	0	0	0	0
40	38	-110.374	42.465	Mini Beaver Creek	2342	Girard	Girard	0	0	0	0	0	0	2	0
41	39	-110.263	42.388	Dry Piney Creek	2192	Girard	Girard	0	0	0	0	0	0	0	7
42	40	-110.267	42.387	Dry Piney Creek	2196	Girard	Girard	0	0	0	0	0	0	0	3
43	41	-110.324	42.372	Black Canyon	2291	Girard	Girard	0	0	0	0	0	0	0	4
44	42	-106.04	41.03	Laramie River	2385	Peterson	Peterson	0	0	0	75	0	0	0	0
45	43	-105.98	41.14	Laramie River	2257	Peterson	Peterson	0	0	0	50	1	0	0	0
46	44	-105.64	41.28	Laramie River	2181	Peterson	Peterson	0	0	0	0	1	0	0	0
47	45	-105.61	41.32	Laramie River	2178	Peterson	Peterson	0	0	0	35	18	0	0	0
48	46	-105.74	41.48	Laramie River	2174	Peterson	Peterson	0	0	0	0	0	0	0	0
49	47	-105.74	41.67	Laramie River	2135	Peterson	Peterson	0	0	0	0	0	0	0	0
50	48	-105.42	41.93	Laramie River	1967	Peterson	Peterson	0	0	0	0	46	0	0	0
51	49	-105.12	42.06	Laramie River	1424	Peterson	Peterson	0	0	0	0	0	0	0	0
52	50	-105.72	41.23	Laramie River	2191	Maitland	Maitland	0	0	0	86	100	0	0	0

	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE
1	MWF	PSC	UTS	LSC	CKC	CSH	LND	OTD	JDT	IDT	NPD	YEP	BHS	STK	WHS	FMS
2	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	4
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	38	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	3	0	0	0	0	0	0	0	0	0	29	0
9	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	46
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	54	0
12	0	0	0	0	0	0	163	0	0	0	0	0	0	0	156	3
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	1
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	40	0	73	6
16	0	0	0	0	0	0	0	0	0	0	0	0	1	0	17	121
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	51	0	12	0	0	0	0	0	0	0	74	0
20	0	0	0	0	13	0	22	0	0	0	0	0	0	0	38	0
21	0	0	0	0	1	0	853	0	0	0	0	0	0	0	465	0
22	0	0	0	0	0	0	265	0	0	0	0	0	0	0	426	0
23	0	0	0	0	4	0	73	0	0	0	0	0	0	0	20	0
24	0	0	0	0	4	0	7	0	0	0	0	0	0	0	2	0
25	0	0	0	0	0	0	22	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	79	0	0	0	0	0	0	0	1	0
27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
28	0	0	0	0	0	0	58	0	0	0	0	1	0	0	35	0
29	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	216	0	0	0	0	0	0	0	13	0
31	0	0	0	0	2	0	37	0	0	0	0	0	0	0	6	0
32	0	0	0	0	0	0	25	0	0	0	0	0	0	0	3	0
33	0	0	0	0	10	0	11	0	8	0	0	0	0	0	10	0
34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
39	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
42	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44	0	0	0	0	1	0	84	0	0	0	0	0	0	0	8	0
45	0	0	0	0	0	0	141	0	0	1	0	0	0	0	0	0
46	0	0	0	0	10	0	74	0	2	3	0	0	0	0	8	0
47	0	0	0	0	54	53	28	0	3	5	0	0	0	0	86	0
48	0	0	0	0	4	2	55	0	14	7	0	0	0	0	4	0
49	0	0	0	0	3	0	115	0	0	2	0	0	0	0	0	0
50	0	0	0	0	37	3	143	0	4	0	0	0	0	0	40	0
51	0	0	0	0	16	1	0	0	4	0	0	1	0	0	9	0
52	0	0	0	0	191	42	1290	0	442	342	0	0	0	0	216	0

	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO	AP	AQ	AR	AS	AT
1	RSS	SPD	UTC	FSD	NOP	WAE	SAR	SDS	FHM	NRH	STR	SMB	HHC	EMS	BLC
2	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	68	4	0	0	0	0	0	0	39	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	17	126	0	0	0	0	0	0	0	0	0	0	0	0	0
9	30	26	0	0	0	0	0	0	1	0	0	0	0	0	0
10	0	409	0	0	0	0	0	0	0	0	0	0	0	0	0
11	9	48	0	0	0	0	0	0	6	0	0	0	0	0	0
12	321	51	0	0	0	0	0	0	75	0	0	0	0	0	0
13	1	0	2	0	0	0	0	0	2	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	229	182	0	0	0	0	0	0	11	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	112	2	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
21	0	0	0	0	0	0	0	9418	693	5	0	1	0	0	0
22	0	0	0	0	0	0	0	3057	11	36	0	26	0	0	0
23	0	0	0	0	0	0	0	15	1	10	0	0	0	0	0
24	0	0	0	0	0	0	0	3969	25	2	0	0	0	0	0
25	0	0	0	0	0	0	0	1029	3	0	0	0	0	0	0
26	0	0	0	0	0	0	0	9262	32	0	0	0	0	0	0
27	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	14	112	32	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	2	131	3	161	0	0	0	0	0
31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
39	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
42	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
46	0	0	0	0	0	0	0	0	9	0	0	0	0	0	0
47	0	0	0	0	0	0	0	0	60	0	0	0	0	0	0
48	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	0	0	1	0	0	0	29	0	0
51	0	0	0	0	0	0	0	3	1	2	21	8	0	0	0
52	0	0	0	0	0	0	0	0	146	0	0	0	0	0	0

	AU	AV	AW	AX	AY	AZ	BA	BB	BC	BD	BE	BF	BG	BH	BI	BJ
1	GCP	STS	QBK	LKC	GZS	FHC	CRP	BMN	CCF	BLB	RTC	BMS	GDE	GSF	LMB	PKF
2	4	4	4	4	4	4	4	4	5	5	5	5	5	5	5	5
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0
13	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	59	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	28	0	0	0	0	14	0	0	0	0
20	0	0	0	0	0	19	6	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	292	80	0	26	5	0	0	5	0	0	6
22	0	0	0	0	0	222	73	0	33	111	0	0	9	0	0	0
23	0	0	0	0	0	28	0	2	0	0	0	0	0	0	0	0
24	0	0	0	0	0	621	0	0	386	0	0	0	0	1	0	24
25	0	0	0	0	0	539	0	0	64	0	0	0	0	0	0	54
26	0	0	0	0	0	2250	3	0	25	0	0	0	3	0	0	948
27	0	0	0	0	0	220	0	0	0	0	0	0	2	0	0	0
28	0	0	0	2	0	8	51	0	1	0	0	0	0	0	2	0
29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	23	10	0	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
39	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
42	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
46	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0
47	0	0	0	0	0	0	2	37	0	0	0	0	0	0	0	0
48	0	0	0	0	0	0	0	62	0	0	0	0	0	0	0	0
49	0	0	0	0	0	0	45	39	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	39	0	0	0	0	0	0	0	0	0
51	0	0	0	0	0	0	28	2	1	0	0	0	0	5	2	0
52	0	0	0	0	0	0	0	359	0	0	0	0	0	0	0	0

	BK	BL	BM	BN	BO	BP	BQ	BR	BS	BT	BU	BV
1	**PMN**	**PTM**	**RCS**	**RDS**	**RKB**	**SGC**	**SMN**	**STC**	**SMM**	**% Guild 1**	**% Guild 2**	**% Guild 3**
2	5	5	5	5	5	5	5	5	5	MWAT 18.1/DM 21.7	MWAT 19.3/DM 23.8	MWAT 22.0/DM 27.8
3	0	0	0	0	0	0	0	0	0	0.138121547	0	0.861878453
4	0	0	0	0	0	0	0	0	0	0.036480687	0.006437768	0.957081545
5	0	0	0	0	0	0	0	0	0	0	0	0.255033557
6	0	0	0	0	0	0	0	0	0	1	0	0
7	0	0	0	0	0	0	0	0	0	1	0	0
8	0	0	0	0	0	0	0	0	0	0.005102041	0.005102041	0.625
9	0	0	0	0	0	0	0	0	0	0	0	0.06557377
10	0	0	0	0	0	0	0	0	0	0	0	0.14953271
11	0	0	0	0	0	0	0	0	0	0	0	0.526315789
12	0	0	0	0	0	0	0	0	0	0	0.00257732	0.414948454
13	0	0	0	0	0	0	0	0	0	0	0	0.611111111
14	0	0	0	0	0	0	0	0	0	0.5	0.5	0
15	0	0	0	0	0	0	0	0	0	0	0	0.209415584
16	0	0	0	0	0	0	0	0	0	0	0.005649718	0.310734463
17	0	0	0	0	0	0	0	0	0	0.303370787	0.073033708	0.623595506
18	0	0	0	0	0	0	0	0	0	0.214285714	0.214285714	0.5
19	0	0	0	0	0	0	0	0	0	0	0.013468013	0.461279461
20	0	0	0	0	2	0	0	23	0	0	0.007692308	0.6
21	0	0	33	0	0	0	0	111	0	0	0	0.110045852
22	0	0	26	0	0	0	0	79	0	0	0.000228258	0.159096097
23	1	0	0	0	1	0	0	5	0	0	0	0.60625
24	0	0	63	0	0	0	0	2	0	0	0	0.002546024
25	0	0	7	0	0	0	0	4	0	0	0	0.012775842
26	0	0	146	0	0	0	0	6	0	0	0	0.006817113
27	17	0	0	0	0	40	0	0	0	0	0	0.003533569
28	0	0	9	0	0	0	0	0	0	0	0.023323615	0.303206997
29	0	0	0	0	0	0	0	0	0	0	0.870967742	0.129032258
30	0	0	21	0	0	0	0	1	0	0	0.001718213	0.39347079
31	0	0	0	0	0	0	0	0	0	0	0.383561644	0.616438356
32	0	0	0	0	0	0	0	0	0	0	0.711340206	0.288659794
33	0	0	0	0	0	0	0	0	0	0	0.183673469	0.795918367
34	0	0	0	0	0	0	0	0	0	0.086956522	0	0.913043478
35	0	0	0	0	0	0	0	0	0	1	0	0
36	0	0	0	0	0	0	0	0	0	0	0	1
37	0	0	0	0	0	0	0	0	0	0	0	1
38	0	0	0	0	0	0	0	0	0	0	0	1
39	0	0	0	0	0	0	0	0	0	1	0	0
40	0	0	0	0	0	0	0	0	0	0	0	1
41	0	0	0	0	0	0	0	0	0	0	0	1
42	0	0	0	0	0	0	0	0	0	0	0	1
43	0	0	0	0	0	0	0	0	0	0	0	1
44	0	0	0	0	0	0	0	0	0	0	0.446428571	0.553571429
45	0	0	0	0	0	0	0	0	0	0	0.264248705	0.735751295
46	0	0	0	0	0	0	0	0	0	0	0.008849558	0.85840708
47	0	0	0	0	0	0	0	0	0	0	0.139107612	0.601049869
48	0	0	0	0	0	0	0	0	0	0	0	0.573333333
49	0	0	0	0	0	0	0	0	0	0	0	0.588235294
50	0	0	0	0	0	0	0	1	0	0	0.134110787	0.66180758
51	0	0	0	5	0	0	0	4	0	0	0	0.274336283
52	0	0	0	0	0	0	0	0	0	0	0.057871811	0.785003111
53										MWAT 18.1/DM 21.7	MWAT 19.3/DM 23.8	MWAT 22.0/DM 27.8
54										**% Guild 1**	**% Guild 2**	**% Guild 3**

	BW	BX	BY	BZ	CA	CB	CC
1	% Guild 4	% Guild 5	MeanAug.thermograph	MWAT.thermograph	DM.thermograph	Min.thermograph	MeanAug.modeled
2	MWAT 26.0/DM 30.0	MWAT 29.0/DM 32.0					
3	0	0	13.14671	14.70829	20.17	6.26	13.61
4	0	0	13.412613	14.04	20.09	7.84	14.05
5	0.744966443	0	14.68332	16.2775	19.04	10.55	15.69
6	0	0	9.951848	10.62232	13.25	6.74	9.3
7	0	0	10.64356	11.42521	14.03	7.37	9.3
8	0.364795918	0	16.62337	17.68923	20.5	12.28	16.17
9	0.93442623	0	18.19909	19.53407	26.83	9.31	18.02
10	0.85046729	0	13.59468	14.42186	14.75	12.58	15.2
11	0.473684211	0	15.96786	16.80264	18.07	14.25	16.17
12	0.579896907	0.00257732	17.547	19.28693	22.49	11.79	18.3
13	0.388888889	0	17.279565	19.36471	**28.71**	7.43	18
14	0	0	17.0591	**18.77871**	**26.11**	8.53	17.79
15	0.790584416	0	15.75826	17.4715	18.63	11.41	16.55
16	0.683615819	0	16.36716	18.097	**25.09**	10.1	16.58
17	0	0	13.64418	15.58029	18.42	7.31	14.82
18	0.071428571	0	13.32724	15.09843	19.22	6.37	14.3
19	0.478114478	0.047138047	17.80476	**19.42223**	**27.83**	9.41	18.74
20	0.2	0.192307692	17.99655	19.22143	22.9	14	19.14
21	0.874447687	0.015506461	19.86648	**23.7265**	**28.82**	13.41	20.46
22	0.781784981	0.058890664	19.67085	**23.00471**	**27.66**	13.16	20.01
23	0.35	0.04375	24.18871	**26.74286**	**31.1**	15.5	22.42
24	0.904230317	0.093223658	20.12552	**24.32125**	**31.8**	11.79	20.9
25	0.912311266	0.074912892	19.655258	**23.424**	**32.68**	9.09	20.23
26	0.904795487	0.0883874	20.01899	21.81895	**29.49**	11.1	20.33
27	0.787985866	0.208480565	20.59355	**22.88571**	**28.4**	13.1	21.52
28	0.638483965	0.034985423	20.75824	**22.20409**	**26.45**	16	20.46
29	0	0	12.988401	13.43707	17.058	10.25	12.36
30	0.567010309	0.037800687	21.9592	**24.21254**	**28.95**	17.73	21.73
31	0	0	17.99387	**19.99**	**23.97**	10.55	15.5
32	0	0	16.37645	18.56571	22.52	10.36	15.83
33	0.020408163	0	17.68581	19.24286	21.86	12.98	18.64
34	0	0	13.1145	13.9514	18.24	7.58	13.22
35	0	0	10.9852	11.6557	17.09	6.78	11.55
36	0	0	9.7277	10.3771	18.33	3.37	12.45
37	0	0	14.901	16.15	25.12	4.83	14.13
38	0	0	13.2877	13.9129	18.33	7.98	14.99
39	0	0	13.8326	14.88	19.57	8.58	11.14
40	0	0	12.2506	12.84	16.62	7.38	13.44
41	0	0	15.0423	16.17	24.06	8.08	15.36
42	0	0	16.2997	17.5243	27.37	6.88	15.39
43	0	0	13.4897	14.4529	19.47	8.58	14.55
44	0	0	16.8555	17.7943	22.24	11.24	15.7
45	0	0	16.7316	17.8443	22.43	10.75	16.37
46	0.132743363	0	19.3084	**20.6843**	**26.49**	3.37	17.75
47	0.25984252	0	18.9829	**20.2514**	**26**	3.47	17.49
48	0.426666667	0	18.96	20.4914	26.39	4.73	18.03
49	0.411764706	0	18.5465	20.0657	25.61	4	18.01
50	0.201166181	0.002915452	18.3152	**19.7357**	21.95	4.93	18.72
51	0.575221239	0.150442478	20.1642	**22.0886**	25.61	4.93	20.88
52	0.157125078	0	18.4103	**19.7457**	23.11	13.47	17.37
53	MWAT 26.0/DM 30.0	MWAT 29.0/DM 32.0					
54	% Guild 4	% Guild 5					

	CD	CE	CF	CG	CH	CI
1	Tier: Predictor Variable	Exceedances	Tier: P/A	Exceedances	Tier: 10% Threshold	Exceedances
2						
3	1	No	1	No	1	No
4	1	No	1	No	2	No
5	2	No	3	No	3	No
6	1	No	1	No	1	No
7	1	No	1	No	1	No
8	2	No	1	No	2	No
9	3	No	3	No	4	No
10	1	No	3	No	3	No
11	2	No	3	No	3	No
12	3	No	2	No	3	No
13	3	DM	3	DM	3	DM
14	3	No	1	MWAT,DM	2	DM
15	2	No	3	No	3	No
16	2	DM	2	DM	3	No
17	1	No	1	No	1	No
18	1	No	1	No	1	No
19	3	No	2	MWAT,DM	3	No
20	3	No	2	No	3	No
21	4	No	3	MWAT,DM	3	MWAT,DM
22	4	No	2	MWAT,DM	3	MWAT
23	4	MWAT,DM	3	MWAT,DM	3	MWAT,DM
24	4	DM	3	MWAT,DM	4	DM
25	4	DM	3	MWAT,DM	4	DM
26	4	No	3	DM	4	No
27	4	No	3	MWAT,DM	4	No
28	4	No	2	MWAT,DM	3	MWAT
29	1	No	2	No	2	No
30	4	No	2	MWAT,DM	3	MWAT,DM
31	2	MWAT,DM	2	MWAT,DM	2	MWAT,DM
32	2	No	2	No	2	No
33	3	No	2	No	2	No
34	1	No	1	No	3	No
35	1	No	1	No	1	No
36	1	No	3	No	3	No
37	1	DM	3	No	3	No
38	1	No	3	No	3	No
39	1	No	1	No	1	No
40	1	No	3	No	3	No
41	1	DM	3	No	3	No
42	1	DM	3	No	3	No
43	1	No	3	No	3	No
44	2	No	2	No	2	No
45	2	No	2	No	2	No
46	3	No	2	MWAT,DM	3	No
47	2	MWAT,DM	2	MWAT,DM	2	MWAT,DM
48	3	No	3	No	3	No
49	3	No	3	No	3	No
50	3	No	2	MWAT	2	MWAT
51	4	No	3	MWAT	3	MWAT
52	2	MWAT	2	MWAT	3	No
53						

Appendix D Notes

Further details on the sources of fish survey and thermograph data are listed below.

WGFD: Fish surveys conducted by the Wyoming Game and Fish Department (WGFD) vary in survey method, reach length, and other sampling protocols. All surveys were conducted between the months of May through October, between the years 1989 and 2016. Data were compiled by various WGFD employees and shared with me by Kevin Gelwicks of the WGFD.

Chandler et al. 2016: Chandler et al. (2016) compiled thermograph records from various sources throughout the western United States to be used for building the AWAE models used in this thesis. Temperatures were summarized in the form of a daily mean, daily maximum, and daily minimum temperature throughout the month of August.

Hickerson: Fish survey and thermograph data were collected by University of Wyoming masters student Brian Hickerson as part of his research on the Hornyhead Chub. Sites were sampled by multi-pass electrofishing, and reach lengths ranged from approximately 100 to 300 meters. Temperature data were recorded hourly.

Girard: Fish survey and thermograph data were collected by University of Wyoming masters student Carlin Girard as part of his research on the impacts of oil and natural gas development. Sites were sampled by electrofishing. Temperature data were recorded at 30-minute intervals.

Peterson: I sampled the stream fish species assemblage at eight sites on the Laramie River in the summer of 2015. Sites were sampled using single-pass electrofishing. At each site, I sampled three 50 meter reaches, for a total of 150 meters per site. These three reaches were opportunistically selected to encompass the different habitat types available at each site. Temperature data were recorded at 30-minute intervals.

Maitland: Fish survey and thermograph data were collected by University of Wyoming PhD student Bryan Maitland. Sites were sampled by electrofishing. Temperature data were recorded hourly.

Appendix D References

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