Evaluating Standards for Protecting Aquatic Life in Washington's Surface Water Quality Standards

Temperature Criteria

Draft Discussion Paper and Literature Summary

<u>Excerpts on the Protection of Char Provided at the Special Request of the USEPA</u>

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III. Methodology and Considerations in Establishing Criteria Recommendations

This chapter discusses the methodology used and some of the underlying thoughts and concerns that went into establishing the temperature criteria recommendations contained in this paper.

1. The Multiple Lines of Evidence (MLE) Methodology

Scientific information comes in a wide variety of forms. These include:

- Laboratory testing where the temperature is held constant,
- Laboratory testing where the temperature is made to fluctuate at a set rate,
- Controlled field studies using either natural or artificial channels,
- Field studies where environmental variables such as shade are altered, and
- Field observational studies where the patterns of fish are observed in the wild.

All of these sources of information provide valuable insights, but it can be a challenging task to try and compare and contrast such different types of research. This has led many researchers to simplify their approach and select only a single type of research. This simplification, while understandable, can result in a loss of understanding. More importantly, however, it can result in a lost opportunity to demonstrate how well all of these very different types of studies correspond to one another. The key to using a diversity of information types is to convert the results into a common metric.

The multiple lines of evidence (MLE) approach used in this paper was developed as a means to use all of the available scientific information to support sound decision making. The MLE methodology was developed to provide a method for making recommendations that are transparent to the reviewer and that can be predictably modified when new information becomes available. The basic approach is rather simple. All the scientific information is sorted first by the life-stage (e.g., spawning, rearing, migration, etc.) or by some discrete environmental risk (e.g., lethality, smoltification, disease, etc.). The information is then sorted into different categories of study types. The following provides a simplified example of how this information can be categorized into independent lines of evidence (ILOE) for the life-stage of juvenile rearing:

Study types (ILOE): Constant temperature laboratory testing of growth
Fluctuating temperature laboratory testing of growth
Controlled field studies on growth
Studies on the distribution and health status of natural populations
Laboratory studies examining competition and predation
Field studies examining competition and predation

For each line of evidence the study conclusion are standardized into a standardized exposure metric and summarized as the range of individual study results. Depending upon the line of evidence, this range may be either the absolute range or the dominant range (e.g., 90th percentile of distribution of study results).

The standard metric for this temperature analysis is a 7-day average of the daily maximum temperatures (7DADMax). This metric was chosen primarily because:

1. Sublethal chronic biologic reactions generally take more than a week's exposure to become meaningful;
2. Small daily maximum temperature fluctuations beyond some "healthy" target level will not be biologically meaningful, but if a single daily maximum metric were chosen and then not attained such fluctuations would have regulatory repercussions; and
3. It is not as defensible to use weekly averages of the daily average temperatures because fluctuations about the mean temperature can be highly variable and extreme fluctuations will erase or diminish the benefits of otherwise healthy average temperatures.

To make the conversions to a standard metric, this analysis relies upon the conversion equations provided by Dunham et al. (2000) that are based on data from 752 stream sites located in the Western United States; particularly the Northwest. For conversting the temperature research results for protecting bull trout and Dolly Varden (Washington's most cold water loving fish species), it is assumed that their habitat will have very stable temperatures. This analysis uses the assumption that summer average diel fluctuations are less than 2°C in char habitat. This is consistent with the state's information showing that colder streams (7DADMax <15C) have median average fluctuations of 2.1°C (90% between 1.1-3.6°C). It is also consistent with the commonly held belief that many of these waters are kept thermally stable due to a higher reliance on input from groundwater. For salmon and trout waters, the conversion is based on the assumming that the summer average diel fluctuations are from 4-6°C. This is consistent with the state's data showing that warmer streams (7DADMax 15-19°C) have a median average fluctuations of 1.2-5.3°C (90 percentile range – median 2.6°C). It also recognizes that the waterbodies used by salmon and trout have the most variable temperature regimes overall. The following table shows the adjustment calculations that were used to convert temperatures to a common metric.

Table (III-1): Conversion equations for standardizing duration of exposure scenarios. These are used to convert study results to the standard metric of a 7-day average of the daily maximum temperatures.

Convert from:	To a 7DADMax (°C)	Summer Average of the Diel Ranges (°C)
In Char Spawning Habitat:		
Summer max	Subtract 0.55	0-2
Summer mean	Add 2.00	0-2
Weekly mean (highest)	Add 0.93	0-2
Daily mean (highest)	Add 0.62	0-2
In Salmon and Trout Habitat:		
Summer max	Subtract 0.95	4-6
Summer mean	Add 4.64	4-6
Weekly mean (highest)	Add 3.18	4-6
Daily mean (highest)	Add 2.60	4-6

The metric adjustment step was also used where appropriate to put bounds on the potential correct estimate on each line of evidence. This bounding process was used where there was reasonable uncertainty about the duration of exposure that best represented the line of evidence and the related biological response. For example, growth studies are generally conducted for a relatively long period of time 30-90 days, but significant changes in growth between different test temperatures are commonly obvious after the first week or two. Thus there is uncertainly whether the results of these tests should be applied as if they are summer average exposures or weekly average exposures. In the face of this uncertainty conversions are made for both possible cases. The range produced by using these two adjustment factors creates a range within which the most probable correct answer would be expected to occur.

The results of this MLE process are presented in tabular form, and a range is produced by independently averaging both the lower and upper range values for each line of evidence. This creates a range within which the best estimate should be found. The midpoint of this range is considered to be the overall best estimate, unless overriding concerns with any particular line of evidence suggest another course is warranted. In such a case the suspect line of evidence is noted and either dropped entirely from the final range calculation, or is used as a basis for conditioning the recommendation. The following is a simplified example based on protecting the juvenile rearing life-stage of salmon and trout:

Table (III-2): Juvenile rearing of salmon and trout:

Line of Evidence (LOE)	7DADMax (°C)	Midpoint	Comments Regarding LOE
Laboratory Growth Studies at Constant Temperatures	x-z	y	Based on well controlled laboratory tests.
Laboratory Growth Studies at Fluctuating Temperatures	x-z	y	
Field Studies on Growth	x-z	y	
Predation and Competition	x-z	y	
Ranges Identified as Optimal	x-z	y	Basis for estimates and intended metrics unclear.
Comparing Discrete Test Regimes	x-z	y	
Laboratory Temperature Preferences	x-z	y	
Swimming Performance and Scope for Activity	x-z	y	
Field Distribution of Healthy Populations	x-z	y	This estimate relies on the general upper range considered healthy, and temperatures above which coldwater species begin to loose dominance
Summary Statistics and Final Estimated Range:	**Ave(x)-Ave(y)**	**Midpoint**	

Based on previous draft reviews of the temperature requirements of Washington's native fish, it was determined the differences between species were generally slight. Only division into three species groupings (guilds) appears warranted (Hicks, 1998, 2000). Therefore, the multiple lines of evidence procedure was conducted separately in this current review only for the guilds of 1) Char, and 2) Salmon and trout, and 3) Warm water species.

2. General Thoughts and Observations

a) Adjusting Laboratory Data for Application to Natural Waters

Laboratory tests do not represent the full range of conditions that an organism will face in the natural environment. In most laboratory tests fish are exposed to a constant temperature environment, while in natural waters the temperature fluctuates during each day, between days, and in seasonal trends of spring warming and fall cooling. In natural waters, fish must actively maintain position and seek food and shelter in the currents of rivers, succeed in the face of inter- and intra-species competition for both food and shelter, avoid predation, and resist disease. In laboratory studies, however, the fish are often in test chambers without substantial currents, fed food in pellet form, treated to prevent disease, and seldom need to compete or avoid predation. On the other hand, in laboratory tests, fish are often crowded into very small unnatural spaces, even styrofoam cups, and forced to perform using electrical stimulation or prodding, subjected to laminar artificial flows, and often fed unusual rations with large time intervals of starvation.

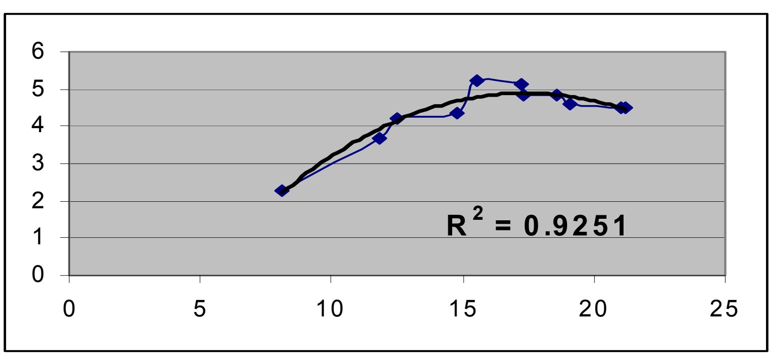
Because of the differences between laboratory conditions and the environmental conditions that fish face in the natural world, we must use caution in how we apply laboratory-derived data in setting ambient water criteria. We must ensure that the temperature regimes used in the laboratory tests are considered in any application to natural streams.

Growth Studies:

Most of the research on optimal growth temperatures is conducted with water kept at a constant temperature. Water quality standards, however, must apply to naturally fluctuating thermal environments. Since temperature directly effects the metabolism of the fish, a fish kept continuously in warm water will experience more metabolic enhancement than one which only experiences that same temperature for one or two hours per day. Thus, constant test results cannot be directly applied as a daily maximum temperature in a fluctuating stream environment. The literature examined for this paper strongly suggests that constant temperature test results can be used to represent daily mean temperatures (Hokanson et al., 1977; Clarke, 1978; Grabowski, 1973; Thomas et al., 1986; Hahn, 1977; and Dickerson, Vinyard, and Weber, 1999, and unpublished data, as cited in Dunham, 1999); at least in systems with moderate temperature fluctuations. Growth studies may be conducted for substantially varying periods of time (14 to 90 days) but generally encompass time-frames that would match reasonably well with periods of maximum summer temperatures (20-60 days).

For illustrative purposes we can examine the findings of Hokanson et al. (1977). This study compared specific growth and mortality rates of juvenile rainbow trout for 50 days at seven constant temperatures between 8°C and 22°C and six diel temperature fluctuations (sine curve of amplitude +/- 3.8°C about mean temperatures from 12°C to 22°C

Figure (III-1): Relationship between growth rates and mean temperature exposures. Based on Hokanson et al.(1977).



Plotting the growth rates against the mean temperatures for both the constant and fluctuating tests produced a characteristic normal distribution for growth rate and temperature (Figure III-1, above). Thus a strong relationship appears between the daily mean temperatures in fluctuating tests and those in the constant tests. A pattern was demonstrated, however, where daily mean temperatures in the fluctuating tests at means of 12.5 and 15.5°C produced greater growth rates than comparable constant temperatures at 11.8 and 14.8°C. At the constant optimal temperature of 17.2°C and above, however, this pattern was reversed. This pattern led Hokanson et al. to suggest that the growth of rainbow trout appears to be accelerated at fluctuating treatments when the mean temperature is below the constant temperature optimum for growth and retarded by mean fluctuating temperatures above the constant temperature optimum. Hokanson et al. suggested that water quality standards (based on weekly mean values) should be set such that the average weekly temperature is below the constant test temperature producing maximum growth.

Like Hokanson et al. (1977), other researchers (Thomas et al., 1986; and Everson, 1973) have found that fluctuating temperature regimes actually enhance growth over what is found at constant temperature exposures; at least where the mean of the fluctuating regime is at or below that of the constant exposure test temperature producing optimal growth. The works by these authors also suggest that high peak temperatures may create stress which will harm growth even though the daily average temperature appears optimal. For example, Thomas et al. (1986) noted stress conditions occurring in cycles with daily peak temperatures of 20°C.

Variable Feeding Regimes:

Growth rates are related to both temperature and food rates. As temperature goes up, more food is necessary to supply basic physiological needs but also the efficiency goes up for utilizing excess foods. This relationship results in a situation where at maximum feeding rates fish will grow larger in warmer water, but at reduced feeding rates in the same warm water growth rates will suffer. In cooler waters maximum growth rates are achieved at feeding rates well below those that produced maximum growth in the warmer waters. This relationship between feeding rates and temperature means that laboratory test results would need to be modified to account for the feeding regimes present in natural stream environments to be able to confidently set a very precise maximal growth temperature.

Numerous authors have demonstrated that food availability in the natural environment is well below that used in laboratory growth studies (Brett et al., 1982; Saski, 1966; Nedham and Jones, 1959; Wurtsbaugh and Davis, 1977; Ensign et al., 1990; Bisson and Davis, 1976; as cited in ODFW, 1992; Elliott 1975, McCullough 1975, 1979, Murphy and Hall 1981, Edwards et al. 1979, Vannote et al. 1980, Bisson and Bilby 1998, and James et al. 1998; as cited in USEPA, 2001, and others). As an example of the influence of feeding rates, McMahon, Zale, and Selong (1999) tested bull trout growth and found that at satiation (maximum) and 66% satiation ration levels growth was highest at 16°C, whereas at a 33% satiation ration growth rate was maximized at 12°C. Thus in waters of lower productivity, maximum growth may occur at temperatures well below those that produce optimal growth at high rations.

While the basic relationship between feeding rates and growth at various temperatures is well established, there is a problem with trying to apply an adjustment factor to laboratory test results. In the laboratory tests reviewed for this paper, feeding rates and regimes varied significantly. In addition, the nutritional value can be different between feeds, the size and type of food along with its method of presentation can influence the ability of fish to feed and consequently grow, and the specific starting size of the test fish will greatly influence growth rates. Given that the feeding regimes and test conditions were so highly variable, trying to make a standard adjustment to laboratory test results to try and match natural feeding regimes is problematic. Nevertheless, it is important that this factor be recognized when setting water quality criteria recommendations for juvenile rearing.

There are at least a couple of ways that this factor can be accounted for without having to develop complex growth models to test various temperature regime scenarios. The first is to make a standard 2-4°C adjustment downward to the temperature value determined optimal for growth at satiation feeding. The second is to apply the criteria to a relatively brief window of time (e.g., 2-3 weeks), even though the growth tests often lasted 4 weeks or more, and recognize that temperatures will need to be below this value most of the time in even the warmest years to result in compliance, thus virtually ensuring that temperatures will produce excellent growth overall. In assessing the risks associated with making such simplifying assumptions it is important to recognize that growth rates diminish on either side of the optimal temperature range. It is not substantially different to err slightly on the warmer side of optimal than it is to err on the cooler side of optimal, barring any other detrimental biologic responses. By extending just beyond the warmer side of optimum during the warmest period of the warmest years the fish will actually be experiencing a greater number of days in the optimum range over most years. In the recommendations of this paper, except where noted for testing that examined reduced feeding rates, temperatures that consistently resulted in maximum growth at satiation feeding were used to set the criteria value.

Incubation Studies:

Specific studies were not found that compared the effects of constant to fluctuating temperature on incubating fish. However, it is assumed in this paper that that incubating fish generally respond to the daily mean temperature. This seems warranted given the strong basis provided through the use of the standardized "temperature unit" calculations in hatchery operations and in fisheries science in general. It is fortunate that many of the incubation studies were conducted at fluctuating water temperatures (highlighted in the discussion on individual species). This provided a good opportunity to generally check the effect of applying the results as average temperatures and to assess the risks of allowing higher daily maximum temperatures. Additionally, a natural safety factor often exists to protect egg incubation. Since salmonids bury their eggs in the gravel of the stream bed, they are buffered slightly from both daily maximum and daily minimum stream temperatures. The buffering of the stream bed gravel can effectively reduce the daily maximum temperature by at least 1-1.5°C (Crisp, 1990). While this natural safety factor is not accounted for in laboratory tests it is also not dependable. Therefore, in the recommendations of this paper no adjustment is made to account for this often occurring buffering effect. It is useful, however, when reviewing the potential risks of the recommendations in this paper to recognize that sudden and unseasonable rises in stream temperature during incubation will often not cause similar temperature exchanges in the egg pockets situated in the gravel.

Few studies examined the risk of short-term lethality to eggs from unusually high temperatures for individual species, so the few that were conducted are used broadly to suggest limits on daily maximum temperatures during the incubation period for all related species. Limits for daily maximum temperatures are also based on the results from controlled laboratory tests where the temperature regime experienced by the fish was started at varying high daily maximum temperatures and then allowed to fluctuate and fall in concert with the seasonal changes in the natural waters used to supply water for the tests. From these experiments it can be observed what temperatures at the start of the incubation tests are generally associated with reduced incubation performance, and what temperatures appear not to hinder incubation.

Lethality and Acute Effects:

The water quality standards must be applicable to a broad range of human activities. The standards must protect against both gradual basin-wide increases in temperature as well as localized shifts in daily maximum temperatures. Rapid or site-specific changes in temperature can be caused by unique human activities (such as industrial cooling waters process wastewaters, and water releases from reservoirs). While localized extreme changes in water temperature are not as common as the gradual basin-wide changes, they do exist, and their regulation through discharge permits and water quality certification programs require careful application of biologically-based temperature standards. These localized point sources of temperature change are also those most capable of creating short-term lethality to aquatic life as they may discharge water significantly hotter or colder than the ambient water to which organisms are acclimated.

The incipient lethal level (ILL) is typically determined by exposing juvenile fish to constant temperatures and determining the test temperature that causes 50% mortality of test fish within typically a 7-day exposure period. It would not be appropriate to establish a criteria that would allow 50% mortality, however, so the ILL value needs to be adjusted to a level that would not be expected to cause any mortality. The National Academy of Sciences (1972) and Coutant (1973) recommend subtracting 2°C from the LT50 value to determine a safe (no more than 1% mortality – an LT1) short-term temperature limit. Some reasons for extra caution in interpreting lethality studies include that:

1. The time above lethal levels appears cumulative (DeHart, 1974, 1975, and Golden, 1978);
2. Adults appear more sensitive than the juveniles which are most commonly tested (Coutant, 1970; Becker, 1973; Bouck and Chapman, 1975);

3. Individual stocks possess slightly different tolerance levels (Beacham and Withler, 1991);
4. Indirect acute effects are often cited to occur just below lethal levels (e.g., increased predation, feeding cessation, migration blockage); and
5. The range between no mortality and high mortality rates is often described by as little as 0.5°C (Charlon, Barbier, and Bonnet, 1970).

The selection of laboratory results for use in developing recommendations focuses on test fish that had previously been acclimated to reasonably cool water temperatures. This recognizes that fish migrating from cooler upstream tributaries or from marine waters may not be fully acclimated to warmer mainstem summer river temperatures. It also helps to bridge the gap in protection that occurs when protecting fish from hot thermal discharges occurring in the late fall through early spring period when the ambient river temperatures are often very cold.

Although test results that determine lethal threshold temperatures are used as one line of evidence in this paper for recommending water temperature criteria that will prevent acute (short-term) effects, the final recommendations are not based on just avoiding lethality. Temperatures that would result in any detrimental acute effect such as causing a barrier to adult fish spawning or migration take precedence in the recommendations. Thus, while a species may be able to survive in a laboratory environment at a given temperature, research may show that the temperature maximum would be unacceptable in natural waters.

IV. Temperature Requirements of Char, Salmon, and Trout Species

1. Native Char Temperature Requirements

a) General Life History Information:

Bull trout (*Salvelinus confluentus)* and Dolly Varden (*Salvelinus malma*) are the only two species of char native to Washington (Hass and McPhail, 1991). Perhaps more than any other species, cold waters are critical to maintaining healthy populations of these native char. These two closely related species are difficult to taxonomically identify from one another in the field (Hass and McPhail, 1991). Cavender (1978) may have first recognized that what had previously been considered an interior form of Dolly Varden was in fact a distinct species, now referred to as the bull trout. Goetz (1989) suggests that bull trout may be more directly related to the Arctic char (*Salvelinus alpinus*), and in fact a sister to the Arctic char-Dolly Varden group. Spalding (1997) found that for Washington's Olympic Peninsula many of the anadromous char previously assumed to be Dolly Varden keyed out to be bull trout. While important to advancing scientific understanding, the historic problems with discriminating between these char appear to pose little practical problems in terms of setting water quality criteria. This is because Dolly Varden and bull trout are generally considered to have very similar biological requirements, and the management measures needed to protect both Dolly Varden and bull trout may be identical (WSDFW, 1994).

The Washington State Department of Fish and Wildlife considers the majority of native char stocks in the state as being "Vulnerable Populations" requiring special protection. Bull trout in particular have received considerable publicity in recent years because of their status as a threatened species under the federal Endangered Species Act. The results of a 12-month study evaluating stock status by U.S. Fish and Wildlife Service noted serious declines of bull trout populations statewide (USFWS, 1997). Rieman et al. (1997) examined the distribution and status of bull trout across 4,462 sub-watersheds of the interior Columbia River basin and the Klamath River basin and found that bull trout are more likely to occur and the populations are more likely to be strong in colder, higher-elevation, low- to mid-order watersheds with lower road densities. They noted that while bull trout were widely distributed across their potential range, strong populations may exist in only 6% of this potential range.

Upon hatch, char fry will either remain in the localized area or move downstream to larger streams or lakes to rear (Goetz, 1989; Williams and Mullen, 1992; Reiser et al., 1997). Movements to more suitable upstream waters has also been observed (Fraley and Shepard, 1989; Armstrong and Morrow, 1980, as cited in Goetz, 1989). Unless information clearly demonstrates that a stretch of water would not be used for summer rearing even under natural conditions, temperature criteria assigned to these migration paths should also be set to protect the rearing of char fry.

Some research suggests that age 0-1 juvenile char have cooler temperature preferences than age 1+ juveniles; however, there is little consistency in the values identified. The preference values for age 0-1 bull trout range from an average of 4.5°C (Ratliff, 1992), to maximum stream temperatures of 10°C and 13°C (Ratliff, 1987; and Martin et al., 1991). Resident forms of bull trout remain in or near their natal streams for their entire life. Fluvial and adfluvial forms may remain in the area of their natal stream for 1 to 3 years and then migrate significant distances to more productive waters for greater juvenile growth opportunities (Pratt, 1992; Ratliff, 1992; Riehle et al., 1997; Fraley and Shepard, 1989; Goetz, 1989); although, some stocks have also been observed to migrate to lakes or reservoirs immediately after hatching (Reiser et al., 1997). Sea-run (anadromous) forms will migrate hundreds of miles to take advantage of productive near-shore marine habitat (Goetz, 1989). Temperature standards would ideally be set in consideration of these various life-strategies.

The needs of resident forms may be slightly different from the various migratory forms. Juvenile bull trout and Dolly Varden have difficulty competing with several common salmonid species in warmer waters (Haas, 2001; McMahon et al., 1999). This may partially explain why researchers have observed young juvenile fish remaining in their natal stream for the first several years before moving downstream to warmer and more productive waters. It is plausible that the lack of significant competitors in their cold natal streams may compensate for the reduced productivity of these pristine environments. Since non-migratory resident bull trout must remain in and defend their natal habitat for their entire life, temperatures here should clearly favor bull trout over competing species such as chinook salmon and rainbow trout (Martin et al., 1991; Mullan et al., 1992; Ziller, 1992; Adams and Bjornn, 1997; WSDFW, 1994; Haas, 2001).

b) Spawning Requirements

Field Observations of Spawning Initiation

Maximum temperatures should generally be below 12°C and on a fall season cooling trend at the time char enter their spawning streams (Fraley and Shepard, 1989). In a study on the Rapid River in Idaho, pairing behavior was noted to begin after average water temperatures dropped from 10 to 6.5°C (generally equivalent to a change in single daily maximum temperatures from 11-7.5°C) (Schill, Thurow, and Kline, 1994). In the same river, Elle and Thurow (1994) found that daily maximum water temperatures below 10°C influenced the movements of spawners both in and out of the Rapid River. While daily maximum temperatures may need to fall below 9 to 11°C (WSDFW, 1994) for redd construction to begin, no authors have been found to suggest spawning will begin at daily maximum temperatures above 10°C. Most place the temperature that triggers spawning below 9°C (Goetz, 1989; Pratt, 1992; Kramer, 1991; Fraley and Shepard, 1989), with the peak of spawning activity not occurring until stream temperatures falls below 7°C (James and Sexauer, 1997; Wydoski and Whitney, 1979). Reiser et al. (1997) suggested that a daily average temperature between about 6.8 to 8.1°C (generally equivalent to a single daily maximum range of 7.8-9.1°C) was necessary to initiate spawning activity. Temperatures above 8°C were noted by Kramer (1994) as appearing to cause spawning activity to temporarily cease in char in northwest Washington streams. The Washington Water Power Company (1995) studied the distribution of fish in the lower Clark Fork River in Idaho and found that bull trout spawning was confined to an artificial spawning channel created to mitigate the effects of the Cabinet Gorge Dam. Water temperatures in theses spawning areas were consistently cooler (5-7°C) than other areas of the channel, and during the period of redd construction bull trout used the area of the channel where the temperature was 11°C due to ground water seeps.

Bull trout are noted to begin spawning as soon as conditions are suitable and redds are constructed. Temperature may be the primary cue used by the fish to determine when to begin migratory movements (Elle and Thurow, 1994; Swanberg, 1997) as well as to initiate spawning (Kramer, 1994). It is important that temperatures at the initiation of spawning be within a range that would not hinder ovulation and would not cause obvious harm to offspring of any early spawning individuals.

The field observations and citations noted above are in strong concurrence that spawning behavior (pairing and redd construction) will not begin 7DADMax temperatures fall below 8.45-9.45°C, and that spawning itself will only be initiated once the daily maximum temperature falls below 7.45-8.45°C.

Laboratory Studies of Spawning Initiation

Only a single study was found that addressed the question of what temperatures are required to initiate spawning. In a study by Gillet (1991) ovulation in char was found to be completely inhibited at constant temperatures above 11°C and slowed down above 8°C as compared to fish held at 5°C. This would be correlated with 7DADMax values of 11.62-11.93°C and 8.62-8.93°C, depending upon the constant test exposures being treated as if they represent on-day average and seven-day daily average stream exposures. Transfers from 8°C to 5°C were found to stimulate ovulations. Gillet also found that exposure to temperatures of 8°C prior to ovulation were favorable to fecundity rates, and assumed based on their work that very cold water was only necessary during the last weeks before spawning. The work of Gillet suggests that for the closely related Arctic char, temperatures should be falling below 8°C to stimulate healthy spawning, and falling towards 5°C to ensure full survival of fertilized eggs (only 11, 8, an 5°C were tested, so specific incubation thresholds were not determined). Based on this one laboratory study it would appear that a 7DADMax of less than 8.62-8.93°C is necessary to allow healthy ovulation to occur in bull trout.

Summary on Spawning Initiation Requirements

There is strong agreement among both field and laboratory research and observations on the spawning requirements of bull trout. The weight of the evidence supports the position that initial spawning behavior (pairing and redd construction) is hindered by daily maximum stream temperatures above 9-11°C and that the act of spawning may be impaired by daily maximum water temperatures greater than 8-9°C.

Laboratory Studies on Incubation Success

Only a few studies were found that tested the incubation requirements of bull trout in the laboratory. Fredenberg (1992) reported that eggs from wild bull trout incubated at an average temperature of 3.1°C had egg survival averaging 97.4% from unfertilized egg to eye-up and 97.1% from unfertilized egg to hatch. Eggs were subsequently collected from the hatchery raised broodstock and incubated at an average temperature of 5.8°C (5.0°C minimum and 6.6°C maximum), and while no growth or survival data was collected the author suggested that it appeared normal. Fredenberg, Dwyer, and Barrows (1995) collected gametes from wild spawning bull trout from the Swan River drainage of northwest Montana during September of 1993 and 1994. Fertilized eggs were produced by paired matings and incubated in 1993 at approximately 3.1°C with a resultant 97.1% survival from green eggs to hatching. Eggs in 1994 were incubated at approximately 6.5°C with a resultant 95.5% survival.

McPhail and Murry (1979) tested incubation of bull trout at constant laboratory temperatures of 2, 4, 6, 8, and 10°C in a series of three replicate tests. In the one test lot that escaped high transit-related mortality during movement to the laboratory after fertilization, McPhail and

Murry (1979) found that survival was excellent (90-95%) at 2, 4, and 6°C, good (85%) at 8°C, and poor (20%) at 10°C. In the two other test lots, which experienced significant transit-related stress (40% egg mortality during transit), survival rates were noted to steadily decline from 2 to 4, to 6°C and drop to zero at 8 and 10°C. Similarly, constant test temperatures in the range of 7-11°C were reported to result in "poor" survival in hatchery culture by Brown (1985). McPhail and Murry (1979) noted that mortalities at low temperatures (<6.0C) typically occurred at blastopore closure, while at high temperatures (>8.0) mortality is associated with hatching. In studies on the related species of Arctic char, Humpesch (1985) reported optimal incubation to occur at 5°C.

The above studies generally found that constant temperatures in the range of 3.1-6.5°C capable of producing excellent (90-97.4%) survival of char eggs, with survivals equally high throughout the range. At temperatures 8 to 10°C survival rates may drop precipitously from 85% to 0%. The research suggests that a constant temperature of 6.5°C may most confidently define the upper limit for fully protecting incubation. This would be equivalent to a 7DADMax temperature of 7.43°C when correlated as if it were a one-week average daily exposure, and equivalent to a 7DADMax temperature of 8.5°C when correlated as if it were an incubation season-long average exposure (assuming a stable stream temperature with 0-2°C diel variation). Based on the above, the laboratory studies suggest full incubation protection will occur if the highest 7DADMax temperature during the incubation period does not exceed 7.43-8.5°C. It is important to note that this process is not trying to determine an acute criteria for eggs or embryos. It only identifies temperatures that can occur at the initiation of incubation that will fully protect native char incubation under a normal temperature regime (i.e., fall cooling trends).

It is important to note that even though 2°C has been shown to be suboptimal at a constant incubation temperature, natural seasonal declines in temperature down to 2°C in the incubation period are unlikely to reduce survival rates. Salmonids have been shown to undergo conditioning in the early stage of incubation that allows excellent survival at very low temperatures occurring later. Where the conditioning does not occur, and the eggs are incubated at an early stage at very low temperatures, significant reductions in survival have been noted (Murry and Beacham, 1986; Seymour, 1956). This assertion is also supported by work showing that newly hatched bull trout alevins are tolerant of temperatures near 0°C (Baroudy and Elliott, 1985) and that the lower limit for hatching in the related Arctic char is less than 1°C. Such conditioning, however, may not only protect embryos from later exposure to colder waters but may help increase tolerance for warm water fluctuations as well. Bebak, Hankins, and Summerfelt (2000) examined the hatching success and posthatch survival of three stocks of Arctic char and found that if incubation had been well initiated at a favorable (6°C) temperature then later transfers to waters as warm as 10-12°C still allowed for excellent hatch rates (90-98%). It is noteworthy, however, that they also found that survival rates post-hatch declined over time at both 10°C and 12°C.

Field Evidence on Incubation Requirements

Little evidence was found from field studies on the incubation requirements of bull trout or Dolly Varden. In one study that was reviewed, however, it was noted that bull trout redds in the upper Flathead River basin in Montana had mean temperatures that ranged from 2.1-5.4°C (Weaver and White, 1985). This season-long estimate of average field temperatures would correlate with a 7DADMax temperature range of 4.1-7.4°C. It is important to point out that just noting the average temperature of redds does not indicate whether it was healthy, and is not very useful for describing of the upper boundary for successful incubation. For this reason, only the upper half of the range will be used to represent this line of evidence, the next preferred option would be to not use this range at all to estimate incubation requirements. Based on the above discussion, field temperatures of bull trout redds should be considered to have an upper range of 5.75-7.4°C.

Conclusion on Spawning and Incubation

While spawning and incubation were discussed separately above, it is important to recognize they actually occur concurrently in the natural stream environment. Once spawning has occurred the eggs begin to incubate. The multiple lines of evidence created from the wide variety of field and laboratory studies can be brought together in support of selecting a temperature standard for application at the beginning of the spawning and incubation period. The focus on the temperature at the initiation of incubation is viewed as appropriate since temperatures will be at their highest at this time. They should also be on a trend of fall cooling that will soon reach temperatures that are naturally determined by the elevation and geographic location of the site. The interim conclusions from each line of evidence are summarized below:

Table (IV-1): Spawning and Incubation requirements of native char.

Line of Evidence	7DADM - Range (°C)	Median (°C)
Field observations on spawning initiation	***7.45-8.45***	***7.95***
Laboratory studies on spawning initiation	***8.62-8.93***	***8.77***
Laboratory studies on incubation success	***7.43-8.5***	***7.97***
Field study on typical average redd temperatures in Montana	***5.75-7.4***	***6.57***
Best Estimate of Criteria	***7.31-8.32***	***mid. pt. 7.82***

The range of these independent lines of evidence is 5.75-8.93°C with a mean range of 7.31-8.32°C and an overall midpoint of 7.82°C. This strongly suggests that a 7-day average daily maximum temperature of 7.82°C will fully protect the spawning and incubation of char. In recognition that temperatures of 8.0°C have been noted as hindering spawning in char, it may not be advisable in this situation to select a spawning criteria from the upper end of the range presented above. It is concluded that a 7-day average of the daily maximum temperatures of 7.5-8.0°C best represents the highest temperature that can occur at the initiation of spawning without causing detrimental effects to either spawning or subsequent incubation.

c) Juvenile Rearing

Field Distribution Work Examining Fish Presence

Dunham et al. (2001) surveyed the distribution of juvenile/small bull trout (Note: small resident stock fish cannot be distinguished apart from juveniles of migratory stocks) in 6 basins (109 sites) in Washington state and found that summer maximum temperatures best defined their presence in streams. In their study, 95% of the bull trout were found in streams with temperatures above 12°C with an interquartile range of 13.3-14.7°C (with the median and mode both at 14°C). This is similar to a study by Rieman and Chandler (1999) who examined 581 sites throughout the Western United States and found that the majority of sites with juvenile/small bull trout had summer maximum temperatures of 11-14°C (95% were from waters with summer maximums less than 18°C). Goetz (1997b) surveyed 13 drainages in Washington and Oregon and was unable to find juvenile bull trout in streams with temperatures above 14°C. In a study in British Columbia, Hass (2001) found that the warmest study streams containing bull trout (resident juveniles or adults) had summer maximum temperatures of 16°C, which is similar to the findings of numerous other researchers that 15-16°C formed the upper temperature limit to bull trout (juveniles or adults) summer distributions (Fraley and Shepard 1989, Shepard 1985, Goetz, 1989, Pratt, 1992, Martin et al. 1991) and that a temperature of 15°C can trigger the out-migration of char from otherwise suitable habitat (Goetz, 1997). The general findings for bull trout discussed above are also supported by the work of Jensen (1981) who found that 14°C (as a 10-day mean) appeared to form a barrier to the distribution of the closely related Arctic char.

The above studies demonstrate that daily maximum temperatures in the range of 14-15°C (7DADMax 13.45-14.45°C) set the upper boundary for commonly finding juvenile/small bull trout. It is important to note that some researchers have both wider and narrow margins of distribution. Some authors have found that colder summer maximum temperatures (10-11.5°C) formed the general limits to bull trout distributions in specific watersheds (Ratliff, 1987). While other authors have reported finding juvenile bull trout at much warmer (17-20.5°C) temperatures (Brown, 1992; Goetz, 1989, Adams and Bjornn, 1997; Reiman and Chandler, 1999). It was noted by Adams (1999) that bull trout found at 20.5°C held in the coolest water available in the area (<17.2°C) and looked physically unhealthy. This point is made to remind the reader that the mere presence of a fish does not indicate that it is healthy or that the stream is capable of supporting healthy populations.

Field Work that Considered Dominance, Density, and Competitive Advantage

While studies that describe the stream temperatures associated with the presence of a species are a useful line of evidence, they cannot be used to say whether or not the population is in good health at the observed temperature regimes. Researchers have tried to answer the question of what is healthy for bull tout in field studies by identifying sites with high densities of bull trout, and by identifying temperatures beyond which bull trout begin to loose dominance over other competing species. Health has also been assessed more directly by evaluating the condition of the fish using standard bio-metrics.

Haas (2001) found that a 7-day average of the daily maximums of 11.6°C (correlating with a single daily maximum of 12.15°C) consistently determined the dominant presence and better condition of bull trout in 26 sites in the Columbia River drainage in British Columbia. Haas reasoned that bull trout populations would be supported by maintaining summer maximum temperatures below 13°C, and noted that rainbow trout were found to be dominant over bull trout and in better condition as summer maximum temperatures approached 14-15°C. This corresponds well to the Dunham et al. (2001) finding that 90% of the sites that did not have bull trout had summer maximum temperatures greater than 13.5°C (interquartile range of 14.6-19.8°C and median of 17°C). It also corresponds well with Williams and Mullen (1992) finding that rainbow trout excluded the first two age classes of bull trout at weekly average temperatures above approximately 11-12°C (correlating with single day maximums of 12.49-13.49°C). Williams and Mullan (1992) found that bull trout growth in the Early Winters Creek basin of northern Washington steadily increased with increasing temperatures at three synchronous test sites having annual maximum weekly average temperatures of 8.7, 10.3, and 11.7°C, respectively. The maximum weekly average of 11.7°C correlates to a 7DADMax of 12.63°C. Growth was not tested at any warmer sites, thus the 7DADMax temperature that would allow for optimal growth in this stream system was not identified, but would likely be greater than 12.6°C. Similarly, Martin et al. (1991) and Goetz (1989, 1997) concluded that bull trout are dominant in streams with summer maximum temperatures less than 13°C. Saffel and Scarnecchia (1999) examined 18 reaches of six streams and found that the density of bull trout increased with increasing maximum temperature below 14°C (range 7.8-13.9°C) and decreased with increasing temperature above 18°C (range 18.3-23.3°C) The highest densities were found in reaches with maximum summer temperatures between 10-13.9°C. In this work there were no study streams having summer maximum temperatures within the range of 14-18°C, so it cannot be said whether or not densities would have begun to decline just above 14°C. Kitano et al. (1994) found that brook trout and cutthroat trout coexisted with bull trout in the Flathead River basin in Montana in waters with a temperature range of 5.3-8.9°C in early September, but they provided no information on the relative health of these populations or on when competition would be impaired.

Based on the above works, it is reasonable to expect that streams with summer maximum temperatures of 12-14°C (7DADMax 11.45-13.45°C) will be capable of producing and maintaining strong populations of bull trout. Not all of the research examined, however, fully supports this assertion. Sexauer and James (1997) studied four bull trout streams in the Yakima and Wenatchee River watershed in central Washington that were selected because they were considered “healthy” and found summer maximum temperatures in the year the study was conducted ranged from 9-12.5°C. Further, Ratliff (1992) and Ziller (1992), reported that bull trout began to lose dominance as summer average temperatures rose above 7.9°C (correlating with single day maximums of 10.45°C).

The wealth of studies across the Northwest when considered in combination demonstrate some strong patterns of occurrence. Any study of a single basin or stream needs to be carefully considered prior to accepting its conclusions. For example, in the cold groundwater dominated Metolius River system in Oregon, Ratliff (1987) reported that bull trout were rarely found at temperatures above 10°C. While true, it is important to recognize that warmer waters are largely unavailable in this tributary system. Thus care should be exercised before concluding that 10°C has been shown to create a barrier to bull trout populations. Similarly, many of the studies were conducted over a single year, and thus the long-term relationship between the presence healthy populations and maximum ambient temperatures at the site is often not documented. So while Sexauer and James (1997) studied streams with healthy populations, they only reported temperatures from a single year. The actual temperature regime for these sites, which hold healthy char populations, may include years with warmer temperatures than those observed during the study year.

Summary of Evidence from Field Studies on Juvenile Rearing

A preponderance of juvenile/small bull trout in Washington may be found in streams with summer maximum temperatures between 13.3-14.7°C (7DADMax 12.75-14.15°C). This is reasonably consistent with surveys extending throughout the Western states that found most juvenile use to occur in stream segments with maximum temperatures not exceeding 14°C. It is also well supported by studies of in-stream growth, density, and competitive dominance which suggest healthy bull trout streams have summer temperatures that do not exceed 12-14°C. While field studies are a very useful line of evidence for developing temperature criteria, they can be strengthened by cross-checking the conclusions with laboratory findings.

Laboratory Studies Supporting Juvenile Rearing

In a controlled hatchery environment, Fredenberg et al. (1995) found that constant exposure to 8.3°C produced greater growth of bull trout at maximum rations than at lower test temperatures. This would be equivalent to a single-day maximum of 9.79°C (7DADMax 9.24°C) if the constant hatchery temperature is treated as it represented the warmest one-week average stream temperature; and a single-day maximum of 10.85°C (7DADMax 10.3°C) if it were equivalent to a summer season-long average stream temperature.

In a laboratory study, McMahon et al. (1998) found that growth was highest at a constant 12°C, but not significantly less at 14 and 16°C at maximum rations. Growth declined sharply at temperatures greater than 18°C and less than 10°C. In follow-up tests, the authors (McMahon et al., 1999) found that growth at maximum and at 66% of maximum rations were highest at 16°C, but that at 33% of maximum ration growth was maximized at 12°C. In modeling the available calories in low productivity streams (the ration used and the basis for its selection was not provided) against the growth observed in their tests, the authors suggested the optimum growth range of 12-16°C would shift to 8-12°C. McMahon et al. (2000) examined the growth of bull trout over a 60-day period in both constant and fluctuating temperature regimes. Peak growth at a moderately restricted ration (0.66) occurred at 12.4°C at a constant temperature and at a mean of 12.2°C in fluctuating treatments (+/- 3°C around the mean - giving a 60-day average daily maximum of 15.2°C). Peak growth at an unrestricted ration occurred at 13.2°C and at a severely restricted ration (0.11) occurred at 12.3°C. In this work the authors found that growth was higher in constant exposure tests overall, and opined this was due to the fluctuating temperatures increasing metabolism without increasing food intake. Similar findings were produced using the related Arctic char (Swift, 1975; as cited in Jensen, 1995; and Jobling, 1983) where maximum growth occurred at about 12-14°C (at satiation rations). These growth studies may help explain why Shepard et al. (1984) found that bull trout growth was slower in the middle fork of the Flathead River, Montana, even though it was warmer and more productive. The work of McMahon et al. (2000) suggest that an average temperature of 12-13°C can produce maximal growth under both severely restricted and satiation diets, respectively. A constant laboratory test temperature exposure of 12-13°C can be correlated with 7DADMax summer stream temperature maximums of 12.93-13.93°C based on correlations with the warmest one-week average stream temperature; and 7DADMax summer maximums of 14-15°C based on correlations with the summer season-long average stream temperature. There is reason to also believe that in some cases growth could be maximized, or not statistically different, at even higher constant temperatures. Their work also suggests that daily maximum temperatures of 15-16°C (7DADMax 14.45-15.45°C) may be producing thermal stress or excess metabolic demands that may hinder growth in juvenile char that are at otherwise healthy daily mean temperatures. This is supported by the findings of Bonneau and Scarnecchia (1996) who noted that temperatures above 15-16°C are associated with increased metabolic stress and swimming impairment in bull trout. The line of evidence produced using the above laboratory studies suggests that streams with 7DADMax temperatures not exceeding 12.93-15°C are likely to fully support the growth of juvenile char.

Laboratory Studies Examining Competition for Food

Brook trout are a species of char that have been widely introduced in the northwest that have often been cited as eliminating bull trout from their native habitat. McMahon et al. (1999), found that the presence of brook trout in sympatry (together) with bull trout resulted in significantly greater growth of brook trout and significantly lower growth for bull trout than occurred with either species in allopatry (alone), especially at constant water temperatures equal to or greater than 12°C. McMahon et al. (2000) examined bull trout and brook trout competition under two constant (11 and 17°C) temperatures. At a constant 11°C there were not significant differences in the growth of bull trout and brook trout in allopatry and sympatry. However, at the higher temperature (17°C) brook trout grew significantly more (a 2.5-times greater growth rate) than bull trout in both allopatry and sympatry. Behavioral observations were also made at temperatures of 8 and 16°C. When in the presence of brook trout, bull trout feeding rates declined 50% at 8°C and 64% at 16°C, whereas feeding by brook trout showed no change. The work of McMahon et al. (1999, 2000) suggests that as average water temperatures rise above 12°C bull trout may begin to loose their competitive ability against brook trout. It also points out the difficulty of trying to protect bull trout from displacement by brook trout since the brook trout are capable of significantly out-competing the bull trout even at very low temperatures (8°C).

In trying to correlate the laboratory studies on competition to stream temperatures, it is important to recognize that competition may be related as much to the absolute temperature at any point in time as much as a weekly or seasonal average temperature regime. However, since the effect of competition on the health of a species will not be determined by a portion of a single day allowing for detrimental competition, it is still considered reasonable to correlate average stream temperatures with the constant laboratory test temperature at which competition was not favored by water temperature (12°C). A single daily average and a weekly average are used below to represent the effects found with constant laboratory exposures and make conversions to a 7DADMax temperature metric. The above cited work suggests that a 7DADMax summer temperature of 12.62-12.93°C may best describe a stream which does not provide any thermal advantage in competition between bull trout and brook trout. It is important to remind the reader that the laboratory tests did not include temperatures within the range of 12-16°C making it difficult to determine if a threshold exists within this range above which most of the change in competitive ability occurs.

Summary of Laboratory Studies

The work of McMahon et al. (1999, 2000) suggest that a constant or average temperature of 12°C can produce maximal growth under even severely restricted diets. Their work also suggests that as water temperatures rise above 12°C bull trout begin to loose their ability to compete with brook trout. As noted above, the research on competition seems best viewed by comparison with a single week's average temperature, rather than as a single day of detrimental competition. So, while the range produced for the laboratory growth tests is compared as either weekly average temperatures or season-long average temperatures, the laboratory study on brook trout competition is only compared here as a weekly average temperature. After appropriately converting the constant laboratory test results to 7DADMax temperature metrics the studies on growth and competition overlap each other. Growth should be maximized at a 7DADmax of 13.5-15.5°C and competition with brook trout should not be materially worsened at temperatures below 13.5°C.

Conclusion on Rearing

The multiple lines of evidence created from the wide variety of field and laboratory studies can be brought together in support of selecting a summer rearing temperature standard. The interim conclusions from each line of evidence is summarized below:

Table (IV-2): Juvenile Rearing of Native Char:

Line of Evidence	7DADM - Range (°C)	Median (°C)
Field studies on limit to where most commonly found	***13.45-14.45***	***13.95***
Filed studies on density, and dominance	***11.45-13.45***	***12.45***
Laboratory Growth Studies	***12.93-15***	***13.96***
Laboratory Competition Studies	***12.62-12.93***	***12.75***
Best Estimate of Criteria (averages)	***12.61-13.96***	***mid. pt. 13.29***

The range of these independent lines of evidence is 11.45-15°C with a mean range of 12.61-13.96°C and an overall midpoint of 13.29°C. This strongly suggests that streams having 7-day average daily maximum summer temperatures not exceeding 13.29°C are fully protective of juvenile/small bull trout rearing. After cross checking this conclusion against each independent line of evidence, no overriding factors of disagreement appear to exist. The slight conflict with the field studies on density and dominance, and the laboratory competition studies do, however, suggest that rounding the estimate down to the nearest 0.5°C increment, rather than up, may be more appropriate. It is therefore concluded that 13°C as a 7-day average of the daily maximum temperatures will fully support the life-stage of juvenile/small char rearing.

d) Migratory Adult and Sub-Adult Char Populations

As noted previously, fluvial and adfluvial forms of char may remain in the area of their natal stream for 1 to 3 years and then migrate significant distances to more productive waters for greater juvenile growth opportunities (Pratt, 1992; Ratliff, 1992; Riehle et al., 1997; Fraley and Shepard, 1989; Goetz, 1989). The larger size of these migrants is generally believed to allow them to better compete for resources, and to make use of a larger prey base that includes the juvenile fish of other species. This is similar to the way the ocean is used by Pacific salmon to enable them to grow to significantly greater sizes than would be possible if they were to remain in freshwater tributaries. This may be a very important survival trait of these migratory populations, and serve to free up food resources in the tributary system for juvenile char. These adult and non-spawning sub-adult fish, may also move out of tributary systems to hold in lower mainstem areas during the winter to avoid unsuitable winter conditions of ice and storm flows. In Washington, bull trout may migrate all the way from headwater streams to the Puget Sound to feed and rear. Relatively little is known about the temperature preferences and requirements of these migratory fish which makes setting temperature criteria for them problematic.

Heimer (1965) examined the use by Dolly Varden of an off channel artificial spawning on the lower Clark Fork River in Idaho below the Cabinet Gorge Dam. The channel was constructed in an area where cool spring water would make the artificial channel cooler than the mainstem river during part of the year. Temperatures in the majority of the spawning channel were between 8-11°C. The author noted that fish observed in the spawning area were consistently in the areas of cooler water. As river temperatures declined in the fall a portion of the fish in the spawning area left without spawning. These fish were presumably present because of the cooler waters, as the mainstem temperatures in the Clark Fork River did not decline to below 13.9°C until after September 26th. The Washington Water Power Company (1995) also studied the distribution of fish in the lower Clark Fork River in Idaho and found that while mainstem river temperatures were 18°C on September 28th temperatures in the adjacent channel used by bull trout for spawning was 11°C. These two studies when considered together suggest that bull trout will actively avoid rivers having fall water temperatures above 18°C. The strong contrasting temperatures between the river and the channel, the combination of spawning and non-spawning fish, competition with other salmonids also using the channel for refuge, and the lack of specific temperature metrics in association with char movements all combine to prevent using these studies to estimate a threshold response.

Swanberg (1997) found that bull trout residing in the lower Blackfoot River in Montana migrated out when daily maximum temperatures reached 18-20°C, and non-spawning sub-adult fish began returning once maximum temperatures declined to 12°C. The few fish that did not migrate were found in association with the confluence of a small cold tributary with a daily maximum temperature of 12°C. Elle and Thurow (1994) found that adfluvial bull trout in the Rapid River in Idaho began leaving the lower system in peak numbers seven out of nine years as the daily maximum temperatures began to exceed 10°C and returned as the temperature of the lower river declined to 10°C. These fish moved to lower mainstem rivers to hold for the winter. Movements to avoid unhealthy winter conditions are common in salmonids, and Jakober et al. (1998) found that bull trout and westslope cutthroat trout in two drainages in Montana made extensive downstream movements as temperatures dropped precipitously in the Fall. These movements were most extensive in mid-elevation streams where frequent freezing and thawing led to anchor ice formation and super cooling (<0°C) of the water.

Several very import issues and questions need to be addressed prior to setting criteria to protect these adult and sub-adult fish. These include:

- Is it ecologically appropriate to base temperatures in salmon and steelhead strongholds on the temperature requirements of char?
- How, and should, populations that are in mainstems to rear be separated from those that may be leaving inhospitable winter conditions in the tributaries?

- Is rearing protected only by maintaining favorable temperatures in these lower rivers year-round, or can migration out of the lower reaches during maximum summer temperatures be considered a normal and thus acceptable natural pattern?
- Should temperatures considered protective of these adult and sub-adult fish be based on assumptions of relative food abundance and lack of competition?

Until these questions are reasonably answered, there does not seem to be sufficient foundation in the research to justify setting temperature criteria in lower mainstem rivers below those appropriate for the protection of salmon and steelhead.

e) Lethality to Adults and Juveniles:

As shown above in the discussion of juvenile rearing, waters that fully protect the health of native char will have temperatures well below those posing a threat of acute lethality. Thus, the conclusions that follow are intended for application in the evaluation of special projects. They can also be used as an aid in assessing the relative safety for char moving through mainstem rivers predominantly protected for salmon and steelhead.

The only research found directly testing one of Washington's native char species (bull trout) was the works of McMahon et al. (1998, 1999) as published in Selong et al. (2001). McMahon et al. (1998, 1999) conducted 60-day lethality studies of juvenile bull trout. In their 1998 study, 98% survival occurred at temperatures between 7.5-18°C. Mortality was 21% at 20°C over the 60-day test period, but was 100% within 24 hours at 26°C, within10 days at 24°C, and within 38 days at 22°C. In the 1999 study, survival was 46% at 21°C and 53% at 20°C, with the time to 50% mortality varying from 10-days at 23°C to 24 days at 22°C. Using the data from both the 1998 and 1999 studies, the authors determined a 60-day UUILT (Ultimate Upper Incipient Lethal Temperature) of 20.8°C for juvenile bull trout and estimated that a 7-day UILT (Upper Incipient Lethal Temperature) would be 23.5°C (Selong et al., 2001).

The work of McMahon et al. (1998, 1999) and Selong et al. (2001) strongly suggest that lethality will be prevented at constant temperature exposures of 18-19°C or less. This assertion comes from two sources of information. The first is that in tests at a constant 18°C there was at least 98% survival over a 60-day exposure. The second is derived by using the 60-day UUILT of 20.9°C. After applying the adjustment factor recommended by the USEPA (Brungs and Jones, 1977) to change from a temperature that kills 50% of the exposed fish to a temperature that is unlikely to kill any fish. The non-lethal temperature estimate would change to a constant 18.9°C (20.9°C minus 2°C). Constant temperatures of 18-19°C would be correlated to 7DADMax temperatures of 21.18-22.18°C and 1-day maximums (1DMax) of 22.13-23.13°C when treated as if they were based on weekly temperature exposure. When treated as if they were based on a season-long exposure (which may be justified in this case since the laboratory tests were 60 days long) these values change to 22.64-23.64°C (7DADMax) and 23.60-24.60°C (1DMax). This line of evidence suggests that acute mortality will be prevented in acclimated fish by maintaining 7DADMax temperatures below 21.18-23.64°C or 1-day maximum temperatures below 22.13-24.6°C.

While a constant temperature exposure would generally be similar to an average temperature in a natural stream, daily maximum temperatures above the lowest determine lethal concentration (20.9°C with a 60-day exposure) will begin to accumulate lethal stress. To avoid exposure to temperatures that create lethal stress altogether (would eventually cause lethality if exposure period is sufficient) daily maximum temperatures should not exceed 20.9°C (7DADMax 19.95°C). Since this is not an estimate of a threshold beyond which acute mortality would be expected, it should only be viewed as a line of evidence for establishing a lower-bound estimate of temperatures that would avoid lethality and severe stress.

Using the data of Selong et al. (2001) we can also estimate the general risk of mortality from multiple days of exposure in the potentially lethal range. By assuming that temperature exposure in the lethal range is additive (DeHart, 1974, 1975; Golden, 1978), and by examining the potential lethal dose that occurs with each hour spent over the lowest lethal level (20.9°C), the risk of mortality can be reasonably described. The equation in Selong et al. (2001) giving the relationship between exposure temperature and time to mortality (LC50) can be used to estimate the number of hours that would need to be spent at each daily temperature increment (one-hour intervals used herein) above the an ultimately lethal temperature (20.9°C) to cause mortality (LC50). Using this approach, the number of daily cycles of temperature that would occur before causing mortality can be predicted. Based on this technique, bull trout in a stream with a daily average temperature of 20.9°C (21°C) and a diel range above the daily mean of 4.13°C would be expected to experience high mortality (LC50) in approximately 10 days or less. In streams with mean temperatures 19 and 18°C, high mortality (LC50) would occur after 54 and 163 days of repeat exposure, respectively. This approach to evaluating the risk of mortality is only useful in assessing relative risk. Nevertheless, it provides a good support for the position that weekly average temperatures of 18-19°C and summer peak daily maximum temperatures of 22-23°C (7DADMax 21.05-22.05°C) pose little risk of creating acutely lethal conditions in char populations.

While having relatively sensitive optimal temperature limits, adult and juvenile char do not appear unusually sensitive to acute temperature limits. With acclimation, juvenile and adult char are very tolerant of temperature extremes in a laboratory environment – capable of withstanding temperatures of –1.2°C (below zero) for up to 5 continuous days and having upper lethal temperature limits similar to, but towards the lower end, of that for juvenile Pacific salmon (Selong et al. 2001).

Table (IV-3): Temperature induced lethality of in native char.

Line of Evidence	7DADMax (°C)	Midpoint (°C)
Direct laboratory observation of no mortality, and conversion of LC50 to no effects temperature using Brungs and Jones (1977).	21.18-23.64	22.41
Laboratory estimate of temperature exerting lethal stress	19.95	19.95
Modeling risk associated multiple day exposures to fluctuating temperatures	21.05-22.05	21.55
Best Estimate of Criteria	*20.73-21.88*	*mid. pt. 21.31*

The range of the independent lines of evidence discussed above is 19.95-23.64°C with a mean range of 20.73-21.88°C and an overall midpoint of 21.31°C. This strongly suggests that not allowing single daily maximum temperatures to exceed 21.31°C (7DADMax of 21.35°C) will prevent acute lethality in char populations. Based on the above it is concluded that an annual highest single-day maximum temperature not exceeding 21°C will prevent direct lethality to Washington's juvenile native char.

It is important to point out, however, that only juveniles of one stock of bull trout were tested. Juvenile Dolly Varden, other stocks of juvenile bull trout (Beacham and Withler, 1991), and adults of either species could be somewhat more (or less) sensitive (Coutant, 1970; Becker, 1973; Bouck and Chapman, 1975). It would be unwise to assume that temperatures at the upper end of the range identified above are of equal merit for consideration as an acute criteria until more stocks have been tested. The data cited below by Ugedal et al. (1994) lend further support for being cautious about assuming the upper end of the predicted range would be fully protective.

Support for these findings can be found in research on related species of char (Arctic char and Arctic grayling). The estimated LT50 (lethal to 50% of test population within 7 days) values for a variety of char species at acclimations of 5-20°C generally group between 21.5-24°C. Lohr et al (1996) determine a 7-day LC50 of 23-25°C for juvenile Arctic Grayling; Lyytikainen et al. (1997) determined a 14-day LC50 of 23-24°C for juvenile Arctic Char; and Baroudy and Elliott (1994) determine a 7-day LC50 of 21.5-21.6°C for Arctic char fry and parr. These ranges were determine primarily by varying the acclimation temperatures. In a modified CTM test, the authors also found that fry and parr experienced 10-minute LT50 values of 24.79-26.57°C at acclimation temperatures from 10 to 20°C. Ugedal et al. (1994), in conducting a 104-day growth test using Arctic char, found that when water temperature rose from an initial 12-13°C (daily mean) to a brief 20°C (average temperature for approximately 10 days) before falling again a slight increase in mortality (approx 5%) occurred during the period that water temperatures reached 20°C.

Some additional information from studies with these related species are worth noting here. At full acclimation to temperatures of 15-18°C, sudden exposure to 29°C water produce LC50 values within 2-4 minutes in Arctic char (Lyytikainen et al., 1997). At an acclimation of 15°C a test temperature of 26°C produced LC50 results in just 44 minutes**.** Baroudy and Elliott (1994) found that the Arctic char alevins had 7-day UILTs of 18.67, 19.67, 20.83, and 20.79°C at acclimation temperatures of 5, 10, 15, and 20°C. Alevins experience 50% mortality within ten minutes at 23.33, 25.09°C, and 25.39°C at acclimation temperatures of 5, 10, and 15°C.

Research useful for estimating daily maximum temperatures that will protect developing embryos and alevins was only found for Arctic char (Baroudy and Elliott,1994). Since the work of Baroudy and Elliott was based on a non-indigenous species of char, and tested only the short-term effects to the alevin life-stage it is insufficient for setting an acute lethality criteria for char incubation. It can be used, however, to demonstrate that incubation of char is more sensitive then juvenile rearing, and to suggest that daily maximum temperatures would likely need to remain below 16.7°C to prevent acute lethality to char alevins. This estimate was made by subtracting 2°C from the LC50 value determined at an acclimation temperature appropriate for incubation (5°C) to convert to a temperature that should not produce any short-term mortality (USEPA, 1977).

IX. Summary of Temperature Requirements for Indigenous Aquatic Life

1. Cold Water Species

The following table summarize the individual conclusions made previously to protect the state's cold water aquatic habitats. For the two salmonid guilds examined, the life-stages are presented along with other thermal stressors that would influence the health of these life-stages (e.g., disease, other associated community and prey species). This approach is useful in identifying what temperature criteria would be most appropriate to provide for a fully protective thermal environment. The conclusions are provided as summary statements in Table X-1 below.

Table X-1: Ranges within which lie temperatures likely to fully protect specific species and life-stages.

Requirements by Species Guild and Life Stage	7DADMax Temperature Range (°C)	Midpoint of Range (°C)
Bull Trout and Dolly Varden (Char)		
Char spawning and incubation	7.31-8.32	7.82

Char juvenile rearing	12.61-13.96	13.29
Disease - Virtual elimination of warmwater disease effects in salmon and trout	12.58-16.18	14.38
Macroinvertebrate lethality in headwater streams	13.08-17.18	15.13
Char lethality (7-day exposure)	20.73-212.88	21.31
Summary: *Temperatures (7DADMax) should be below 7.5-8°C at the time of spawning for char and below 13-13.5°C outside of the incubation period. This temperature regime will also provide full protection from warm water disease and support sensitive headwater species of macroinvertebrates.*		

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