**Bull Trout (*Salvelinus confluentus*) Thermal Tolerance Analyses – Juvenile and Adult, Summer**
May 2017

## Introduction

Recommended summer thermal tolerance values for juvenile and adult bull trout and their justification are discussed below. The recommended tolerance values were developed in accordance with the "*Methodology for Developing Summer Thermal Tolerance Thresholds for Various Juvenile and Adult Fish in Nevada*" (NDEP, March 2017) with some modifications.

As described in the Methodology, NDEP desires to develop both chronic and acute temperature criteria using MWAT (Maximum Weekly Average Temperature) and MDMT (Maximum Daily Maximum Temperature), respectively, for the various fish species being evaluated. This approach is consistent with EPA recommendations presented in Brungs and Jones (1977). However in the case of bull trout, EPA Region 10 (2003) recommends only acute criteria (MWMT – Maximum Weekly Average Temperature) that are intended to also be protective against chronic effects. Therefore, NDEP's review focuses on potential acute summer criteria (MWMT) for juvenile and adult bull trout.

Another modification from the Methodology involves separate thermal tolerance recommendations for juveniles and adults. While Brungs and Jones (1977) includes recommendations for the protection of two life stage groups: 1) spawning/incubation, and 2) juveniles/adults, the Region 10 Guidance for bull trout provides recommendations for three life stage groups: 1) spawning/incubation; 2) juvenile rearing; and 3) adult/sub-adult foraging and migrating. This difference between the Brungs and Jones guidance and the Region 10 Guidance is driven in part by the unique life history of bull trout. As with other trout, bull trout can exhibit both resident and migratory life history strategies within a given stream. Resident forms can spend their entire life in the headwaters in which they spawn and rear, while migratory forms move between larger downstream rivers, lakes, etc. for foraging and headwater tributaries for spawning. Juvenile bull trout of the migratory form will rear near their natal (place of birth) streams for 1 to 4 years prior to their migration-spawning cycle (NRCS, 2006). In response, the Region 10 Guidance provides separate recommendations for rearing juveniles and adults. Therefore, NDEP's review focuses on separate acute summer recommendations for juveniles (rearing) and adults (foraging and migration).

## Juvenile Rearing - Thermal Tolerance Threshold

Table 1 provides a summary of the important acute and chronic temperature considerations compiled from the literature by EPA Region 10 and utilized in the development of the EPA Region 10 criterion recommendations for juvenile bull trout rearing. Based upon these values, EPA Region 10 recommends an acute threshold of 12°C maximum 7DADM (7-day average of the daily maxima, also known as MWMT) for the protection of juvenile bull trout. When evaluating what MWMT values would protect against chronic effects, EPA considered constant temperature thresholds identified in the literature and added about 0.5°C (thought to be the typical difference between MWMT and average conditions in bull trout waters). NDEP considers 0.5°C to be too low. An evaluation of data for 35 stream sites within the Jarbidge drainage indicate that MWMT (acute ) values are about 2°C higher than the MDAT (chronic) values for the colder sites (Figure 1).

**Table 1. Summary of Temperature Considerations for Bull Trout Juvenile Rearing – EPA Region 10 (2003)**

| Temperature Consideration | Temperature (°C) |
|---|---|
| ***Acute Effects*** | |
| Lethal Temperature (7-day exposure) | 22 – 23 (constant) |
| Highest Probability to Occur in Field | 12 – 13 (daily maximum) |
| ***Chronic Effects*** | |
| Optimal Growth | |
| Unlimited Food | 12 – 16 (constant) |
| Limited Food | 8 – 12 (constant) |
| Competition Disadvantage | >12 (constant) |

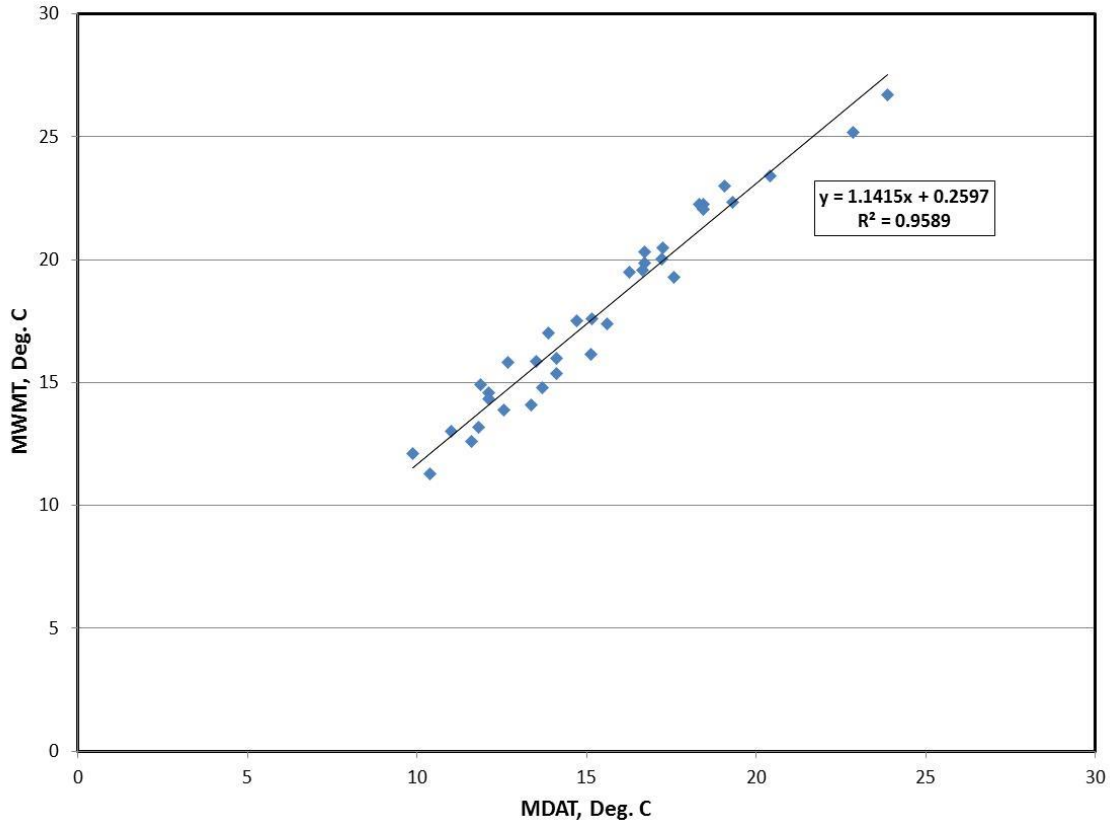


**Figure 1. MDAT v. MWMT for Streams in Jarbidge River Watershed**

Table 2 provides a summary of the range of acute (maximum) and chronic (average) thermal tolerance values found in the literature for juvenile bull trout for various lines of evidence. These values are based upon a review of 16 papers and publications, the details of which are summarized in Attachment A.

NDEP's approach is to accept the EPA recommendations unless the literature review provides a compelling reason to utilize other values. EPA Region 10's threshold of 12°C (MWMT) falls within the lower end of the range of potential criteria found in the literature, and is recommended as the thermal tolerance level for the rearing of juvenile bull trout. While some of the literature suggests that a slightly higher MWMT value would be protective of juvenile rearing, it is unlikely that a higher value would be acceptable to EPA and the U.S. Fish and Wildlife given that the bull trout are listed as threatened under the Endangered Species Act.

**Table 2. Summary of Thermal Tolerances – Juvenile Rearing**

| Category | Temperature Tolerances (°C) | Potential Acute Criteria (°C), MWMT |
|---|---|---|
| Laboratory Optimal Growth Studies – Constant Temperature | | |
| Optimum (sufficient food) | 12.0 – 13.2 | 14.0 – 15.2[1] |
| Optimum (limited food) | 8.0 – 12.0 | 10.0 – 14.0[1] |
| Upper Optimum (80% of optimum growth) | 17.0 | 19.0[1] |
| Lessened competitive disadvantage with brook trout | <12.0 | <14.0[1] |
| Laboratory Lethal Studies | | |
| UUILT | 20.9 – 23.5 | 18.9 – 21.5[2] |
| CTM | | |
| Acclim. = 8 - 12°C | 26.4 – 27.1 | 20.5 – 21.2[3] |
| Acclim. = 12 - 16°C | 27.1 – 28.3 | |
| Acclim. = 16 - 20°C | 28.3 – 28.9 | |
| Field Studies – Highest probability to occur in field | | |
| Summer Average | 6.0 - 10.6 | 10.2 – 16.0[4] |
| Maximum Temperature | 6.0 – 14.0 | 6.0 – 14.0 |
| Thresholds from EPA (MWMT) | 10.0; 12.0 | |
| Threshold from Idaho (Essig et al. 2003) (MWMT) | 13.0 | |
| **Recommended Chronic Temperature Tolerance (MWMT)** | **12.0** | |

[1]Chronic value increased by 2°C to account for relationship between MDAT and MWMT values (Figure 1). Note: EPA Region 10 used a much lower adjustment factor or 0.5°C.
[2]UUILT values reduced by 2°C to provide 100% survival (See *Methodology*)
[3]CTM values reduced by 3.9°C to estimate quasi-UILT values. Quasi-UILT value then reduced by 2°C to provide 100% survival (See *Methodology*)
[4]Estimated MWMT value using Standardization conversion discussed in *Methodology* document (MWMT = 1.26 x Jun-Aug Average + 2.6)

**Adult Foraging and Migration - Thermal Tolerance Thresholds**

Unfortunately, there is limited information specifically for adult bull trout thermal tolerances. The only studies (identified by NDEP) which deal with adult bull trout are field studies, and the bulk of these examined the occurrence of juveniles/adult combined, not separately. Given that rearing juveniles are considered to have lower thermal tolerances than migrating adults, these studies would tend to yield thermal tolerances biased toward the more sensitive juveniles, and are not deemed appropriate for deriving migrating adult thermal tolerances. Only 1field study was identified by NDEP which provided thermal tolerances specific to adult bull trout only.

EPA Region 10 also found little information on adult bull trout thermal tolerances and concluded that the current knowledge of bull trout migration timing and their main channel temperature preferences is limited, making it challenging to establish criteria for the protection of foraging and migrating adults. However, it is known that adult bull trout *"…prefer water temperatures less than 15°C, that they take advantage of cold water refugia during the period of summer maximum temperatures, and that spawning adults move toward spawning grounds during the period of summer maximum temperatures*." Given the lack of adult temperature preference information, EPA opted to recommend a MWMT value of 16°C that was established for the protection of moderate to high density summertime salmon and trout (not including bull trout) juvenile rearing. The EPA Region 10 Guidance concludes that this recommendation may be reconsidered as more is learned about adult foraging and migration.

As stated earlier, NDEP's approach is to accept the EPA recommendations unless the literature review provides a compelling reason to utilize other values. Given the limited information available and the threatened listing status of the bull trout, NDEP recommends a MWMT criterion of 16°C for summer maximum conditions for the protection of adult and sub-adult foraging and migration.

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**ATTACHMENT A**
**Detailed Summary of Chronic and Acute Thermal Tolerance Values for Bull Trout, Juvenile Rearing, Summer**

**Table A-1. Chronic Temperature Tolerances – Laboratory Optimal Growth Studies – Juveniles**

| Reference | Age or Size | Acclim. Temp. (°C) | Optimum Growth Temperature | | Upper Optimum Growth Temperature | |
|---|---|---|---|---|---|---|
| | | | Temp. (°C) | Comment | Temp. (°C) | Comment |
| McMahon et al. (1999) | Juvenile | Unknown | 12 - 16 | Fed to satiation and 66% satiation | | |
| | | | 8 - 12 | Fed to 33% satiation | | |
| McMahon et al. (2007) | 8 months posthatch | 8 | 12.3 | | 17.0 | Temperature at 80% of optimum growth |
| | | | 12[1] | | | |
| Selong et al. (2001) | 7 months posthatch | 8 | 13.2 | | 17.0 | Temperature at 80% of optimum growth |

[1]Growth study showed the presence of brook trout had a marked depressive effect on the growth of bull trout. Bull trout grew 33% less with brook trout present than without brook trout. Brook trout grew 42% more with bull trout present than without bull trout. Growth differences became more prominent at warmer temperatures, increasing from about twofold greater growth in brook trout at 12°C to more than threefold greater growth at temperatures above 16°C.

**Table A-2. Chronic Temperature Tolerances – Field Studies - Juveniles**

| Reference | Temperature (°C) | Comment |
|---|---|---|
| Garnett (2002) | 10 (mean summer temperature) | Juvenile and adult bull trout were present in all streams <10°C. |
| | <12 (mean summer temperature) | Juvenile and adult bull trout present in 40% of sites with temperature <12°C. No bull trout were present in sites with temperature >12°C. |
| Isaak (2009) | <13 (mean summer temperature) | Surveys of 12 Idaho streams found bull trout occasionally occurred in mean summer temperatures nearing 13°C |
| | <11 (mean summer temperature) | Surveys of 12 Idaho streams found high bull trout abundance rare at mean summer temperatures > 11°C |
| Johnson and Weller (1994) | 10.6 (mean summer temperature) | In the Jarbidge drainage, sites with a density of at least 2 bull trout per 100 feet had a mean summer water temperature of 10.6°C or less and a measured discharge > 1.0 cfs. |
| Reiman and Chandler (1999) | 6 – 9 (mean summer temperature) | Juvenile and adult bull trout more likely to occur at mean summer temperatures of 6 - 9°C. |
| Zurstadt (2000) | 7 – 8.5 (mean summer temperature) | The highest densities of juvenile bull trout in this study were in reaches with mean summer stream temperatures between 7 and 8.5°C. |

**Table A-3. Acute Temperature Tolerances – Laboratory Lethal Temperatures, UILT/UUILT - Juveniles**

| Reference | Size or Age | Acclim. Temp. (°C) | Test Duration | UILT | | UUILT | |
|---|---|---|---|---|---|---|---|
| | | | | Temp. (°C) | Comment | Temp. (°C) | Comment |
| Selong et al. (2001) | 7 months posthatch | NA | 60-day duration | | | 20.9 | Developed using the Acclimated Chronic Exposure (ACE) method |
| | | | 7-day duration | | | 23.5 | |

**Table A-4. Acute Temperature Tolerances – Laboratory Lethal Temperatures, Critical Thermal Maximum - Juveniles**

| Reference | Size or Age | Acclim. Temp. (°C) | Rate | Temperature (°C) | Endpoint |
|---|---|---|---|---|---|
| Selong et al. (2001) | 7 months posthatch | 8 | 0.17°C/min (10.2°C/hour) | 26.4 | Loss of equilibrium |
| | | 12 | | 27.1 | |
| | | 16 | | 28.3 | |
| | | 20 | | 28.9 | |

**Table A-5. Acute Temperature Tolerances – Field Studies - Juveniles**

| Reference | Temperature (°C) | Comment |
|---|---|---|
| Adams and Bjornn (1997) | 18.2 (maximum daily temperature) | Maximum daily temperature recorded where juvenile and adult bull trout were found between August 1 and September 29, 1993 ranged from 3.6 to 18.2°C. |
| Dunham and Chandler (2001) | <20 (maximum summer temperature) | Based upon an analysis of fish survey data, the probability of occurrence of juvenile or small resident adult bull trout is predicted to be very low as temperatures exceed 20°C. |
| | 6 – 12 (maximum summer temperature) | Based upon an analysis of fish survey data, the probability of occurrence of juvenile bull trout is predicted to be high (75%) with MDMT between 6 and 12°C. |
| Dunham et al. (2003) | <14 – 16 (maximum summer temperature) | The probability of the occurrence of juvenile bull trout exceeded 50% when the maximum daily temperature was less than 14 - 16°C. |
| Fraley and Shepard (1989) | <15 (maximum summer temperature) | Juvenile bull trout were rarely observed in streams with summer maximum temperatures exceeding 15°C. |
| Garnett (2002) | 8.8 – 14.9 (maximum temperatures) | Juvenile and adult bull trout densities greater than 10 fish/100m$^2$ occurred at maximum temperatures between 8.8 and 14.9°C but bull trout densities were relatively low at temperatures greater than about 15°C. |
| Goetz (1989) | <18 (maximum temperatures) | Maximum temperatures in which juveniles occur may vary but are usually below 18°C C. |
| Goetz (1994) | 13 (maximum temperatures) | The highest temperatures at which juvenile bull trout were found was 13°C. |
| Isaak (2009) | <17.5 (MWMT) | Surveys of 12 Idaho streams found bull trout occasionally occurred in MWMT temperatures nearing 17.5°C |
| | <15 (MWMT) | Surveys of 12 Idaho streams found high bull trout abundance rare at MWMT temperatures > 15°C |
| Reiman and Chandler (1999) | <13 – 14 (maximum summer temperature) | Juvenile and adult bull trout more likely to occur at summer maximums < 13 - 14°C. |
| Saffel and Scarnecchia (1995) | 7.8 – 13.9 (maximum summer temperature) | Reaches with high densities (3.9 to 11.2 fish/100 m$^2$) of age 0 and age ≥ 1 juvenile bull trout had maximum summer temperature ranging from 7.8 to 13.9 C, whereas most reaches with low densities (< 1.0 fish/100 m$^2$) had higher maximum summer temperatures (18.3 to 23.3 C). |

**Table A-7. Acute Temperature Tolerances – EPA and Idaho - Juveniles**

| Reference | Temperature (°C) | Comments |
|---|---|---|
| ***Bull Trout Spawning and Rearing – Summer Maximum Temperatures*** | | |
| EPA (1997) | 10 (MWMT) | In 1997, EPA established (40 CFR 131.33) a MWMT criterion of 10°C for the months June-September for the protection of bull trout spawning and juvenile rearing in natal streams in Idaho. |
| ***Bull Trout Juvenile Rearing near Natal Streams – Summer Maximum Temperatures*** | | |
| EPA (2003) | 12 (MWMT) | The guidance recommends a MWMT criterion of 12°C for summer maximum conditions for the protection of moderate to high density summertime juvenile rearing near their natal streams in their first years prior to making downstream migratations. EPA recommends this criterion to:<br>(1) Safely protect juveniles from lethal temperatures;<br>(2) Provide upper optimal conditions under limited food during summer and optimal temperature for other times of the growth season;<br>(3) Provide temperatures where juveniles are not at a competitive disadvantage with other salmonids; and<br>(4) Provide temperatures that are consistent with field studies showing where juveniles have the highest probability to occur.<br><br>EPA recommends that the spatial extent of this use include:<br>(1) Waters with degraded habitat where high and low density juvenile rearing currently occurs or is suspected to occur during the period of maximum summer temperatures;<br>(2) Waters with minimally-degraded habitat where moderate to high density juvenile rearing currently occurs or is suspected to occur during the period of maximum summer temperatures;<br>(3) Waters where bull trout spawning currently occurs;<br>(4) Waters where juvenile rearing may occur and the currently MWMT is 12°C or lower; and<br>(5) Waters where other information indicates the potential for moderate to high density juvenile rearing during the period of maximum summer temperatures. |

**Table A-7. Acute Temperature Tolerances – EPA and Idaho - Juveniles (cont'd)**

| Reference | Temperature (°C) | Comments |
|---|---|---|
| ***Bull Trout Juvenile Rearing near Natal Streams – Summer Maximum Temperatures*** | | |
| Essig et al. (2003) | 13 (MWMT) | In response to US EPA's 1997 bull trout rule (40 C.F.R. § 131.33), Idaho reviewed the available information to develop their own criterion recommendation for juvenile rearing protection. Based upon their review of the laboratory studies, field studies, and presence-absence studies, they concluded that optimal temperatures for juvenile bull trout rearing occur between 11 and 14°C (MWMT), and that an MWMT of 13°C would be fully protective of juvenile rearing. |

**ATTACHMENT B**
**Detailed Summary of Acute Thermal Tolerance Values for Bull Trout, Adult Foraging and Migration, Summer**

**Table B-1. Acute Temperature Tolerances – Field Studies - Adults**

| Reference | Temperature (°C) | Comment |
|---|---|---|
| Goetz (1994) | <16.5 (maximum temperature) | The highest temperatures at which adult bull trout were found were 16.5°C. |

**Table B-2. Acute Temperature Tolerances – EPA - Adults**

| Reference | Temperature (°C) | Comments |
|---|---|---|
| ***Bull Trout Adult and Sub-Adult Foraging and Migration – Summer Maximum Temperatures*** | | |
| EPA (2003) | 16 (MWMT) | The guidance recommends a MWMT criterion of 16°C for summer maximum conditions for the protection of adult and sub-adult foraging and migration. "*Our current knowledge of bull trout migration timing and their main channel temperature preference is limited, but we do know that they prefer water temperatures less than 15°C, that they take advantage of cold water refugia during the period of summer maximum temperatures, and that spawning adults move toward spawning grounds during the period of summer maximum temperatures. EPA, therefore, believes its recommended approach would protect migrating and foraging bull trout because average river temperatures will likely be below 15°C, a fair amount of cold water refugia is expected in rivers that attain a maximum 7DADM* [MWMT] *of 16°C, and maximum temperatures below 16°C are likely to occur upstream of the downstream point of this use designation where most bull trout migration and foraging is likely to occur during the period of summer maximum temperatures"* |