DRAFT Redband Trout (*Oncorhynchus mykiss gairdneri*) Thermal Tolerance Analyses – Juvenile and Adult, Summer
May 2016

Introduction

Recommended summer chronic and acute thermal tolerance values for juvenile and adult redband trout and their justification are discussed below. The recommended tolerance values were developed in accordance with the "*DRAFT Methodology for Developing Thermal Tolerance Thresholds for Various Fish in Nevada – Juvenile and Adult, Summer*" (September 2015).

Chronic Thermal Tolerance Thresholds

Table 1 provides a summary of the range of chronic temperature tolerance values for redband trout for various lines of evidence. These values are based upon a review of five papers and publications, the details of which are summarized in Attachment A. A review of the laboratory and field studies suggests that an appropriate chronic criterion for redband trout should fall between 12 – 22°C. NDEP's approach is to accept the EPA recommendations from Brungs and Jones (1977) unless the literature review provides a compelling reason to utilize other values. However, in the case of redband trout, Brungs and Jones did not provide a recommended chronic value.

Redband trout are a loosely classified group of rainbow trout subspecies (Behnke, 1992), but there is uncertainty as to whether or not the wild redband trout in Nevada should be assigned different thermal tolerances from the other rainbow trout populations in the state. According to Behnke (1992), redband trout in the desert basins of western North American have been thought to have evolved adaptations for warmwater tolerance. Behnke (1992) reported that redband trout from eastern Oregon had optimum growth efficiencies at temperatures >19°C, while other rainbow trout stock growth rates were decreasing for temperatures above 16°C (Zoellick, 1999). This would suggest that it would be appropriate to recommend a higher chronic temperature tolerance value for redband trout than for other rainbow trout populations in Nevada. However until more information becomes available, it is recommended that the rainbow trout chronic value (19°C) be also used for redband trout.

Table 1. Summary of Chronic Temperature Tolerances

Category	Temperature (°C)
Laboratory Optimal Growth Studies – Fluctuating Temperature	
Optimum	12 - 22
Other Laboratory Growth Studies	>19
Laboratory Temperature Preference Studies	12.7 – 14.7
Temperature Preference Field Studies	16
Thresholds recommended for Oregon (MWAT)	18.5
Recommended Chronic Temperature Tolerance (MWAT)	**19**

Acute Thermal Tolerance Thresholds

Table 2 provides a summary of the range of acute temperature tolerance values for redband trout for various lines of evidence. These values are based upon a review of eight papers and publications, the details of which are summarized in Attachment B.

For ease of presentation, the UILT and CTM values have been summarized by acclimation temperature ranges. However, as discussed in the methodology document, only UILT and CTM values for acclimation temperatures near the recommended chronic criterion (19°C) are to be included in the acute criterion development process. UILT and CTM values for acclimation temperatures of 20°C and 16.5°C, respectively, are utilized for criterion development.

Table 2. Summary of Acute Temperature Tolerances

Category	Temperature Tolerances (°C)	Potential Acute Criteria (°C)
Laboratory Lethal Studies - UILT		
Acclim. = 15°C	26.2	
Acclim. = 20°C	26.2	24.2[1]
Acclim. = 23°C	26.2	
Laboratory Lethal Studies – CTM		
Acclim. = 14°C	29.0	
Acclim. = 16.5°C	29.6	23.7[2]
Acclim. = 22°C	29.7	
Field Studies	25.5 – 29.0	
Other Studies	24 – 27.5	
Thresholds recommended for Oregon (MDMT)	22.9 - 24	
Criteria adopted by Oregon (MDMT)[3]	20.8	
Recommended Acute Temperature Tolerance (MDMT)	**24**	

[1]UILT and UUILT values reduced by 2°C to provide 100% survival (see *Methodology*)
[2]CTM values reduced by 3.9°C to estimate quasi-UILT values. Quasi-UILT values then reduced by 2°C to provide 100% survival (see *Methodology*)
[3] Estimated MDMT value using Standardization conversion discussed in *Methodology* document (MDMT = 1.04 x MWMT)

A review of the laboratory and field studies suggests that an appropriate acute criterion for redband trout should fall between 20.8 – 29.0°C. NDEP's approach is to accept the EPA recommendations from Brungs and Jones (1977) unless the literature review provides a compelling reason to utilize another value. However, in the case of redband trout, Brungs and Jones did not provide a recommended acute value.

As discussed above, there is uncertainty as to whether or not the wild redband trout in Nevada should be assigned different thermal tolerances from the other rainbow trout populations in the state. According to Behnke (1992), redband trout in the desert basins of western North American have been thought to have evolved adaptations for warmwater tolerance. Rodnick et al. (2004) found that redband trout have more available energy than rainbow trout at 24°C, suggesting that a higher acute thermal tolerance value for

redband trout is appropriate. However, Rodnick et al. (2004) also found similar CTM values for redband compared to rainbow trout. Therefore until more information becomes available, it is recommended that the rainbow trout acute value (24°C) also be used for redband trout.

References

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ATTACHMENT A
Detailed Summary of Chronic Thermal Tolerance Values for Redband Trout, Juvenile and Adult, Summer

Table A-1. Chronic Temperature Tolerances – Laboratory Optimal Growth Studies, Fluctuating Temperatures

Reference	Age or Size	Acclim. Temp. (°C)	Test Temp. (°C)	Optimum Growth Temperature	
				Temp. (°C)	Comment
Cassinelli and Moffitt (2010)[1]	Age-0	**Montane** Daily cycle = 8 – 14 Average = 11 **Desert** Daily cycle = 18 – 24 Average = 21	**Montane** Daily cycle = 9 – 16 Average = 12 **Desert** Daily cycle = 18 – 26 Average = 22	12 – 22	Daily average

[1] No traditional optimal growth studies were identified. However, Cassinelli and Moffitt (2010) did examine growth rates for 2 different temperature regimes. In 2006 and 2007, fish from desert and montane streams were exposed to 35 days of fluctuating temperatures with diel cycles ranging from 9 to 16°C (average = 12°C) for montane conditions and 18 to 26°C (average = 22°C) for desert conditions. For acclimation, the peak temperature was kept at 1 to 2°C below the daily maximum. During the 2006 tests, authors found changes in weight and length were greater in the montane treatments than in the desert treatments. However in the 2007 tests, they did not detect growth differences attributed to the temperature treatment. These results suggest that the desert temperature regime used in the test is near the upper limit of optimum growth conditions.

Table A-2. Chronic Temperature Tolerances – Other Laboratory Growth Studies

Reference	Age or size	Temperature (°C)	Comments
Behnke (1992)	Juvenile	>19	Based upon unpublished data from Pat Dwyer (U.S. Fish and Wildlife Service), Behnke (1992) concluded that redband trout from a desert basin in eastern Oregon experienced greater growth at 19°C than at 13 and 16°C. No information available for temperatures higher than 19°C.

Table A-3. Chronic Temperature Tolerances – Laboratory Preference Studies

Reference	Age or Size	Acclim. Temp. (°C)	Average Preference Temperature		Upper Preference Temperature	
			Temp. (°C)	Comment	Temp. (°C)	Comment
Gamperl et al. (2002)	10 – 20 cm	15 ± 1	12.7 ± 0.6 (stand. error of mean)	Little Blitzen Creek fish	14.7	Based upon 1 stand. dev. above avg.
			12.9 ± 0.5 (stand. error of mean)	Bridge Creek fish		

Table A-4. Chronic Temperature Tolerances – Preference Field Studies

Reference	Temperature (°C)	Comment
Meyer et al. (2010)	<16 (present at all sites)	Average June-August temperature
	20 (present at 50% of the sites)	
	22 (present at 33% of the sites)	
	18.4 (present at all sites)	Estimated MWAT values using Standardization conversion discussed in *Methodology* document (MWAT = 1.05 x Jun-Aug Average + 1.6)
	22.6 (present at 50% of the sites)	
	24.7 (present at 33% of the sites)	

Table A-5. Chronic Temperature Tolerances – Oregon

Reference	Temperature (°C)	Comments
Gamperl and Rodnick (2003)	18.5 (MWAT)	Based upon their research and literature review, Gamperl and Rodnick stated that temperature criterion that incorporated both a maximum daily temperature (MDMT) of 24°C and a maximum weekly average temperature (MWAT) of 18.5°C would be best for the preservation and restoration of redband trout populations in southeastern Oregon. However, Gamperl and Rodnick believed that the application of two temperature metrics (MDMT and MWAT) would create problems for the State of Oregon regarding the implementation of both measures. Therefore, they recommended using a different metric (MWMT – maximum weekly maximum temperature) with a criterion of 22°C. The MWMT metric is considered to be an acute criterion and therefore these values are not shown in this table.

ATTACHMENT B
Detailed Summary of Acute Thermal Tolerance Values for Redband Trout, Juvenile and Adult, Summer

Table B-1. Acute Temperature Tolerances – Laboratory Lethal Temperatures, UILT

Reference	Size or Age	Acclim. Temp. (°C)	Test Duration	UILT	
				Temp. (°C)	Comment
Sonski (1984)	~10 – 12 month	15	8 – 24 days	26.2	Sonski performed nonstandard lethal temperature experiments that were a hybrid of the typical UILT and CTM tests. Following acclimation, temperatures were slowly increased at 0.5°C/day (a rate much lower than traditional CTM tests - 18°C/hour) until all the fish died. LT_{50} (temperatures at which 50% mortality occurred) values were then derived from the test results.
		20		26.2	
		23		26.2	

Table B-2. Acute Temperature Tolerances – Laboratory Lethal Temperatures, Critical Thermal Maximum

Reference	Size or Age	Acclim. Temp. (°C)	Rate	Temperature (°C)	Endpoint
Rodnick et al. (2004)	1-2 year	~22 avg (19-25 evening min/max)[1]	2°C/hour	29.7	Loss of equilibrium
	1-2 year	~16.5 avg (14-19 evening min/max)[1]		29.6	Loss of equilibrium
	1-2 year; 3-5 year	~14 avg (13-15 evening min/max)[1]		29.0	Loss of equilibrium

[1] Rodnick et al. (2004) performed streamside measurements of CTM for redband trout from 3 streams in the high-desert region of the southeastern Oregon. The evening before each experiment, the test fish were transferred into a respirometer near the stream with water supplied directly from the stream overnight. Unfortunately, acclimation temperatures were not specifically reported by Rodnick et al. (2004). Based upon information in the paper, it is estimated that the evening temperatures averaged about 14 to 22°C. The following morning, stored stream water at 14°C was used for the remainder of the experiment.

Table B-3. Acute Temperature Tolerances – Field Studies

Reference	Temperature (°C)	Comments
Behnke (1992)	28.3	Behnke (1992) reports to have caught native redband trout in Chino Creek, Nevada by fly fishing water at 28.3°C. He reported that the redband trout were actively feeding at this temperature and fought vigorously when caught.
Zoellick (1999)	25.5 – 29.0	During 3 separate summers, Zoellick (1999) examined stream temperatures and the distribution of redband trout in 4 streams in southwestern Idaho. Zoellick found that redband trout in these streams tolerated maximum temperatures of 25.5 to 29.0°C.

Table B-4. Acute Temperature Tolerances – Other Studies

Reference	Size or Age (mm)	Acclimation Temperature (°C)	Temperature (°C)	Comments
Cassinelli and Moffitt (2010)	Age-0	18 – 24 (daily cycle)	26	Fish were exposed to 35 days of fluctuating temperatures with diel cycles ranging from 18 to 26°C for desert conditions. Nearly all fish survived the daily peak of 26°C during 35-d test.
		18 – 26 (daily cycle)	27.5	Fish were exposed to daily fluctuating temperatures ranging from 18 – 25.5°C (Day 1); 18 – 27.5°C (Day 2), 18 – 28.2°C (Day 3), 18 – 29.5°C (Day 4) and 18 – 30.3°C (Day 5). Mortality started occurring during Day 3 when temperatures were greater than 27.5°C. All fished died by Day 5 with a maximum temperature of 30.3°C.
Gamperl et al. (2002)	10-20 cm	N/A	24	Gamperl et al. (2002) performed tests streamside to characterize metabolism and swimming performance at 12°C and 24°C, and concluded that redband trout are able to tolerate short exposures to temperatures approaching 24°C.

Table B-5. Acute Temperature Tolerances – Oregon

Reference	Temperature (°C)	Comments
Gamperl and Rodnick (2003)	24 (MDMT)	Based upon their research and literature review, Gamperl and Rodnick stated that temperature criterion that incorporated both a maximum daily temperature (MDMT) of 24°C and a maximum weekly average temperature (MWAT) of 18.5°C would be best for the preservation and restoration of redband trout populations in southeastern Oregon. However, Gamperl and Rodnick believed that the application of two temperature metrics (MDMT and MWAT) would create problems for the State of Oregon regarding the implementation of both measures. Therefore, they recommended using a different metric (MWMT – maximum weekly maximum temperature) with a criterion of 22°C.
	22 (MWMT); 22.9 (MDMT)[1]	
State of Oregon (2016)	20 (MWMT); 20.8 (MDMT)[1]	Though Gamperl and Rodnick recommended using a MWMT criterion of 22°C, the State of Oregon ultimately adopted a MWMT criterion of 20°C for the protection of redband trout. It is unknown why Oregon decided to adopt a more stringent value.

[1] Estimated MDMT values using Standardization conversion discussed in *Methodology* document (MDMT = 1.04 x MWMT)