

# DRAFT Rainbow Trout (*Oncorhynchus mykiss*) Thermal Tolerance Analyses – Juvenile and Adult, Summer

December 2015

## Introduction

Recommended summer chronic and acute thermal tolerance values for juvenile and adult rainbow 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 rainbow trout for various lines of evidence. These values are based upon a review of twenty-one papers and publications, the details of which are summarized in Attachment A.

There is obviously a wide range of temperatures from which to select an appropriate value and best professional judgment is called for. 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. EPA’s chronic value of 19°C falls within the upper end of the range of potential criteria found in the literature, and is recommended as the chronic thermal tolerance level for adult/juvenile rainbow trout. As discussed in the methodology, chronic temperature criteria are generally not set to ensure the most optimum conditions. In fact, Brungs and Jones (1977) recommends that the chronic criterion for a given fish species be between the optimum temperature and the UUILT.

**Table 1. Summary of Chronic Temperature Tolerances**

<b>Category</b>	<b>Temperature (°C)</b>
Laboratory Optimal Growth Studies – Constant Temperature	
Optimum	13.1 – 19.0
Upper Optimum	18.2 – 22.0
Laboratory Optimal Growth Studies – Fluctuating Temperature	
Optimum mean temperature	15.5
Upper Optimum mean temperature	19.1
Laboratory Temperature Preference Studies	
Average Preferences	11.0 – 22.2
Upper Preferences	14.8 – 23.4
Laboratory Upper Temperature Avoidance Studies	13.0 – 27
Temperature Preference Field Studies	14.5 – 24
Thresholds from EPA and Colorado (MWAT)	18.2 – 19
<b>Recommended Chronic Temperature Tolerance (MWAT)</b>	<b>19.0</b>

## Acute Thermal Tolerance Thresholds

Table 2 provides a summary of the range of acute temperature tolerance values for rainbow trout for various lines of evidence. These values are based upon a review of twenty-five 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 the UILT and CTM values for acclimation temperature near the recommended chronic criterion (19°C) are to be included in the acute criterion development process. For rainbow trout, UILT and CTM values for acclimation temperatures 17 - 20°C are utilized for criterion development.

**Table 2. Summary of Acute Temperature Tolerances**

Category	Temperature Tolerances (°C)	Potential Acute Criteria (°C)
Laboratory Lethal Studies – UILT/UUILT		
UILT		
Acclim. = 4 - 8°C	22.6 – 25.0	
Acclim. = 9 - 12°C	24.0 – 25.9	
Acclim. = 13 - 16°C	24.7 – 26.0	
Acclim. = 17 - 20°C	24.3 – 26.7	22.3 – 24.7 <sup>1</sup>
Acclim. = >20°C	25.5 – 26.2	
UUILT	26.0 – 26.2	24.0 – 24.2 <sup>1</sup>
Laboratory Lethal Studies – CTM		
Acclim. = 4 - 8°C	26.9	
Acclim. = 9 - 12°C	27.0 – 30.7	
Acclim. = 13 - 16°C	28.4 – 30.0	
Acclim. = 17 - 20°C	26.6 – 31.2	20.7 – 25.3 <sup>2</sup>
Acclim. = >20°C	31.5 – 32.0	
Field Studies	16.6 – 25	
Thresholds from EPA and Colorado	23.8 – 24	
<b>Recommended Acute Temperature Tolerance (MDMT)</b>	<b>24.0</b>	

<sup>1</sup>UILT and UUILT values reduced by 2°C to provide 100% survival (See *Methodology*)

<sup>2</sup>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*)

A review of laboratory studies suggest that an appropriate acute criteria should fall between 22.3 and 25.3°C, while field studies suggest a wider range of 16.6 to 25.0°C. This is obviously a wide range from which to select an appropriate value and best professional judgment is called for. 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. EPA's acute value of 24°C falls within the upper end of the range of potential criteria found in the literature, and is recommended as the acute thermal tolerance level for adult/juvenile rainbow trout.

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**ATTACHMENT A**

**Detailed Summary of Chronic Thermal Tolerance Values for Rainbow Trout, Juvenile and Adult, Summer**

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

Reference	Age or Size	Acclim. Temp. (°C)	Optimum Growth Temperature		Upper Optimum Growth Temperature	
			Temp. (°C)	Comment	Temp. (°C)	Comment
<b><i>Constant Temperature Studies</i></b>						
Bear (2005)	Juvenile	14	13.1		18.2	Upper 95% confidence interval on opt. growth temperature
Hokanson et al. (1977)	Juvenile	16	17.2 – 18.6		22.0 <sup>1</sup>	Estimated temperature at growth rate = 80% of optimum
Myrick and Cech (2000)	Age-0	10 – 25	19		<22	Temperature at growth rate = 85 – 95% of optimum
Papoutsoglou and Papapaskeva-Papoutsoglou (1978)	Juvenile	8 – 20	17		20	Growth rate = 95% of optimum
<b><i>Fluctuating Temperature Studies</i></b>						
Hokanson et al. (1977)	Juvenile	16	Diel fluctuation = 11.7 – 19.3; mean = 15.5		Diel fluctuation = 17.2 – 24.8; mean = 21.0 <sup>1</sup>	Temperature at growth rate = 85% of optimum

<sup>1</sup>There was a marked increase in mortality for those fish subjected to 21.2 and 22.3°C

**Table A-2. Chronic Temperature Tolerances – Laboratory Preference Studies**

Reference	Age or Size	Acclim. Temp. (°C)	Average Preference Temperature		Upper Preference Temperature		Final Preferendum	
			Temp. (°C)	Comment	Temp. (°C)	Comment	Temp. (°C)	Comment
Cherry et al. (1975)	<1 year	6 – 24	11.6 – 22.0		11.7 – 22.5	Upper 95% confidence limits on averages		
Cherry et al. (1977)	<1 year	12 – 24	14.1 – 22.2		15.7 – 23.4	Upper 95% confidence limits on averages	19.2 – 19.8	
Garside and Tait (1958)	1 – 2 years	5 – 20	11.6 – 15.7		12.5 – 18.8	Based upon 1 stand. dev. above avg.		
Javaid and Anderson (1967a)	Fingerling	20	18.5	Fasted fish				
			21.5	Fed fish				
Javaid and Anderson (1967b)	Underyearling	10 – 20	15.8 – 22.0	Mean of modes of multiple readings				
Kwain and McCauley (1978)	1 – 6 mo.	10 – 20	16.9 – 17.6	Light intensity varying from total darkness to 2200 lux				
	7 – 12 mo.	10 – 20	13.1 – 16.0	Light intensity varying from total darkness to 2200 lux				



**Table A-2. Chronic Temperature Tolerances – Laboratory Preference Studies (cont'd)**

Reference	Age or Size	Acclim. Temp. (°C)	Average Preference Temperature		Upper Preference Temperature		Final Preferendum	
			Temp. (°C)	Comment	Temp. (°C)	Comment	Temp. (°C)	Comment
McCauley and Pond (1971)	Underyearling	15 - 20	18.4		19.6 – 21.1	Based upon 1 stand. dev. above avg.		
McCauley and Huggins (1975)	Juvenile	10	16.1 – 17.1					
McCauley et al. (1977)	15 months	5 - 25	9.8 – 12.7	Range of average temperatures occupied by fish	11.1 – 15.6	Based upon 1 stand. dev. above avg.		
Peterson et al. (1979)	Juvenile	12.1 – 12.7	14.3 - 14.7		15.5 – 16.0	Based upon 1 stand. dev. above avg.		
Schurmann et al. (1991)	Juvenile	18	16.1	Average of median preferences	17.2	Based upon 1 stand. dev. above avg.		
Stauffer et al. (1984)	Young-of-year	6 - 24	14.7		19	Estimated upper temperature preferred by 85% of test fish		

**Table A-3. Chronic Temperature Tolerances – Laboratory Upper Temperature Avoidance Studies**

Reference	Age or Size	Acclim. Temp. (°C)	Temperature (°C)	Comment
Cherry et al. (1975)	<1 year	6 - 24 <sup>1</sup>	13 – 25	
Cherry et al. (1977)	<1 year	12 - 24	18 – 26	
Schurmann et al. (1991)	Juvenile	18	16.3	Mean of median temperatures
			17.4	Average upper limit of occupied temperatures
Stauffer et al. (1984)	Young-of-the-year	6 - 24	18 – 27	

<sup>1</sup>Attempts to acclimate to levels above 24°C caused some mortality

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

Reference	Temperature (°C)	Comment
Baltz et al. (1987)	14.5 – 20.0	Temperature range for all fish
	15.5 – 19.5	Temperature range for 90% of fish
Eaton et al. (1995)	24.0	Based upon 95 <sup>th</sup> percentile of 5% highest weekly average temperatures

**Table A-5. Chronic Temperature Tolerances – EPA and Colorado**

Reference	Temperature (°C)	Comments
EPA (1977)	19	Recommended level as MWAT
Colorado WQCD (2007)	18.2	Recommended level as MWAT

**ATTACHMENT B**

**Detailed Summary of Acute Thermal Tolerance Values for Rainbow Trout, Juvenile and Adult, Summer**

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

Reference	Size or Age	Acclim. Temp. (°C)	Test Duration	UILT		UUILT	
				Temp. (°C)	Comment	Temp. (°C)	Comment
Alabaster and Welcomme (1962)	Juvenile	18	1-d	26.5	Based upon median survival time		
Bear (2005); Bear et al. (2007)	Juvenile	See Note <sup>1</sup>	7-d	26.0			
			60-d	24.3			
Bidgood and Berst (1969)	7 mo.	15	1 to 4-d	25 – 26			
Black (1953)	Fingerling	11	1-d	24.0			
Hokansen et al. (1977)	Juvenile	16	101-h	25.6			
Ineno et al. (2005)	Fry (6 mo.)	20	1-d	26.2			
			4-d	24.3			
Kaya (1978)	Fingerling, juvenile	7-d	5	23.2 - 25.0		26.2	
			9	24.2 – 25.2			
			13	24.7 – 25.2			
			17	25.2 – 25.7			
			21	25.7 -26.2			
			24.5	26.2			
Stauffer et al. (1984)	Young-of-year	7-d	6	24.6		26.0	
			12	25.9			
			18	26.7			
	Juvenile		24	26.0			

**Table B-1. Acute Temperature Tolerances – Laboratory Lethal Temperatures, UILT/UIILT (cont'd)**

Reference	Size or Age	Acclim. Temp. (°C)	Test Duration	UILT		UIILT	
				Temp. (°C)	Comment	Temp. (°C)	Comment
Threader and Houston (1983)	Fingerling	4	1 to 4-d	22.6 – 22.8			
		8		24.0 – 24.1			
		12		24.5 – 24.6			
		16		25.1 – 25.4			
		20		25.5 – 25.9			
		12 ± 4 <sup>2</sup>		24.8 – 25.6			
		12 ± 6.5 <sup>2</sup>		25.0 – 25.4			

<sup>1</sup>Bear (2005) used the acclimated chronic exposure (ACE) thermal test method. Because the fish are gradually acclimated to the test temperatures, the acclimation and test temperature are the same for the ACE method. See the Methodology document for more details.

<sup>2</sup>Fish were acclimated to daily varying temperature prior to ILT tests.

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

Reference	Size or Age	Acclim. Temp. (°C)	Rate	Temperature (°C)	Endpoint
Becker and Wolford (1980)	Juvenile	8	0.1°C/min (6°C/hour)	26.9	Loss of equilibrium
				27.4	Death
Carline and Machung (2001)	Juvenile	9.8	0.3°C/min (18°C/hour)	27.6 – 28.1 <sup>1</sup>	Loss of equilibrium
Currie et al. (1998, 2004)	Juvenile	10	0.3°C/min (18°C/hour)	28	Loss of equilibrium
		15		29.1	
		20		29.8	
		15 followed by 10 – 20 diel cycling		27.3 – 29.3	
Galbreath et al. (2004)	Juvenile	15	2, 4, 8, 24°C/day (0.08, 0.17, 0.33, 1°C/hour)	28.4 – 28.8	Loss of equilibrium
Galbreath et al. (2006)	Juvenile	12 – 17 <sup>2</sup>	2°C/day (0.08°C/hour)	27.7 - 28.3	Loss of equilibrium
Grande and Andersen (1991)	2-3 months	17	1°C/day (0.04°C/hour)	26.6	Death
Ineno et al. (2005)	Fry	15	5°C/hour	29.7	Loss of equilibrium
				30.1	Death
				29.9 – 30.4	Loss of equilibrium
				30.2 – 30.6	Death
Lee and Rinne (1980)	Juvenile	10	0.02°C/min (1.2°C/hour)	28.5	Loss of equilibrium
		20		29.4	
		10	Daily fluctuation of 6°C; increased 1°C every 48 hours (0.02°C/hour)	27.0 <sup>3</sup>	Loss of equilibrium

**Table B-2. Acute Temperature Tolerances – Laboratory Lethal Temperatures, Critical Thermal Maximum (cont'd)**

Reference	Size or Age	Acclim. Temp. (°C)	Rate	Temperature (°C)	Endpoint
Myrick and Cech (2000)	Age-0	10	0.3°C/min (18°C/hour)	27.6 - 27.7	Loss of equilibrium
		14		28.4 - 28.6	
		19		29.3 – 30.6	
		22		30.0 - 31.0	
		25		31.5 – 32.0	
Patra et al. (2007)	Juvenile	10	0.8°C/min (48°C/hour)	30.7	Loss of equilibrium
Recsetar et al. (2012)	Juvenile, adult	18	0.3°C/min (18°C/hour)	31.2	Loss of equilibrium
Strange et al. (1993)	Fingerling	15	0.3°C/min (18°C/hour)	29.4 - 30	Loss of equilibrium

<sup>1</sup>Tested both wild and domestic strains with little difference in results

<sup>2</sup>Only a range of acclimation temperatures is reported in paper

<sup>3</sup>Maximum daily temperature with temperatures varying from 21 to 27°C

**Table B-3. Acute Temperature Tolerances – Field Studies**

Reference	Temperature (°C)	Comments
Huff et al. (2005)	16 – 22.4 (MWMT)	Values are upper limits of Realized Thermal Niche
	16.6 – 23.3 (MDMT)	Estimated MDMT values using Standardization conversion discussed in <i>Methodology</i> document (MDMT = 1.04 x MWMT)
Kaya et al. (1977)	24 (average) 25 (daily maximum)	

**Table B-4. Acute Temperature Tolerances – EPA and Colorado**

<b>Reference</b>	<b>Temperature (°C)</b>	<b>Comments</b>
EPA (1977)	24	No metric (DM, MWMT, etc.) recommended
Colorado WQCD (2007)	23.8	Recommended level as DM

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