DRAFT Bluegill Sunfish (*Lepomis macrochirus*) Thermal Tolerance Analyses – Juvenile and Adult, Summer
January 2016

Introduction

Recommended summer chronic and acute thermal tolerance values for juvenile and adult bluegill sunfish 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 bluegill sunfish for various lines of evidence. These values are based upon a review of 24 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 32°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 bluegill sunfish. 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 chronic criterion for a given fish species that is between the optimum temperature and the UUILT.

Table 1. Summary of Chronic Temperature Tolerances

Category	Temperature (°C)
Laboratory Optimal Growth Studies – Constant Temperature	
Optimum	30 – 31
Laboratory Temperature for Maximum Critical Swimming Performance	
Maximum median temperature	21.5 – 30.4
Maximum third quartile temperature	26.2 – 31.4
Laboratory Temperature Preference Studies	
Average Preferences	18.7 – 33.5
Final Preferendum	27.4 – 31.0
Laboratory Upper Temperature Avoidance Studies	22 – 39
Temperature Preference Field Studies	22 – 37
Thresholds from EPA and Colorado (MWAT)	32 – 31.8
Recommended Chronic Temperature Tolerance	**32**

Acute Thermal Tolerance Thresholds

Table 2 provides a summary of the range of acute temperature tolerance values for bluegill sunfish for various lines of evidence. These values are based upon a review of 17 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 (32°C) are to be included in the acute criterion development process. For bluegill sunfish, UILT and CTM values for acclimation temperatures 30 – 35°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. = 1 – 10°C	23.3 – 30.6	
Acclim. = 10 – 20°C	27.5 – 31.5	
Acclim. = 20 – 25°C	31.0 – 36.1	
Acclim. = 25 – 30.0°C	33.8 – 37.4	
Acclim. = 30 – 35°C	33.8 – 39.0	31.8 – 37.0[1]
Laboratory Lethal Studies – CTM		
Acclim. = 10 – 20°C	30.4 – 37.3	
Acclim. = 20 – 25°C	35.6 – 39.1	
Acclim. = 25 – 30°C	35.8 – 41.2	
Acclim. = 30 – 35°C	37.4 – 42.8	31.5 – 36.9[2]
Field Studies		
Thresholds from EPA and Colorado	35 – 33.5	
Recommended Acute Temperature Tolerance	**35**	

[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*)

A review of laboratory studies suggests that an appropriate acute criterion should fall between 31.5 and 37.0°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 35°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 juvenile/adult bluegill sunfish.

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ATTACHMENT A
Detailed Summary of Chronic Thermal Tolerance Values for Bluegill Sunfish, Juvenile and Adult, Summer

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
Beitinger and Magnuson (1979)	16.8 g ± 3.45 g	Test temperatures[1]	31[2]			
Lemke (1977)	Juvenile	20	30			

[1]Bluegills, captured from Lake Mendota, Wisconsin during autumn, were acclimated to test temperatures in the laboratory for at least 2 weeks prior to experiments.
[2]Although the growth of bluegills was greatest at 31 C, no significant differences occurred among fish at 25.0, 28.0, and 31.0 C ($F = 0.629$; $P > 0.50$).

Table A-1a. Chronic Temperature Tolerances – Laboratory Temperature for Maximum Critical Swimming Speed

Reference	Age or Size	Acclim. Temp. (°C)	Optimum Swimming Performance Temperature		Upper Optimum Swimming Performance Temperature	
			Temp. (°C)	Comment	Temp. (°C)	Comment
Kelsch (1996)	135 – 175 mm	13	21.5	Median	26.2	Third quartile
		25	28.1		29.8	
		30	30.4		31.4	

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
Beitinger (1974)	Juvenile 71 – 100 mm	25	31.2					
Beitinger (1976)	91 mm ± 10 mm	25	31.8 – 32.0					
Beitinger (1977)	71.9 mm ± 10.1 mm	25	31.2					
Cherry (1975)	> 1 year	6 – 30	18.7 – 31.7					
Cherry (1977)	< 1 year 50 – 100 mm fork length	12 – 36	24.1 – 31.8					
Hill et al. (1973)	Yearling	16	22.5					
		21	23.3					
		26	28.2					
Kelsch and Neil (1990)	38 – 75 mm	20	27					
		30	30					
		35	32					
Neill et al. (1972)			27 – 31	Lower and upper limits of temperatures occupied by 1 fish				
Neill and Magnuson (1974)	<1 year 53 – 83 mm	20 – 22	28.5 – 33.5					

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
Peterson and Schutsky (1975)	90 mm	13.0	24.6					
		27.0	30.7					
Reutter and Herdendorf (1974 and 1976)	Adult	Unknown[1]					27.4	Final preferendum during a winter study.[2]
Reynolds and Casterlin (1976)	45 – 110 mm	22	31.7					
Reynolds and Casterlin (1979)		20					31	
Stuntz and Magnuson (1976)	Yearling 75 – 125 mm	25	30					

[1]The water temperature in the acclimation tank was maintained as close to lake temperature as possible (usually within 2°C of lake temperature).
[2]Final preferendum during a winter study. Reutter and Herdendorf (1974) found that winter preferenda were several degrees lower than summer preferenda. A summer study was not conducted for bluegill by Reutter and Herdendorf (1974).

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

Reference	Age or Size	Acclim. Temp. (°C)	Temperature (°C)	Comment
Beitinger (1974)	Juvenile 72 – 105 mm	25	33.1 – 33.8	
Beitinger (1976)	91 mm ± 10 mm	25	33.4 – 33.7	
Cherry (1975)	> 1 year	6 – 30	22 – 35	
Cherry (1977)	< 1 year 50 mm – 100 mm fork length	12 – 36	24 – 39	
Neill and Magnuson (1974)	< 1 year 81 – 97 mm	20 – 22	33.5	
Peterson and Schutsky (1975)	90 mm	1	27.6	
		13	30.3	
		27	33.5	
Stauffer et al. (1976)	Unknown	12	24	
		15	27	
		18	30	
		21	30	
		24	33	
		27	33	
		30	33	
		33	36	

Table A-4. Chronic Temperature Tolerances – Field Studies

Reference	Temperature (°C)	Comment
Block et al. (1984)	32 – 37	Bluegill stayed in water from 32–37°C.
Eaton et al. (1995)	31.7	Based upon 95th percentile of 5% highest weekly average temperatures.
Marcy (1976)	35.0	Listed as maximum and mean temperature
Neill and Magnuson (1974)	<31.5	Young bluegill spend a majority of time at or below 29.4 – 31.3°C and almost no time above 31.5°C.
Yoder and Gammon (1975)	22 – 34	Temperature range where bluegill where captured by electrofishing and in D nets in the summer.

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

Reference	Temperature (°C)	Comments
EPA (1977)	32	Recommended level as MWAT
Colorado WQCD (2007)	31.8	Recommended level as MWAT

ATTACHMENT B
Detailed Summary of Acute Thermal Tolerance Values for Bluegill Sunfish, Juvenile and Adult, Summer

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
Banner and Van Arman (1973)	Juvenile	12.1	1-hour	28.9			
			1-d	28.5			
			2-d	28.5			
			3-d	27.7			
			4-d	27.5			
		19.0	1-hour	34.7			
			1-d	33.0			
			2-d	33.0			
			3-d	32.9			
			4-d	33.0			
		26.0	1-hour	37.4			
			1-d	36.4			
			2-d	34.1			
			3-d	36.1			
			4-d	36.1			
		32.9	1-hour	39.0			
			1-d	37.5			
			2-d	37.4			
			3-d	37.3			
			4-d	37.3			
Cvancara et al. (1977)	Young of the year	24 – 33[1]	2-d	28.5			
Hart (1952)		15		30.7			
		20		31.5			
		30		33.8[2]			

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

Reference	Size or Age	Acclim. Temp. (°C)	Test Duration	UILT		UUILT	
				Temp. (°C)	Comment	Temp. (°C)	Comment
Hathaway (1927)	1 – 2 years old	10	1-d	30 – 30.6[3]			
		21		34[3]			
		30		34.3 – 35.6[3]			
Hickman and Dewey (1973)	37 mm	21.5	1-d	31		35.5	
Peterson and Schutsky (1975)	90 mm	1	4-d	23.3			
		13		29.3			
		27		35.8			

[1]Fish were placed in aquaria maintained at the temperature of the water from the collection site. After 2 hours at constant river water temperature, the water temperature in the aquaria was increased at a rate of 2 – 4°C per hour until the appropriate test temperature was reached. River water temperature ranged from 24 to 33°C during the collection period.
[2]Listed in Table 4 on page 68 as "33.8?" No explanation is given for the question mark.
[3]Variant of UILT, preceded coining of "UILT"; Used only 24 hour tolerances. 4 min, 15 min, 1 hr, and 4 hr. tolerances also reported; Author used weighted average for lethal temperature; unbalanced design.

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

Reference	Size or Age	Acclim. Temp. (°C)	Rate	Temperature (°C)	Endpoint
Carveth et al. (2006)	80 – 116 mm	25	0.3°C/min (18°C/hour)	35.8	Loss of equilibrium
				37.3	Death
		30		38.7	Loss of equilibrium
				39.6	Death
Cox (1974)	7.3-14 cm 4.8-40.5 g	26	0.1°C/min (6°C/hour)	36.6	Loss of equilibrium
				37.5	Cessation of opercular beating
			0.5°C/min (30°C/hour)	37.5	Loss of equilibrium
				39.1	Cessation of opercular beating
			1.0°C/min (60°C/hour)	37.9	Loss of equilibrium
				39.2	Cessation of opercular beating
Dent and Lutterschmidt (2003)[1]	99.7 mm 33.3 g	20	1.0°C/min (60°C/hour)	37.3	Loss of equilibrium
		30		41.2	
Holland et al. (1974)	Juveniles	25	1.0°C/min (60°C/hour)	36.3 – 37.0	Loss of equilibrium
				37.0 – 39.1	Death
		30		37.4 – 39.6	Loss of equilibrium
				39.1 – 40.9	Death
		35		40.4 – 41.4	Loss of equilibrium
				41.9 – 42.8	Death
Lutterschmidt and Hutchinson (1997)	Unknown	10	1.0°C/min (60°C/hour)	30.4	Loss of equilibrium
				33.6	Onset of opercular spasms
Murphy et al. (1975)	40 – 82 mm 0.57 – 5.6 g	16	1.0°C/min (60°C/hour)	31.4 – 31.5	Loss of equilibrium
		24		35.6 – 37.5	
		32		38.5 – 41.4	

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
Schaefer et al. (1999)	96 mm	10	1.0°C/min (60°C/hour)	32.6	Loss of equilibrium
				36.2	Onset of opercular spasms
Smale and Rabeni (1995)	1.5 – 24.1 g	26	0.033°C/min (2°C/hour)	37.9	Loss of equilibrium

[1]Only results from groups with n>4 are reported here.
[2]CTM values were calculated by subtracting the reported differences between mean Death Point and mean CTM from reported mean temperatures for Death Point.

Table B-3. Acute Temperature Tolerances – Other Laboratory Studies

Reference	Size or Age	Acclim. Temp. (°C)	Comment
Beitinger (1974)	Juvenile 72 – 105 mm	25	7 of the 20 fish (35%) exposed to 36.1°C died during treatment. All fish that died lost equilibrium early in the treatment and were dead within 5 minutes.

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

Reference	Temperature (°C)	Comments
EPA (1977)	35	No metric (DM, MWMT, etc.) recommended
Colorado WQCD (2007)	33.5	Recommended level as DM