DRAFT Channel Catfish (*Ictalurus punctatus*) Thermal Tolerance Analyses – Juvenile and Adult, Summer
January 2015

Introduction

Recommended summer chronic and acute thermal tolerance values for juvenile and adult channel catfish 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 channel catfish for various lines of evidence. These values are based upon a review of 18 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 channel catfish. 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	27 – 30
Laboratory Optimum Temperature for Most Rapid Rate of Digestion	
Optimum mean temperature	26.6 – 29.4
Laboratory Optimum Temperature for Swimming Performance	
Optimum mean temperature	30
Upper Optimum mean temperature	35
Laboratory Temperature Preference Studies	
Average Preferences	16.5 – 30.5
Upper Preferences	
Laboratory Upper Temperature Avoidance Studies	25 – 35
Temperature Preference Field Studies	5.1 – 36
Thresholds from EPA and Colorado (MWAT)	32 – 32.2
Recommended Chronic Temperature Tolerance	**32**

Acute Thermal Tolerance Thresholds

Table 2 provides a summary of the range of acute temperature tolerance values for channel catfish for various lines of evidence. These values are based upon a review of 13 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 channel catfish, 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. = 15 – 20°C	30.3 – 32.8	
Acclim. = 20 – 25°C	32.7 – 33.5	
Acclim. = 25 – 30°C	33.5 – 37.3	
Acclim. = 30 – 35°C	37.3 – 37.8	35.3 – 35.8[1]
Laboratory Lethal Studies – CTM		
Acclim. = 10 – 15°C	30.9 – 36	
Acclim. = 15 – 20°C	34.5 – 38	
Acclim. = 20 – 25°C	35.0 – 40.0	
Acclim. = 25 – 30°C	38.7 – 41.0	
Acclim. = 30 – 35°C	39.1 – 42.5	34.2 – 37.6[2]
Thresholds from EPA and Colorado	35 – 35.4	
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 2.9°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 suggest that an appropriate acute criteria should fall between 34.2 and 37.6°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 range of potential criteria found in the literature, and is recommended as the acute thermal tolerance level for adult/juvenile channel catfish.

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ATTACHMENT A
Detailed Summary of Chronic Thermal Tolerance Values for Channel Catfish, 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
Andrews and Stickney (1972)	Fingerlings 4 g	Unknown	30[1]			
Andrews et al. (1972)	Fingerlings 25 g	Unknown	28 – 30			
Buentello et al. (2000)	Juvenile 15 g 10 – 12 cm	Unknown	27 – 28			

[1]The exact temperature for optimum growth and efficiency was not determined during this experiment, but the above data indicated that greater growth and lower conversions were obtained at 30°C than at either 26°C or 34°C.

Table A-1a. Chronic Temperature Tolerances – Laboratory Optimum Temperature for Most Rapid Rate of Digestion

Reference	Age or Size	Acclim. Temp. (°C)	Optimum Digestion Temperature		Upper Optimum Digestion Temperature	
			Temp. (°C)	Comment	Temp. (°C)	Comment
Shrable et al. (1969)	380 g	10 – 29.4	26.6 – 29.4			

Table A-1b. Chronic Temperature Tolerances – Laboratory Optimum Temperature for Swimming Performance

Reference	Age or Size	Acclim. Temp. (°C)	Optimum Swimming Performance Temperature		Upper Optimum Swimming Performance Temperature	
			Temp. (°C)	Comment	Temp. (°C)	Comment
Hocutt (1973)	140 – 154 mm	27 - 31	30		35	Results obtained at 35°C varied only slightly from those obtained at the temperature for optimum performance, 30°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
Cheetham et al. (1976)[1]	50 mm	12	16.5[2]					
		16	21[2]					
		20	21[2]					
		24	27.5[2]					
		28	26					
		32	30					
Cherry et al. (1975)	<1 year	6 – 30	18.9 – 30.5					
Diaz and Buckle (1999)	Juvenile	20	26.5					
		23	26.5					
		26	27.0					
		29	29.0					
		32	27.5					
		23 – 33 fluctuating temperatures[3]	27.0					
		33 – 23 fluctuating temperatures[3]	27.0					
Reutter and Herdendorf (1974 and 1976)	Adult						25.2 – 25.3	

[1]Attempts to acclimate fish at 36°C failed because all fish died before the acclimation period was over.
[2]Mean thermal preference values (except for acclimation temperatures of 26°C and 32°C) were estimated from Figure 1 of Cheetham et al. (1976) to the nearest 0.5 C.

[3]Preferred temperature values were estimated from Figure 1 of Diaz and Buckle (1999) to the nearest 0.5 C.
[4]The water temperature in the acclimation tank was maintained as close to lake temperature as possible (usually within 2°C of lake temperature).

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 - 30	25 – 35	

Table A-4. Chronic Temperature Tolerances – Field Studies

Reference	Temperature (°C)	Comment
Eaton et al. (1995)	29.5	Based upon 95th percentile of 5% highest weekly average temperatures.
Gammon (1973)	30.0 – 32.0	Optimum temperature range. Range of temperatures which probably include the final temperature preferenda of channel catfish in the Wabash River.
Marcy (1976)	5.1 – 28.5	Temperature range
	15.2	Mean temperature
Stauffer et al. (1974)	> 32.2	
Stauffer et al. (1976)	34.4	
Wehrly et al. (2003)	18 – 26	Mean temperatures at sites where channel catfish were present at average or above-average standing stocks ranged from 18°C to 26°C.
Yoder and Gammon (1976)	32 – 36	Temperature range where channel catfish where captured by electrofishing 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)	32.2	Recommended level as MWAT

ATTACHMENT B
Detailed Summary of Acute Thermal Tolerance Values for Channel Catfish, 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
Allen and Strawn (1967)	44 – 57 day old	26.0	7,260 minutes	36.6			
		30.0		37.3			
		34.0		37.8			
Hart (1952)	88.3 – 122.6 g	15	500 minutes	30.3		33.5	The ultimate upper lethal for this species appears to be around 33.5°C as suggested by the relatively small differences in lethal temperatures for fish acclimated to 25°C and 30°C.
		20	600 minutes	32.7 – 32.8			
		25	1,000 minutes	33.5			

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

Reference	Size or Age	Acclim. Temp. (°C)	Rate	Temperature (°C)	Endpoint
Bennet et al. (1998)	8 month old	10	0.15°C/min (9°C/hour)	30.9	Final loss of equilibrium
		20		35.8	
		30		40.1	
		35		42.1	
Cheetham et al. (1976)[1]	50 mm	12	1°C/min (60°C/hour)	34.5	Loss of equilibrium
				36	Death
		16		34.5	Loss of equilibrium
				36.5	Death
		20		35.5	Loss of equilibrium
				37	Death
		24		37.5	Loss of equilibrium
				38.5	Death
		28		39.5	Loss of equilibrium
				40.5	Death
		32		41	Loss of equilibrium
				42.5	Death
Currie et al. (1995 and 1998)	Juvenile 10 cm 15 g	20	0.3°C/min (18°C/hour)	36.4	Loss of equilibrium
		25		38.7	
		30		40.3	
Currie et al. (1995 and 2004)	Juvenile	20	0.3°C/min (18°C/hour)	36.4	Loss of equilibrium
		25		38.7	
		30		40.3	
		25 followed by 20 – 30 diel cycling		39.0	

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
Diaz and Buckle (1999)	Juvenile	20	1°C/min (60°C/hour)	35.0	Loss of equilibrium
		23		37.0	
		26		39.0	
		29		41.0	
		32		42.5	
		23 followed by 23 – 33 fluctuating temperatures[3]		39.0	
		32 followed by 23 – 33 fluctuating temperatures[3]		42.0	
Lutterschmidt and Hutchinson (1997)	Unknown	10	1.0°C/min (60°C/hour)	31.3	Loss of equilibrium
				33.3	Onset of opercular spasms
Recsetar et al. (2012)	62-264 mm	25	0.3°C/min (18°C/hour)	39.9 – 40.0	Final loss of equilibrium[4]
Stewart and Allen (2014)	162-320 mm	30	0.033°C/min (2°C/hour)[5]	39.1 – 39.3	Loss of equilibrium
Watenpaugh et al. (1985)	10.7 g	20	0.3°C/min (18°C/hour)	38.0	Final loss of equilibrium

[1]Attempts to acclimate fish at 36°C failed because all fish died before the acclimation period was over.
[2]CTM values were estimated from Figure 1 of Cheetham et al. (1976) to the nearest 0.5°C.
[3]Water temperature was increased from 23 to 33°C in 5 h, then remained stable for 7 h. Then the water was cooled over 5 h period to lower the temperature to 23°C, it then remained stable for 7 h.
[4]Final loss of equilibrium was the only endpoint examined in this experiment and is the most widely used endpoint in CTMax tests. Final loss of equilibrium is the temperature at which the failure of the righting response occurs (Recestar et al. 2012).

[5]During the summer months of 2009, data from six different catfish aquaculture ponds found water temperatures increased by 1–2°C each hour (E. L. Torrans, U.S. Department of Agriculture Agricultural Research Service, unpublished data from 2010). Based on these data, a heating rate of 2°C per hour was determined to give an accurate estimation of CTmax. Water temperature was increased at a rate of 2.0°C ± 0.1°C per hour until loss of equilibrium (LOE) occurred, to achieve an environmentally realistic rate of temperature increase.

Table B-3. Acute Temperature Tolerances – EPA and Colorado

Reference	Temperature (°C)	Comments
EPA (1977)	35	No metric (DM, MWMT, etc.) recommended
Colorado WQCD (2007)	35.4	Recommended level as DM