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

Introduction

Recommended summer chronic and acute thermal tolerance values for juvenile and adult brook 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*" (March 2017).

Chronic Thermal Tolerance Thresholds

Table 1 provides a summary of the range of chronic temperature tolerance values for brook trout for various lines of evidence. These values are based upon a review of 33 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 brook 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 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	12.4 – 16
Upper Optimum	17 – 19
Laboratory Temperature for Maximum Cruising Speed	
Maximum cruising speed temperature	17 – 19
Laboratory Temperature Preference Studies	
Average Preferences	8.7 – 19
Upper Preferences	9.9 – 21.1
Laboratory Upper Temperature Avoidance Studies	14 – 26
Laboratory Highest Temperature where Feeding was Observed	25.2 – 25.7
Temperature Preference Field Studies	6 – 26.3
Thresholds from EPA and Colorado (MWAT)	18.3 – 19
Recommended Chronic Temperature Tolerance	**19**

Acute Thermal Tolerance Thresholds

Table 2 provides a summary of the range of acute temperature tolerance values for brook trout for various lines of evidence. These values are based upon a review of 26 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 brook trout, UILT and CTM values for acclimation temperatures 15 – 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. = 1 – 5°C	20.4 – 23.4	
Acclim. = 5 – 10°C	19.4 – 23.7	
Acclim. = 10 – 15°C	20.2 – 24.8	
Acclim. = 15 – 20°C	24.3 – 25.3	22.3 – 23.3[1]
Acclim. = 20 – 25°C	25.3 – 26.1	
UUILT	20.1 – 25.3	18.1 – 23.3[1]
Laboratory Lethal Studies – CTM		
Acclim. = 5 – 10°C	28.0 – 29.0	
Acclim. = 10 – 15°C	27.5 – 29.0	
Acclim. = 15 – 20°C	28.0 – 30.8	21.3 – 24.1[2]
Field Studies	15.8 – 28.5	
Thresholds from EPA and Colorado	21.7 – 24	
Recommended Acute Temperature Tolerance	**24**	

[1]UILT and UUILT values reduced by 2°C to provide 100% survival (See *Methodology*)
[2]CTM values reduced by 4.7°C to estimate quasi-UILT values, and reduced by 2°C to provide 100% survival (See *Methodology*)

A review of laboratory studies suggest that an appropriate acute criteria should fall between 18.1 and 24.1°C, while field studies suggest a wider range of 15.8 to 28.5°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 brook trout.

References

Baird, O.E., Krueger, C.C. 2003. Behavioral thermoregulation of brook and rainbow trout: comparison of summer habitat use in an Adirondack river, New York. Transactions of the American Fisheries Society 132:1194-1206.

Baldwin, N.W. 1957. Food consumption and growth of brook trout at different temperatures. Trans. Am. Fish. Soc. 86:323-328.

Barton, D.R., W.D. Taylor, and R.M. Biette. 1985. Dimensions of riparian buffer strips required to maintain trout habitat in southern Ontario streams. North American Journal of Fisheries Management 5:364-378.

Benfey, T.J., McCabe, L.E., Pepin, P., 1997. Critical thermal maxima of diploid and triploid brook charr, Salvelinus fontinalis. Environ. Bioi. Fishes 49:259-264.

Benjamin, J. R., Dunham, J. B., & Dare, M. R. 2007. Invasion by nonnative brook trout in Panther Creek, Idaho: roles of local habitat quality, biotic resistance, and connectivity to source habitats. Transactions of the American Fisheries Society, 136(4):875-888.

Binns, N. A., and F. M. Eiserman. 1979. Quantification of fluvial trout habitat in Wyoming. Transactions of the American Fisheries Society 108:215–228.

Biro, P.A. 1998. Staying cool: behavioral thermoregulation during summer by young-of-year brook trout in a lake. T Am Fish Soc 127:212–222.

Bowlby, J. N., & Roff, J. C. 1986. Trout biomass and habitat relationships in southern Ontario streams. Transactions of the American Fisheries Society, 115(4):503-514.

Brett, J. R. 1944. Some lethal temperature relations of Algonquin Park fishes. University of Toronto Press.

Brungs, W.A. and B.R. Jones. 1977. Temperature Criteria for Freshwater Fish: Protocol and Procedures. EPA-600/3-77-061. Environmental Research Laboratory, Duluth, Minnesota.

Carline, R.F. and J.F. Machung. 2001. Critical thermal maxima of wild and domestic strains of trout. Trans. Amer. Fish. Soc. 130:1211-1216.

Chadwick, J. G., Nislow, K. H., & McCormick, S. D. 2015. Thermal onset of cellular and endocrine stress responses correspond to ecological limits in brook trout, an iconic cold-water fish. Conservation Physiology, 3(1), cov017.

Cherry, D.S., K.L. Dickson, and J. Cairns. 1975. Temperature selected and avoided by fish at various acclimation temperatures. Jour. Of the Fish. Res. Board of Canada 32:485-491.

Cherry, D.S., K.L. Dickson, J. Carns, Jr., and J.R. Stauffer. 1977. Preferred, avoided, and lethal temperatures of fish during rising temperature conditions. Jour. Of the Fish. Research Board of Canada 34:239-246

Colorado Water Quality Control Division. 2007. Colorado temperature database.

Creaser, C. W. 1930. Relative importance of hydrogen ion concentration, temperature, dissolved oxygen, and carbon dioxide tension on habitat selection by brook trout. Ecology 11:246–262.

Cunjak, R. A., D. Caissie, N. El-Jabi, P. Hardie, J. H. Conlon, T. L. Pollock, D. J. Gibson, and S. Komadina-Douthwright. 1993. The Catamaran Brook (New Brunswick) habitat research project: biological, physical, and chemical conditions (1990–1992). Canadian Technical Report of Fisheries and Aquatic Sciences 1914.

De Staso, J. and F.J. Rahel. 1994. Influence of Water Temperature on Interactions between Juvenile Colorado River Cutthroat Trout and Brook Trout in a Laboratory Stream, Transactions of the American Fisheries Society, 123(3):289-297.

Dwyer, W. P., Piper, R. G., & Smith, C. E. 1983. Brook trout growth efficiency as affected by temperature. The Progressive Fish-Culturist, 45(3):161-163.

Eaton, J.G., J.H. McCormick, B.E. Goodno, D.G. O'Brien, H.G. Stefan, M. Hondzo, and R.M. Scheller. 1995. A field information-based system for estimating fish temperature tolerances. Fisheries 20(4):10-18.

Elson, P. F. 1942. Effect of temperature on activity of Salvelinus fontinalis. Jour. Fish Res. Bd. Canada, 5:461-70.

Embody, G.C. 1921. Concerning high water temperatures and trout. Transactions of the American Fisheries Society 51: 58-64.

Fisher, K. C. and Elson, P. F. 1950. The selected temperature of Atlantic salmon and speckled trout and the effect of temperature on the response to an electrical stimulus. Physiological zoology, 27-34.

Fry, F. E. J., Hart, J. S., & Walker, K. F. 1946. Lethal temperature relations for a sample of young speckled trout. *Salvelinus fontinalis*, 1-47.

Galbreath, P. F., Adams, N. D., & Martin, T. H. 2004. Influence of heating rate on measurement of time to thermal maximum in trout. Aquaculture, 241(1):587-599.

Galbreath, P. F., Adams, N. D., Sherrill III, L. W., and Martin, T. H. 2006. Thermal tolerance of diploid versus triploid rainbow trout and brook trout assessed by time to chronic lethal maximum. Environmental Biology of Fishes, 75(2):183-193.

Grande, M. and S. Andersen. 1991. Critical thermal maxima for young salmonids. Journal of Freshwater Ecology 6:275-279.

Hokanson, K. E., McCormick, J. H., Jones, B. R., & Tucker, J. H. 1973. Thermal requirements for maturation, spawning, and embryo survival of the brook trout, *Salvelinus fontinalis*. Journal of the Fisheries Board of Canada, 30(7):975-984.

Huff, D.D., S.L. Hubler, and A.N. Borisenko. 2005. Using field data to estimate the realized thermal niche of aquatic vertebrates. North American Journal of Fisheries Management 25:346-360.

Kilgour, D.M., R.W. McCauley, and W. Kwain. 1985. Modeling the Lethal Effects of High Temperature on Fish. Canadian Journal of Fisheries and Aquatic Sciense Vol. 42, p. 947-951.

Javaid, M.Y. and J.M. Anderson. 1967. Influence of starvation on selected temperature of some salmonids. Jour. Of the Fish. Research Board of Canada 24:1515-1519.

Lee, R.M. and J.N. Rinne. 1980. Critical thermal maxima of five trout species in the southwestern United States. Trans. Am. Fish. Soc. 109:632-635.

McCauley, R.W. 1958. Thermal relations of geographic races of Salvelinus. Can. J. Zool. 36(5):655-662.

McCormick, J. H., Hokanson, K. E., and Jones, B. R. 1972. Effects of temperature on growth and survival of young brook trout, *Salvelinus fontinalis*. Journal of the Fisheries Board of Canada, 29(8):1107-1112.

McMahon, T. E., Zale, A. V., Barrows, F. T., Selong, J. H., and Danehy, R. J. 2007. Temperature and competition between bull trout and brook trout: a test of the elevation refuge hypothesis. Transactions of the American Fisheries Society, 136(5):1313-1326.

Mebane, C.A. 2002. Stream Fish Indexes. Pages 4-1 to 4-65 in C. S. Grafe, editor. Idaho Small Stream Ecological Assessment Framework: an Integrated Approach. Idaho Department of Environmental Quality, Boise.

Meisner, J. D. 1990. Potential loss of thermal habitat for brook trout, due to climatic warming, in two southern Ontario streams. Transactions of the American Fisheries Society, 119(2):282-291.

Müller, R. 1977. Temperature selection of goldfish (*Carassius auratus* L.) and brook trout (*Salvelinus fontinalis* Mitch.) after heterogeneous temperature acclimation. Journal of Thermal Biology, 2(1):5-7.

Nevada Division of Environmental Protection. March 2017. Methodology for Developing Summer Thermal Tolerance Thresholds for Various Juvenile and Adult Fish in Nevada.

Peterson, R.H. 1973. Temperature selection of Atlantic salmon (Salmo salar) and brook trout (Salvelinus fontinalis) as influenced by various chlorinated hydrocarbons. J. Fish. Res. Board Can. 30:1091-1097.

Peterson, R.H., A.M. Sutterlin, and J.L. Metcalfe. 1979. Temperature preference of several species of Salmo and Salvelinus and some of their hybrids. J. Fish. Res. Board Can. 36:1137-1140.

Picard, C. R., Bozek, M. A., & Momot, W. T. 2003. Effectiveness of using summer thermal indices to classify and protect brook trout streams in northern Ontario. North American Journal of Fisheries Management, 23(1):206-215.

Ricker, W. E. 1934. An ecological classification of certain Ontario streams. Ontario Fisheries Research Laboratory 49:7–114.

Robinson J.M., D.C. Josephson, B.C. Weidel, and C.E. Kraft. 2010. Influence of variable interannual summer water temperatures on brook trout growth, consumption, reproduction, and mortality in an unstratified Adirondack lake. T Am Fish Soc 139: 685–699.

Selong, J. H., T. E. McMahon, A. V. Zale, and F. T. Barrows. 2001. Effect of temperature on the growth and survival of bull trout, with application of an improved method of determining thermal tolerance in fishes. Transactions of the American Fisheries Society 130:1026–1037.

Stitt, B.C., G. Burness, K.A. Burgomaster, S. Currie, J.L. McDermid, and C.C. Wilson. 2014. Intraspecific variation in thermal tolerance and acclimation capacity in brook trout (Salvelinus fontinalis): physiological implications for climate change. Physiol Biochem Zool 87: 15–29.

Sullivan, C. M., and K. C. Fisher. 1953. Seasonal fluctuations in the selected temperature of speckled trout, Salvelinus fontinalis (Mitchell). J. Fish. Res. Board Can. 10: 187-195.

Taniguchi, Y., F.J. Rahel, D.C. Novinger, and K.G. Gerow. 1998. Temperature mediation of competitive interactions among three fish species that replace each other along longitudinal stream gradients. Canadian Journal of Fisheries and Aquatic Sciences 55:1894-1901.

Wehrly, K.E., M.J. Wiley, and P.W. Seelbach. 2003. Classifying regional variation in thermal regime based on stream fish community patterns. Transactions of the American Fisheries Society 132:18–38.

Wehrly, K. E., Wang, L., & Mitro, M. 2007. Field-based estimates of thermal tolerance limits for trout: incorporating exposure time and temperature fluctuation. Transactions of the American Fisheries Society, 136(2):365-374.

ATTACHMENT A
Detailed Summary of Chronic Thermal Tolerance Values for Brook Trout, 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
Baldwin (1957)	Yearling	9[1]	13		17	At 17°C feeding decreased.
Dwyer et al. (1983)	0.6 g	Test Temperature[2]	13 - 16		19	The decrease in growth rate of fish held at 19°C was the result of a temperature stress.
Hokanson et al. (1973)	Yearling	9	16		19	10 – 19°C is the optimum range for growth (unrestricted rations) and relative condition factor.
McCormick et al. (1972)	≤ 8 week	2.5 – 15	12.4 – 15.4		17.9	9.8 – 17.9°C provided suitable conditions for brook trout growth.
McMahon et al. (2007)	8 months posthatch	8[3]	14			

[1]After four weeks at one temperature (9, 13, 17, and 21°C) the brook trout were transferred to the next highest or lowest temperature depending on whether it was ascending or descending the temperature series.
[2]Water temperatures were gradually adjusted over a 1-week period until the desired test temperature was reached. Fish were held at that temperature for 1 week before the test was begun.
[3]Fish were held in test tanks for 2 weeks at 8°C before a temperature adjustment of 1.0°C per day to reach the treatment temperature; constant temperatures were then maintained for 60 days.

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

Reference	Age or Size	Acclim. Temp. (°C)	Temperature of Maximum Cruising Speed		Upper Temperature of Maximum Cruising Speed	
			Temp. (°C)	Comment	Temp. (°C)	Comment
McCauley (1958)		10	19			
		17	17			

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	6.0	11.2		12.2	Upper 95% confidence limits on averages		
		9.0	11.3		13.4			
		12.0	13.7		14.6			
		15.0	15.2		16.0			
		18.0	18.0		17.6			
		21.0	18.3		19.3			
		24.0	19		21.1			
Cherry et al. (1977)	<1 year	12.0	13.7		15.0	Upper 95% confidence limits on averages	15.5 – 16.8	
		15.0	15.2		16.1			
		18.0	17.2		17.3			
		21.0	18.3		18.8			
		24.0	19		20.5			
Fisher and Elson (1950)	1 year	4	10					
Javaid and Anderson (1967)	Fingerlings	20	16	Average for fasted fish				
			18	Average for fed fish				
Müller (1977)[2]	4.5 – 7.0 g	10	16.8		17.3	95% confidence interval of mean		
		18	18.0		18.6			
Peterson (1973)	Underyearling	13	12.4 – 15.3		13.5 – 18.5			

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 et al. (1979)	Fry	10.6	8.7		9.9	Upper extent preferences based upon 1 stand. dev. above avg.		
		12.7	11.5		12.6			
	Fingerling	12.1	17.5		19.5			
Sullivan and Fisher (1953)	2 – 3 inches	2 – 8.5	8 – 16.5					
		4	9 – 12					

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[1]	14 – 25	
Cherry et al. (1977)	<1 year	12 – 24[1]	15 – 26	
Elson (1942)	12 cm	10	25 – 26	

[1]Attempts to acclimate to levels above 24°C caused some mortality

Table A-4. Chronic Temperature Tolerances – Other Laboratory Studies

Reference	Age or Size	Acclim. Temp. (°C)	Temperature (°C)	Comment
Chadwick et al. (2015)	Juvenile 0+ (11.7 – 29.0 g)	16	20.7 – 21.2[1]	
Taniguchi et al. (1998)	107 – 165 mm fork length	3 – 26[2]	24[3]	

[1]Laboratory experiments to show that the temperature thresholds in brook trout for increased gill heat shock protein-70 (20.7°C) and plasma glucose (21.2°C) are similar to their proposed thermal ecological limit of 21.0°C.
[2]During acclimation to 24°C, 2 of 10 brook trout died. During acclimation to 26°C, all 10 brook trout died.
[3]For brook trout, there was a significant increase in food consumption at temperatures below 24°C. This indicates that the presence of other fish species, not loss of appetite, was the reason for low food consumption in trials where brook trout was not the dominant species in the stream. However, at 24 °C, there was no significant increase in food consumption and in three of five replicates brook trout consumed no food items even when they were the only species present. Therefore, at 24°C, lack of appetite, not behavioral interactions, was the likely reason that brook trout did not eat in the presence of other species.

Table A-5. Chronic Temperature Tolerances – Highest Temperature where feeding was observed

Reference	Temperature (°C)	Comment
Grande and Anderson (1991)	25.2 – 25.7	Highest temperature where feeding was observed

Table A-6. Chronic Temperature Tolerances – Field Studies

Reference	Temperature (°C)	Comment
Barton et al. (1985)	<22	Streams with a trimean weekly maxima less than 22°C had trout; warmer streams had, at best, only marginal trout populations.
Baird and Krueger (2003)	11.8 – 26.3	Brook trout presence in the higher end of this range was limited to brief excursions from coolwater refugia to feed.
Benjamin et al. (2007)	11 – 19	Occurrence of small and large brook trout in Panther Creek, a tributary to the Salmon River in Idaho
Biro (1998)	15 – 20	In July, when ambient water temperatures ranged from 23°C to 27°C, trout lay on the bottom in the coldest water available (18–20°C).
Chadwick et al. (2015)	<21	Field assays demonstrated increased plasma glucose, cortisol, and heat shock protein-70 concentrations at field site where mean daily temperature exceeded 21.0°C.
Creaser and Brown (1927) as cited in Creaser 1930	<18	Brook trout certainly tolerate and probably prefer waters below 18°C.
Eaton et al. (1995)	22.3	Based upon 95th percentile of 5% highest weekly average temperatures
Elson (1939) as cited in Elson (1942)	<21	When Lake Ainslie reached temperatures above 21°C, brook trout moved to a brook that was generally 4°C to 6°C cooler than the lake.
Mebane (2002)	6 – 22	1.5 times the interquartile value
	11 – 15.5	Lower to upper quartile
	13	Median
Ott and Maret (2003)	13.5 – 18.5	Maximum weekly stream temperature range
Picard et al. (2003)	14.8	Mean summer temperature of brook trout streams in northern Ontario.
	17.1	Estimated MWAT value using Standardization conversion discussed in *Methodology* document (MDMT = 1.05 x Summer Average + 1.6)
Robinson et al. (2010)	≤20	The growth of older, larger brook trout (age ≥ 2) is negatively impacted by warm summer water temperatures (>20°C).
Wehrly et al. (2003)	10 – 22	Mean temperatures at sites where brook trout were present at average or above-average standing stocks ranged from 10°C to 22°C.

Table A-6. Chronic Temperature Tolerances – Field Studies (cont'd)

Reference	Temperature (°C)	Comment
Wehrly et al. (2007)[1]	25.3 (MEANT)	1 d Maximum daily mean temperature (MEANT)
	22.5 (MEANT)	14 d Maximum daily mean temperature (MEANT)
	22.1 (MEANT)	21 d Maximum daily mean temperature (MEANT)
	21.0 (MEANT)	63 d Maximum daily mean temperature (MEANT)
	23.3 (MEANT)	7-d Maximum daily mean temperature (MEANT)
Taniguchi et al. (1998)	9 – 23	Occurrence of brook trout in the Horse Creek drainage of southern Wyoming.

[1]Results based upon field observations of both brook and brown trout.

Table A-7. Chronic Temperature Tolerances – EPA and Colorado

Reference	Temperature (°C)	Comments
EPA (1977)	19	Recommended level as MWAT
Colorado WQCD (2007)	18.3	Recommended level as MWAT

ATTACHMENT B
Detailed Summary of Acute Thermal Tolerance Values for Brook Trout, 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
Brett (1944)	5.69 inches	Unknown	1-d	26.1			
Fry et al. (1946)	Yearling	3	Various	23.4		25.3	
		11		24.5			
		20		25.3			
		24		25.3			
Kilgour et al. (1985)	Unknown	14	Unknown	23.8			
McCormick et al. (1972)	Newly hatched alevin (0.04 – 0.05 g)	2.5	7-d	20.4		20.1	Ultimate Upper 7-d TL_{50}
		7		19.4			
		9.5		20.4			
		12		20.2			
		12	1-d	22.5			
	Swim-up alevin (0.1 – 0.2 g)	7.5	7-d	22.2		24.5	
		9.5		23.7			
		12		24.8			
		15		24.3			

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

Reference	Size or Age	Acclim. Temp. (°C)	Rate	Temperature (°C)	Endpoint
Benfey et al. (1997)[1]	Underyearling (25 g)	Unknown	0.033°C/min (2°C/hour)	Trial 1 = 29.1 Trial 2 = 28.3	Loss of equilibrium
	Underyearling (25 g)		0.25°C/min (15°C/hour)	Trial 1 = 29.5 Trial 2 = 29.8	Loss of equilibrium
	Yearling (668g)		0.033°C/min (2°C/hour)	Trial 1 & 2 = 27.7	Loss of equilibrium
	Yearling (668g)		0.25°C/min (15°C/hour)	Trial 1 & 2 = 29.3	Loss of equilibrium
Carline and Machung (2001)	Unknown	10.6	0.3°C/min (18°C/hour)	Domestic = 28.2 Wild = 28.7[2]	Loss of equilibrium
De Staso and Rahel (1994)	97-182 mm	10	0.2°C/min (12°C/hour)	29	Loss of equilibrium
Galbreath et al. (2004)	Juvenile	15	2, 4, 8, 24°C/day (0.08,0.17, 0.33, 1°C/hour)	28.0 – 28.9	Loss of equilibrium
Galbreath et al. (2006)	Juvenile	12.5 – 16.5[3]	2°C/day (0.08°C/hour)	27.5 - 28.1	Loss of equilibrium
Grande and Anderson (1991)	2-3 months post-hatch	17	1°C/day (0.04°C/hour)	26.2	Death[4]
			2°C/day (0.08°C/hour)	27.2	
Lee and Rinne (1980)	15-20 cm	10	0.02°C/min (1.2°C/hour)	28.7	Loss of equilibrium
		20		29.8	
		10	Daily fluctuation of 6°C; increased 1°C every 48 hours (0.02°C/hour)	28[5]	
Selong et al. (2001)[6]	Unknown	8	0.17°C/min (10.2°C/hour)	28.3	Unknown
		20		30.8	
Stitt et al. (2014)	10.9 – 13.1 cm 12.1 – 24.8 g	8 – 20	0.33°C/min (19.8°C/hour)	27.5	Loss of equilibrium

[1]Tested both diploid and triploid brook trout. No effect of ploidy on CTM was found. Underyearlings had higher CTM values than yearlings (29.2 ± 0.1°C versus 28.5 ± 0.1°C, $p < 0.05$). Female yearlings, which were immature, had higher CTM values than males, which had previously matured as one-year-olds (28.8 ± 0.1° C versus 28.3 ± 0.1° C, $p < 0.001$).
[2]The mean CTMax for wild brook trout was 0.5°C higher than that of domestic brook trout.
[3]Only a range of acclimation temperatures is reported in paper
[4]Critical thermal maxima LT_{50} (temperature giving 50% mortality).
[5]Maximum daily temperature with temperatures varying from 22 to 28°C.
[6]These results are from unpublished data generated by Selong et al. as reported in Selong et al. (2001).

Table B-1. Acute Temperature Tolerances – Other Laboratory Studies

Reference	Size or Age	Acclim. Temp. (°C)	Comment
Taniguchi et al. (1998)	107-165 mm fork length	10	During acclimation to 26°C, all 10 brook trout died. Fish were held at 10°C at least 2 weeks prior to the onset of thermal acclimation for each experiment.

Table B-3. Acute Temperature Tolerances – Field Studies

Reference	Temperature (°C)	Comments
Cunjak et al. (1993)	23 – 26	
Elson (1942)	21	When Lake Ainslie reached temperatures above 21°C, brook trout moved to a brook that was generally 4°C to 6°C cooler than the lake.
Embody (1921)	28.5	The brook trout passed through a temperature of 28.5 C without loss, but with evident distress and failure of appetite. They apparently recovered on a drop of nine degrees overnight and a maximum of 26.5 C the following day. They lived through five succeeding days with the maximal temperatures ranging from 26 to 27 C., but began to die at 29 (mortality 20 percent). None died the following day, July 4, at 28; but on July 5 at a temperature of 28.4 C., the mortality was 100 percent.
Huff et al. (2005)	15.2 (MWMT)	Value is upper limit of Realized Thermal Niche
	15.8 (MDMT)	Estimated MDMT value using Standardization conversion discussed in *Methodology* document (MDMT = 1.04 x MWMT)
Meisner (1990)	24	
Picard et al. (2003)	19.8	Maximum summer temperature of brook trout streams in northern Ontario.
	18.4	Mean maximum summer temperature of brook trout streams in northern Ontario.
Robinson et al. (2010)	20	The growth of older, larger brook trout (age ≥ 2) is negatively impacted by warm summer water temperatures (>20°C)
Wehrly et al. (2007)[1]	27.6	1 d Maximum daily maximum temperature (MAXT)
	24.6	14 d Maximum daily maximum temperature (MAXT)
	24.2	21 d Maximum daily maximum temperature (MAXT)
	22.9	63 d Maximum daily maximum temperature (MAXT)
	25.4	7-d Maximum daily maximum temperature (MAXT)

[1]Results based upon field observations of both brook and brown trout

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

Reference	Temperature (°C)	Comments
EPA (1977)	24	No metric (DM, MWMT, etc.) recommended
Colorado WQCD (2007)	21.7	Recommended level as DM