HANDBOOK OF THE EFFECTS OF TEMPERATURE ON SOME NORTH AMERICAN FISHES

compiled by

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Dec. 1974

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PRELIMINARY ERRATA

p. v, last figure acknowledgement
From: ...J. J. Grahm.
To: ...J. J. Graham.

p. vii, fourth acknowledgement
From: ...Fisheries Society,...
To: ...American Fisheries Society,...

p. 2, 3, 4, 5, single line at bottom of table

p. 6, double line at bottom of table

p. 8, 4th line from bottom of page
From: ...1965; Parish, 1967;...
To: ...1965; Parrish, 1967,...

p. 14, 1st full paragraph
From: ...respones to...
To: ...responses to...

p. 30, 4th citation
From: ...Parish, L. P.
To: ...Parrish, L. P.

p. 31, 8th citation
From: ...steam biota,...
To: ...stream biota,...

p. 47, footnotes should be placed at end of table on p. 48

p. 48, replace 2nd printing of p. 46 with p. 48 (attached)

p. 123, 2nd paragraph
From: ...(Table NA-1) Temperatures...
To: ...(Table NA-1). Temperatures...

p. 124, 244, 308, 311, 322, single line at bottom of table

p. 156, 2nd citation
From: ...*Cyprinum carpio*...
To: ...*Cyprinus carpio*...

p. 188, 2nd full paragraph
From: ...(Campbell and MacCrimmon (1970...
To: ...(Campbell and MacCrimmon, 1970...

p. 308, 3rd line from bottom
From: ...(15.6) Could be below 60
To: ...(below 15.6) below 60

p. 391, 2nd full paragraph
From: ...in 2-4 bluegills...
To: ...in 2-4 in. bluegills...

p. 392, figure heading
From: ...for 2.4 in. bluegills...
To: ...for 2-4 in. bluegills...

p. 394, 1st full paragraph
From: ...see also p. for...
To: ...see also p. 18-19 for...

p. 405, table heading
From: ...various temperatures.
To: ...various temperatures.*

p. 412, table heading
From: ...acclimation temperatures
To: ...acclimation temperatures.*

p. 424, 1st entry in table
From: ...up to 23
To: ...(up to 23)...

p. 429, 1st citation
From: ...Javard, M.Y.,...
To: ...Javaid, M.Y.,...

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August 1975

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ACKNOWLEDGEMENTS

This Handbook is the result of work funded by the American Electric Power Service Corporation. Special thanks are due Mr. R. W. Reeves and Mr. T. A. Miskimen of the AEP Environmental Engineering Division for their encouragement during manuscript preparation.

Earlier drafts of the various sections of this Handbook were commented on by several members of the Department of Biology, University of South Florida, Tampa, Florida, including Dr. J. C. Briggs, Dr. B. C. Cowell, Mr. B. Harrington, Dr. J. M. Lawrence, and Dr. J. L. Simon. Their time and effort is greatly appreciated.

Thanks are also due to Ms. Barbara Jolly who typed the final copy from often illegible drafts, and to my wife, Bonnie, who helped in many ways to bring this project to completion.

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INTRODUCTION

Purpose & Scope

The American Electric Power Service Corporation provides technical support for the construction and operation of power plants in the American Electric Power System. Responsibilities include initiation and management of numerous ecological studies undertaken to evaluate possible impact of power plant operation on aquatic and terrestrial biota. This effort has also included reviews of the scientific literature. Information obtained has aided in interpreting data collected in the field, and is helping to project possible impact of future power generating facilities. This Handbook includes findings to date on many of the fish species reviewed (Table I-1).

This is an evolving document. Release at this time does not imply completeness, only a decision to make these findings available to others at a time of intense activity under section 316(a) of the Water Pollution Control Act Amendments of 1972 (Public Law 92-500) (Act). Its printing by AEP represents the most rapid means of providing this wider public access, though this same speed has precluded critical review of the final manuscript by others. Thus the Handbook represents my unedited appraisal of the literature, with all errors remaining my responsibility alone. Suggestions for improvement will be greatly appreciated.

The Handbook is intended to be a guide to the literature, providing complete referencing for each statement made. Such referencing hopefully will aid the reader in locating original articles. Readers are urged to do this because the large number of fish treated has precluded giving details regarding the studies cited. As a partial

Table I-1. Taxonomic list of fish species reviewed including scientific and common names, and the abbreviations used for figure and table titles in each species section.

Classification	Common Name	Figure and Table Abbreviation
Family Clupeidae		
Alosa pseudoharengus (Wilson)	Alewife	PS
Family Salmonidae		
Coregonus clupeaformis (Mitchill)	Lake whitefish	CL
Coregonus hoyi (Gill)	Bloater	HO
Oncorhynchus kisutch (Walbaum)	Coho salmon	KI
Salmo gairdneri Richardson	Rainbow trout	GA
Salmo salar Linnaeus	Atlantic salmon	SA
Salmo trutta Linnaeus	Brown trout	TR
Salvelinus namaycush (Walbaum)	Lake trout	NA
Family Osmeridae		
Osmerus mordax (Mitchill)	Ranbow smelt	MO
Family Cyprinidae		
Campostoma anomalum (Rafinesque)	Stoneroller minnow	AN
Clinostomus funduloides Girard	Rosy dace	FU

Table I-1 (Continued)

Classification	Common Name	Figure and Table Abbreviation
Cyprinus carpio Linnaeus	Carp	CA
Exoglossum laurae (Hubbs)	Tonguetied minnow	LA
Exoglossum maxillingua (Lesueur)	Cutlips minnow	MA
Nocomis leptocephalus (Girard)	Bluehead chub	LE
Nocomis micropogon (Cope)	River chub	MI
Nocomis platyrhynchus Lachner and Jenkins	Bigmouth chub	PL
Notemigonus crysoleucas (Mitchill)	Golden Shiner	CR
Notropis albeolus Jordan	White shiner	AL
Notropis analostanus (Girard)	Satinfin shiner	AA
Notropis ardens (Cope)	Rosefin shiner	AR
Notropis ariommus (Cope)	Popeye shiner	AI
Notropis atherinoides Rafinesque	Emerald shiner	AT
Notropis cerasinus (Cope)	Crescent shiner	CE
Notropis chrysocephalus Rafinesque	Striped shiner	CH
Notropis galacturus (Cope)	Whitetail shiner	GL
Notropis hudsonius (Clinton)	Spottail shiner	HU

Table I-1 (Continued)

Classification	Common Name	Figure and Table Abbreviation
Notropis photogenis (Cope)	Silver shiner	PH
Notropis procne (Cope)	Swallowtail shiner	PR
Notropis rubellus (Agassiz)	Rosyface shiner	RU
Notropis scabriceps (Cope)	New River shiner	SC
Notropis spilopterus (Cope)	Spotfin shiner	SP
Notropis telescopus (Cope)	Telescope shiner	TE
Notropis volucellus (Cope)	Mimic shiner	VO
Pimephales notatus (Rafinesque)	Bluntnose minnow	NO
Rhinichthys atratulus (Hermann)	Blacknose dace	AU
Rhinichthys cataractae (Valenciennes)	Longnose dace	CT
Semotilus atromaculatus (Mitchill)	Creek chub	AO
Family Catostomidae		
Catostomus catostomus (Forster)	Longnose sucker	CM
Catostomus commersoni (Lacepede)	White sucker	CO
Hypentelium nigricans (Lesueur)	Hog sucker	NI

Table I-1 (Continued)

Classification	Common Name	Figure and Table Abbreviation
Family Ictaluridae		
Ictalurus nebulosus (Lesueur)	Brown bullhead	NE
Ictalurus punctatus (Rafinesque)	Channel catfish	PU
Noturus insignis (Richardson)	Margined madtom	IN
Pylodictis olivaris (Rafinesque)	Flathead catfish	OL
Family Centrarchidae		
Ambloplites rupestris (Rafinesque)	Rockbass	RP
Lepomis auritus (Linnaeus)	Redbreast sunfish	AS
Lepomis cyanellus Rafinesque	Green sunfish	CY
Lepomis gibbosus (Linnaeus)	Pumpkinseed	GI
Lepomis megalotis (Rafinesque)	Longear sunfish	ME
Micropterus dolomieui Lacepede	Smallmouth bass	DO
Micropterus punctulatus (Rafinesque)	Spotted bass	PN
Micropterus salmoides (Lacepede)	Largemouth bass	SL
Pomoxis annularis Rafinesque	White crappie	AF
Poxomis nigromaculatus (Lesueur)	Black crappie	NG

Table I-1 (Continued)

Classification	Common Name	Figure and Table Abbreviation
Family Percidae		
Etheostoma blennioides Rafinesque	Greenside darter	BL
Etheostoma flabellare Rafinesque	Fantail darter	FL
Etheostoma lepidum (Baird and Girard)	Greenthroat darter	LP
Etheostoma osburni (Hubbs and Trautman)	Finescale saddled darter	OS
Etheostoma spectabile (Agassiz)	Orangethroat darter	SE
Percina caprodes (Rafinesque)	Logperch	CP
Perca flavescens (Mitchill)	Yellow perch	FA
Percina maculata (Girard)	Blackside darter	MU
Percina crassa (Jordan and Brayton)	Piedmont darter	CS
Percina oxyrhyncha (Hubbs and Raney)	Sharpnose darter	OX
Percina sciera (Swain)	Dusky darter	SI
Family Cottidae		
Cottus bairdi Girard	Mottled sculpin	BA
Cottus carolinae (Gill)	Banded sculpin	CI

solution brief discussion is often provided and numerous tables and figures from the original articles have been included, thus enabling the reader to extract additional pertinent information and providing an opportunity to make independent assessment of data presented. However these inclusions by no means fully compensate for the condensed treatment given.

The Handbook is an attempt to provide coverage of temperature related life history data for a number of North American fishes. The choice of species reviewed has been dictated by multiple considerations, but includes cold, cool and warmwater fishes variously categorized as sport, commercial or forage species, and several also considered threatened in certain states. Because of past regulatory agency emphasis on effects of high temperatures, it is these effects which are stressed here. For more detailed treatment of effects of cold water and/or rapid temperature drops, the reader is directed to the references cited below.

Many associations between temperature and fish life history are cited in the material which follows, though it should be understood that the reported associations may not always be causally related. Establishment of causality involves sophisticated multivariate laboratory analyses. These have seldom been performed for even a single life history stage. While the idea of environmental variables interacting in various ways to modify the influence of each other is simple, the testing facilities required and the analytical procedures used in data analysis are not. Alderdice (1971) has discussed the merits of multivariate analysis and has reviewed procedures and results.

No attempt has been made here to review how exotic chemicals influence temperature responses, or how temperature might modify chemical toxicity, and only brief mention is made of studies where chemical composition of natural waters has been found to modify a fishes response to temperature. Cairns et al. (1973) have reviewed recent literature on effects of temperature on chemical toxicity.

Available Literature

Thermal effects studies are becoming a major research area (Morgan and Franzreb, 1970). This activity has led to the publication of several bibliographies which consider effects of heated water on fish, including those by Trembley (1960, 1965), Committee on Thermal Pollution (1967), Mackenthun (1967), Kennedy and Mihursky (1967), and several revisions of a bibliography by Raney and co-workers (Raney and Menzel, 1967, 1969), with their most recent effort (Raney et al., 1973) providing the most complete coverage available through 1972. In addition a series of annotated bibliographies of thermal effects literature have been published (Morgan and Franzreb, 1970; Morgan and Coutant, 1972; Morgan, 1973), and a series of annual literature reviews prepared (Coutant, 1968, 1969, 1970a, 1971; Coutant and Goodyear, 1972; Coutant and Pfuderer, 1973a, 1973b, 1974). A number of significant reviews of the effects of temperature on fish are also available (e.g., Brett, 1956, 1970a; Gunter, 1957; Mason, 1962; Fry, 1947, 1964, 1967, 1971; Kinne, 1963; Naylor, 1965; Wurtz and Renn, 1965; Parish, 1967; Thomas, 1967; Rainwater, 1968; DeSylva, 1969; EPA, 1973b; National Academy of Science-National Academy of Engineering (NAS), 1973; see also references to effects of temperature on fish physiology in sections below).

Several data sources organized by species are available which consider temperature effects including compilations of fish life history information by Carlander (1969), and Scott and Crossman (1973). Modes of reproduction in fishes, including temperature considerations, were evaluated by Breder and Rosen (1966), and tabulated data on spawning requirements of some fishes compiled by Wojtalik (unpublished; cited in NAS, 1973). Tabulations by species are also available of temperature preference (Ferguson, 1958; Coutant, 1974), and tolerance (e.g., Altman and Dittmer, 1966; DeSylva, 1969; Brett, 1970a:524-527; EPA, 1973b; NAS, 1973).

In spite of the considerable literature which has accumulated, there has been no attempt to develop a handbook devoted to in-depth treatment by species of various aspects of temperature effects. Perhaps the nearest approach has been the preparation of succinct fish temperature data sheets on life history stages of various species by the National Water Quality Laboratory at Duluth, Minnesota (EPA, 1974), for apparent inclusion in a revision of EPA's (1973a) proposed Water Quality Criteria. Unfortunately the data sheets presently cover a limited number of species, their breadth of coverage is necessarily restricted, and there is no discussion given of methods or results, etc., and there is no visual presentation of data. Therefore, these data sheets also fall short of providing comprehensive information on the effects of temperature on even the treated species. It was in light of such limitations that the present Handbook was developed.

General Concepts and Definitions

Prior to reviewing the effects of temperature on individual species a number of relevant concepts and definitions are presented. Following brief initial remarks, more detailed consideration is given to those concepts of particular importance to an understanding of material presented in the review.

The prominance of temperature as an environmental variable of ecological importance to fish has been long recognized. Despite this recognition there are few instances where the distribution of a species has been indisputedly linked with temperature as the governing factor (Brett, 1970a:558). It does appear however that temperature tolerance of juvenile and older fish may correlate with, but rarely define, limits of distribution, particularly for upper lethal temperatures which may occur 4 to 7 C (7.2 to 12.6 F) above ambient levels (Brett, 1969, 1970a:530). Greater sensitivity occurs in the embryonic stage, affecting hatching and larval survival. Furthermore, the dispersal of adults and the nature of spawning migrations is undoubtedly influenced by the relatively stenothermal characteristics of early developmental stages (Brett, 1969).

Fish are typically poikilothermic animals, unable to regulate their body temperatures. In aquatic environment where fish are exposed to various and changing temperatures, their internal body temperatures reflect those external changes, though with some time delay (Fry, 1967:381). Because of the all-pervading nature of environmental temperature, the fundamental thermal requirement of fishes is an external environmental temperature most suitable to their internal tissue (Brett, 1956), and other organizational levels. That this temperature may not be limited to a few degrees is said to attest to the extent to which the poikilotherm has been able to evolve body functions which can maintain adequate roles despite variations in body temperature (Brett, 1956).

With respect to accommodations made by fish to changing environmental temperatures, three levels of adjustment are described. First is acclimation, the artificial stabilization of some aspect of the immediate environmental history by controlled laboratory conditions (Fry, 1967:376), e.g., temperature,and the achievement by the animal of a physiological steady state response. If on the other hand the fish has lived under natural conditions in the environment, the animal is said to be acclimatized, again physiologically adjusted, but this time to the myriad of interacting environmental variables which influence fish. According to Fry (1971:15) the most significant aspect of acclimatization as opposed to acclimation is that acclimatization allows the organism to acquire an adjustment, say to higher temperature, in advance of the event if that event is appropriate to the seasonal cycle. This acclimatization provides for anticipatory adjustment as well as reactive adjustment.

To the ecologist acclimatization may also have a phylogenetic implication at the subspecific level. In each locality, with its unique environment, a species is subject to different selective pressures as well as to any different ontogenetic influence which bears on the successful individuals (Fry, 1971:15). Mayr (1970:111) has also commented upon the extraordinary sensitivity of the selective response of animals to slight changes in the environment. The extreme sensitivity of the genotype to environmental conditions is said not to be doubted, even in cases where the variability differences are not expressed in the genotype. Phylogenetic adjustments occurring over long periods are considered adaptations by Fry (1967:376).

The precise role which temperature accommodations play in influencing fish success in the environment is illuminated by examining several classifications of fish-environmental interrelations. In 1947, Fry tentatively proposed six categories of effect which the environment may have on the individual: lethal factors, masking factors, directive factors, controlling factors, limiting factors, and accessory factors. In a more recent treatment (Fry, 1971) this number was reduced to five by elimination of the last effect category. Temperature as an environmental factor interacting with the whole organism has been considered in detail by Fry (1967) under the first three effect categories and it is these categories which are examined here. Briefly, temperature may act as a lethal factor when it destroys the integrity of the organism and restricts the range of the environment in which the organism can exist. Temperature may also act as a controlling factor when it acts upon the activity of an organism, an effect which is mediated through the influence of temperature on the rate of biochemical reactions and thus metabolic rate. Lastly, temperature may also act as a directive factor when it influences the spontaneous movements of the organism. These factors are examined in greater detail in the next section.

Another classification is used by Hoar (1966:314-321) who considers three mechanism for thermal responses to temperature: biochemical, neuroendocrine, and behavioral. The biochemical mechanisms underlying acclimation, more fully discussed by Hochachka and Somero (1971) and Somero and Hochachka (1971) are described in summary form in Table I-2. It can be seen that acclimation may involve

Table I-2. Biochemical changes associated with temperature acclimation in poikilothermic organisms*.

Constituent	Change
Enzymes	Different variants in winter and summer rainbow trout
Lipids	Changes in saturation, chain length and quantity of lipid
Metabolic pathways	Increases in activities of pathways associated with biosynthesis in cold-acclimated fish, e.g., increase in hexose monophosphate shunt
Protein synthesis	Change in rate
Nucleic acid synthesis	Change in rate
Blood ions	Changes in relative concentrations
Tissue ions	Same as above
Ribosomes	Differences in ribosome melting temperatures between summer and winter trout
Hemoglobins	Changes in O_2 affinity likely due to changes in modulator concentrations

*From Somero and Hochachka (1971). See Hochachka and Somero (1971) and Precht (1968) for literature dealing with these topics.

profound restructuring of the organism at the molecular level. While mechanism of thermal acclimation at the molecular level are multiple, they are not clearly understood (Prosser, 1973:386). The way in which biochemical changes are initiated in the acclimation process, whether by direct action of temperature at the cellular level, or by nervous or hormonal stimulation is also unclear (Prosser, 1973:386). Evidence for hormonal control of temperature acclimation in fish is said by Prosser (1973:386) to be either contradictory or lacking, though the nervous system is said to play a key role in behavioral and locomoter adaptations, including general activity, kineses, maximum swimming speed, and temperature selection.

Precht (1958, 1967) utilizes a classification based upon homeostatic mechanism, emphasizing that the responses to temperature can be of a different nature for temperatures within the normal range of organism exposure (capacity adaptations), as opposed to respones to temperature extremes (resistance adaptations).

Application of Concepts

Regulations designed to protect fish consider whether the fish can survive and prosper, they are not as concerned with how this is accomplished. Emphasis in the review is therefore given to whole organism responses to temperature, not to the processes which underly them. This being the case, the classification of Fry is most useful, though it should be clear that the classification scheme used by Hoar (1966) underlies organism response to these factors, and that responses temperature extremes can be of a different nature from those to temperatures within the normal range of experience (Precht, 1958, 1967).

Lethal Temperatures and Resistance

Two methods are commonly used in lethal temperature studies. In one (slow heating) method the temperature in the test bath is slowly raised from the acclimation temperature at a constant rate until death occurs, while in the other (rapid transfer) method fish are transferred directly from the acclimation temperature bath into baths at temperatures felt to be lethal and the times to death noted. Various authors have discussed the merits of these two methods (e.g., Fry, 1947, 1967; Hoar, 1966:297-298; Nickum, 1966:5-7; Coutant, 1970b). While a number of authors have used the slow heating method for at least some of their lethal temperature determinations, it appears that the rapid transfer method provides a firmer basis for physiological analysis in the more detailed pattern of response it yields (e.g., Fry, 1967), and resultant improved predictive utility (Coutant, 1970b). The majority of lethal temperature studies cited in the Handbook used the rapid transfer method and use of this method can be assumed unless special note is made.

According to Hart (1952) investigators have determined resistance times for samples of fish by calculating the temperature at which a given percentage survive a given length of time (e.g., Hathaway, 1927), the average survival time at a given constant temperature (e.g., Loeb and Wasteneys, 1912), or the geometric mean survival time at a given constant temperature (e.g., Fry et al., 1946). The method of Fry et al. is most commonly followed.

Fry et al. (1946) also provide what are considered standard definitions for use in temperature studies:

> "The range of any environmental factor in which life of an organism is possible at all may be divided into two zones. Within certain limits the animal can live indefinitely. We proposed to call this zone the <u>zone of tolerance</u>, and levels demarcating this zone the <u>upper</u> and <u>lower incipient lethal levels</u> respectively. At levels beyond the zone of tolerance the organism will be able to exist for a period of time that will depend on the level of the lethal factor. The length of time that an organism can resist the effects of a level of an environmental factor which is beyond its zone of tolerance we propose to call the <u>resistance time</u>. Applying these general definitions to temperature in particular we propose to speak of a zone of thermal tolerance bound by <u>upper</u> and <u>lower incipient lethal</u> temperatures and a zone of thermal resistance beyond these temperatures." (p.9)

The zone of thermal tolerance is often visually presented as a <u>lethal temperature polygon</u> which bounds the zone of tolerance for (usually) 50% of the experimental population.

A number of variables can influence the lethal temperature of a species, including abiotic and biotic influences, as well as procedural details. Considering the first two sources of variation, studies in general suffer from inattention to at least one of the following influences: chemical composition of the water, genetic background of the fish, its age, size, sex, reproductive condition, nutritional state, or the season or photoperiod under which the testing occurred. It is now known that these details can influence lethal temperature (Coutant, 1970b; Prosser, 1973:373). The predictive utility of conclusions drawn from such incomplete accounts are correspondingly reduced.

The procedural details influencing lethal temperatures have been most thoroughly discussed by Brett (1952) and Fry (1971). These papers should be consulted for methods of testing and data analysis. Procedural variables include the <u>acclimation temperature</u> of the fish. Typically, a change in acclimation temperature of 3 C increases the lethal temperature by 1 C (Fry, 1971:28), though a point is eventually reached when an increase in acclimation temperature no longer increases the lethal temperature and a tolerance plateau results. This lethal temperature is designated the ultimate upper incipient lethal temperature. However, as pointed out by Fry (1971:27), it is typical for thermal resistance to continue to increase with acclimation temperature beyond the point where there is no further change in thermal tolerance.

The time allowed for acclimation to be achieved prior to lethal temperature determination also influences the final result. Brett (1970a:532) states that the rate of acclimation in terms of increased heat tolerance is apparently set by the level of the new temperature and is exponentially related to time, being most rapid at the start. Acclimation rates for several fish have been tabulated by Brett (1970a:531). Should testing begin prior to completing the necessary acclimation period, results incorrectly portray tolerance or resistance at the stated acclimation temperature.

Test duration is another consideration which influences the lethal temperature. Prosser (1973:368) states that after about 48-hours no further death occurs, and Fry (1971:23) states that this test duration is most often used, but that a 96-hour test period is more widely approved. However, several workers have noted mortality well beyond a 96-hour test duration. Recognizing that there is no finality to the incipient lethal temperature short of maintaining the test throughout the whole life of the organism, Fry (1971:20) suggests the incipient lethal temperature should be looked on as the boundary of the immediate direct lethal effects, "immediate" being taken as a matter of days or weeks, and "direct" as the operation of temperature directly on a site of metabolism so as to destroy it more rapidly than the organism can keep it in repair.

As an aid in comparing results of lethal temperature tests using differing exposure durations of less than 72 hours, Brett (1970a:523) has provided a table for adjusting lethal temperatures to a common 72-hour exposure time. Adjustments have not been made in data presented here.

Sublethal Indicators of Thermal Stress

In an effort to provide protection for fish, more restrictive constraints on water temperatures are needed than those protecting half of the experimental population from mortality within a few days. Several approaches have been advanced which attempt to arrive at sublethal temperature stress responses which signal impending temperature induced alterations in either immediate potential for survival or longterm changes in population dynamics. One such avenue of research has involved use of equilibrium loss as an indicator of stress. With this as the endpoint, results of several methods of investigation are available. One, determination of the *critical thermal maximum* (CTM), involves slow heating of the experimental animal until equilibrium loss. While results reflect two variables, time and temperature, only temperature is used as an endpoint. In contrast, the *equilibrium loss dose* (ELD) is derived using methods outlined by Fry et al. (1946) for calculation of resistance times, and involves reporting of both temperature and time to loss of equilibrium. Coutant and Dean (1972) have reviewed the relative merits of the two methods, and consider the ELD the better measure of response because both the experimental method and the system of reporting such doses are well established in fisheries literature and have their basis in the statistical analyses of pharmacology (Bliss, 1937; cited in Coutant and Dean, 1972).

Coutant (1973) has also examined another sublethal effect, vulnerability of thermally stressed fish to predation by unstressed predators. A stress still further removed from lethal temperature, altered feeding behavior of competing species exposed to temperature increases has also received preliminary attention (Bowen and Coutant, 1973). Growth, also related to temperature, is discussed separately below.

Each of the three sublethal stresses, equilibrium loss, vulnerability to predation, and altered feeding behavior, has been examined in only a few species and should receive further attention if regulations derived from these stress responses are to reflect real needs of species inhabiting widely different aquatic environments.

Activity and its Relationship to Metabolism

In studies of fish responses to temperature change, Fry (1971:2) makes the careful distinction between metabolism and activity. Fry considers metabolism to be the sum of the reactions yielding energy which the organism utilizes, while activities are a general category of response by which energy derived from metabolism is utilized. By these definitions, activities include such processes as swimming, fighting, or other manifestations of energy released by metabolism. These manifestations are not all movements, for example, growth is activity, and so is excretion. From this it follows that oxygen consumption during a performance test such as swimming does not represent energy expended for that activity alone, because other activities such as maintenance continually take their toll of available energy reserves. Nevertheless, it has been found possible to arrive indirectly at energy expenditure for performance by considering several levels of energy use. A measure of *standard metabolism* represents oxygen consumption requirements necessary to maintain all life processes at zero exertion. If the test animal is then required to exert itself at a maximum sustained level, a measure of *active metabolism* is obtained. The energy available for external work (e.g., swimming) can be derived by deducting standard metabolism from active metabolism. This provides a measure of metabolic *scope for activity*.

When exposed to rapid temperature changes, most poikilotherms acclimated to a specific temperature show a similar series of metabolic responses. Grainger (1958) described these changes, and Prosser (1973:374-376) has retained this scheme. Accordingly, three responses, often measured by oxygen consumption, occur over time. Following an abrupt temperature rise there is an initial *overshoot* or shock reaction lasting seconds or minutes. After the initial reaction to temperature change, a stabilized state is achieved at a somewhat lower level. This state may last for "many hours" and it is usually during this time that (*routine metabolism*) rate determinations are made (Prosser, 1973:374). Finally, if the animal is left at the same altered temperature for many days, its rate functions show further reductions and the animal is said to be acclimated (Prosser, 1973:375).

Not all animals acclimate according to the pattern described above. Precht (1958) presented a scheme for comparing rate function patterns at two acclimation temperatures, and Prosser (1958, 1973; Prosser and

Brown, 1961) added the dimension of Q_{10} by depicting rate functions during the stabilized state over the entire temperature range (Prosser and Brown, 1961:245).

Other variables influence metabolic rate in addition to temperature. A list of seventeen such variables is provided by Brett (1970b) along with a statement of the extent of possible influence.

In the past, temperatures preferred (selected) by fish were not seen to have a consistent relationship to activity. Sullivan (1954) then stated that the rate at which temperature changed appeared to be very important in evaluating the relationship between activity and temperature selection, rapid temperature changes producing a minimum of activity at the selected temperature, while slow rates of change produced a maximum activity at the selected temperature. Fry (1971:82) indicates that this distinction made by Sullivan was important because it differentiated the influence of temperature acting as a directive factor in a rapidly changing environment, while acting as a controlling factor at various constant or slowly changing temperatures. These remarks are interpreted here to mean that a fish in a thermal gradient will show least directional movement in the area of the thermal preference (selection), thus retaining position in the desired temperature interval. For a fish exposed to either separate constant temperatures or to slowly changing temperatures, in which the fish is permitted to come into equilibrium with the ambient temperatures, spontaneous movement is greatest at the preferred temperature, where the animal reacts most vigorously to any stray stimuli (Fry, 1971:83). Variables reported to influence preferred temperature include season (Sullivan and Fisher, 1953), nutritional state (Javaid and Anderson, 1967), and age of fish

(Ferguson, 1958). Acclimation temperature also influences the preferred temperature, most often increasing with acclimation temperature until the final preferendum, that temperature at which the preferred temperature is equal to the acclimation temperature (Fry, 1947). According to Fry it is at this preferendum that fish of a species will ultimately congregate, regardless of their prior thermal experience.

The general effect of the increase in activity associated with temperature acting as a controlling factor is to produce a central horizontal section or even a dip in the curve relating routine metabolism to temperature, or at least to make that curve decidedly convex on a semilogarithmic plot (Fry, 1971:82). This is due to the overlapping influence of increasing metabolic rate as a function of temperature and increased activity associated with the region of preferred (selected) temperature. Fry (1971:83) states that the activity increase has often been mistaken to provide evidence for a broad homeostatic response in the metabolic rate. In a more detailed discussion of this subject, Fry and Hochachka (1970:84-90) state that an impression may be gained from the literature concerning metabolism of the whole organism that temperature compensation may greatly reduce the Q_{10} below 2, but when standard metabolism has been measured in fish acclimated to each temperature, such is not the case (Fry and Hochachka 1970:90). While there have certainly been compensations in metabolic rate, it is said (Fry and Hochachka, 1970:88) compensations in spontaneous activity probably overshadow physiological compensations underlying them.

Growth

Brown (1957) discussed a number of variables which influence fish growth, including temperature. In a more recent review evaluating effects of temperature on fish, Brett (1970a:546) has stated that in the absence of limiting factors, growth is a multiplicative process which under ideal conditions follows an exponential curve, though in actuality the overall configuration is said to generally follow the sigmoid shape of a logistic curve. With the exception of cases where food rations have not been provided above the maintenance level, increasing temperature enhances growth up to an optimum level beyond which moderate growth occurs, with reductions above this level resulting from increased energy requirements for food conversion (Brett, 1970a:545).

Beamish and Dickie (1967) have discussed fish growth in relation to metabolism, and Warren and Davis (1967) have made the further attempt to quantify bioenergetics of growth. The concept of scope for growth is introduced in the latter paper, and is more extensively discussed by Warren (1971:145-150). As defined by Warren (1971:148) scope for growth is the difference between the energy value of all the food an animal can consume and the energy value of all uses and losses of food other than growth under a particular set of environmental conditions. The concept emphasizes that growth is just one manifestation of activity (as defined by Fry, 1947), and while not equivalent to scope for activity, use of the concept enables consideration not only how temperature might influence metabolism, but also how it might interact with food availability in determining the bioenergetics and growth of the organism (Warren, 1971:148). Unfortunately, because of its recent development, few studies have benefited from application of this concept.

In an approach advocated by NAS (1973), net biomass gain or net growth is used as a measure of growth rate. According to McCormick et al. (1972) net biomass gain is derived by subtracting weight lost through mortalities within a test lot from weight gained by members of the test lot.

Format for Species Coverage

The distribution of each species is given first. Either alone or in conjunction with temperature related life history information, distributional data provide a clue to a species temperature relations (Brett, 1969, 1970a:530; see also previous discussion).

Fish are then evaluated according to life history stage in the following sequence: Spawning (adults), Eggs, Larvae, Juveniles, and (non-spawning) Adults. In those instances when a paper did not make clear the life history stage being considered, or when discussion was of the species in general, information has been placed in a separate General and Unspecified section. An exception has been in discussing growth studies. While most fishes have the capacity for sustained though diminishing growth throughout their lives (Lagler et al., 1962:172), growth studies using fish of unspecified age have been included in the Juvenile section.

When a paper provided the age/size/and/or weight of the fish under discussion, but made no statement whether it was a juvenile or adult, an attempt has been made to place the discussion under the correct life history category. The criteria used in this judgement is frequently included, thereby enabling independent assessment of the choice made.

During early efforts to review the literature all temperatures reported in degrees Centigrade were converted to degrees Fahrenheit. That decision was a poor one not only because Centigrade is the proper scientific notation, but also because each conversion results in an increased rounding error. By the time several authors have converted and reconverted data, the temperature may be one or two degrees Centigrade away from that reported in the original paper. When possible, each paper has been reexamined and the original temperature notation given. A temperature conversion is then provided in parentheses, being obtained from a table in Dunathan and Ingle (1968). In that table, when a tenth of a particular degree Centigrade appeared in two Fahrenheit columns (e.g., 10.1 C = 50.1 F and 50.2 F), the higher Fahrenheit temperature has been used. In those instances when a paper could not be reexamined a single temperature appears in degrees Fahrenheit.

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ALEWIFE

Distribution

The alewife is an anadromous species of eastern North America, a marine fish that uses freshwater streams for spawning, and hence is indigenous to the lakes and streams of the Atlantic coastal drainage from Newfoundland to North Carolina. It is now also landlocked in many inland lakes (Scott and Crossman, 1973:14).

Spawning

Spawning may occur between April (e.g. Graham, 1956) and late August (Odell, 1934; cited in Carlander, 1969:74) in water temperatures ranging from 13 C (55.4 F) (Rounsefell and Stringer, 1943; Threinen, 1958; both cited in Carlander, 1969:74) to just below 82 F (27.8 C) (Edsall, 1970).

The spawning time for various locations cited in the literature is given in Table PS-1, and the spawning temperatures are given separately in Table PS-2.

Eggs

According to studies cited in Carlander (1969:74) and Edsall (1970), incubation times for alewives decrease with increasing temperature, though the data, gathered under diverse conditions, certainly do not present a consistent progression (Table PS-3).

In his study using a variety of incubation temperatures, Edsall (1970) found that the incubation time varied from 15 days (360 hours) at 45 F (7.2 C) to 3.7 days (89 hours) at 70 F (21.1 C), and 2.1 days (50 hours) at 84 F (28.9 C). These data are presented in Figure PS-1.

Table PS-1. Alewife spawning times at various locations.

Date	Location	Comment	Author
March - June	Bride Lake, Conn.	Spawning run	Kissil, 1974
Early - Mid April	Lake Mattamuskeet, N.C.	Spawning run	Tyus, 1974
April and June			Wyman, 1856*
April through August	Lake Ontario		Graham, 1956
Late May - June	New Jersey		Gross, 1959**
Late May - Early August	Lake Ontario		Pritchard, 1929
Early June	Pond in New York		Flick and Webster, 1968**
Early June-Late August	Finger Lakes, New York		Odell, 1934**
June and July	Lake Michigan		Edsall, 1964, 1970
June or July	Ohio		Trautman, 1957
Late June	Lake Erie	Hatching	Commercial Fisheries Review, 1961
Late June - Early July	Lake Cayuga, New York		Galligan, 1962

*Cited in Breder and Rosen (1966:86).

**Cited in Carlander (1969:74).

Table PS-2. Alewife spawning temperatures.

Temperature C	F	Comment	Author
(6.7)	44	Spawning migrations begin	Cooper, 1961 ***
(10-15.6)	50 - 60		Data cited in Breder and Rosen, 1966:86
10	(50.0)		Saila et al., 1972
(12.8-15.6)	55 - 60		Bigelow and Shroeder, 1953*
12.9-13.1	(55.3 - 55.6)	Spawning run peak	Tyus, 1974
13 - 16	(55.4 - 60.8)		Threinen, 1958**
13 - 21	(55.4 - 69.8)		Rounsefell and Stringer, 1943**
15.6 - 26.7	60.0 - 81.0		Edsall, 1970
17 - 19	(62.6 - 66.2)		Gross, 1959**
(20.6 - 21.1)	69 - 70	Spawning migrations ceased	Cooper, 1961***
(22.2)	72	Hatching	Commercial Fisheries Review, 1961
(22.8)	73.0		Greeley, 1938***

*Cited in Breder and Rosen (1966:86,87)

**Cited in Carlander (1969:74)

*** Cited in Edsall (1970)

Table PS-3. Incubation times of alewife eggs held at various temperatures.

Temperature C	F	Incubation Time (hours)	Author
13	(55.4)	132	Odell, 1934*
15.5	(59.9)	48-72	Mansueti, 1956*
15.5	(59.9)	144	Rounsefell and Stringer, 1943*
(15.6)	60	144	Bigelow and Welsh, 1925**
(20)	68	72-120	Mansueti and Hardy, 1967**
22	(71.6)	48-96	Rounsefell and Stringer, 1943*
(22.2)	72	48-96	Belding, 1921**
23	(73.4)	81	Odell, 1934*

*Cited in Carlander (1969:74).

**Cited in Edsall (1970)

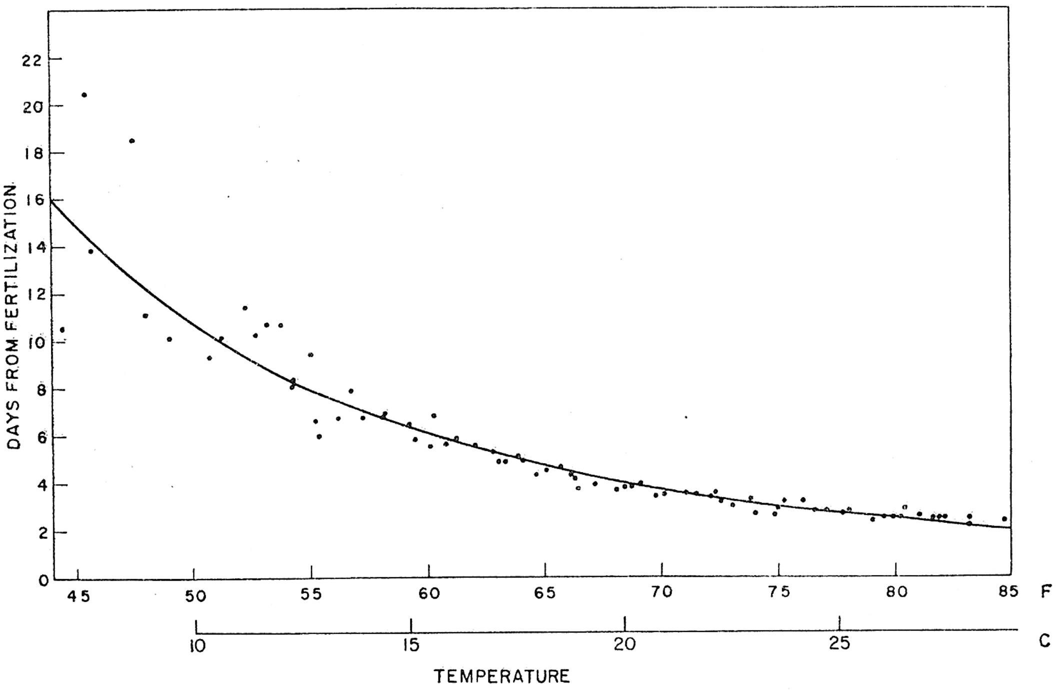

Figure PS-1. Incubation times of alewife eggs at various temperatures. From Edsall, 1970.

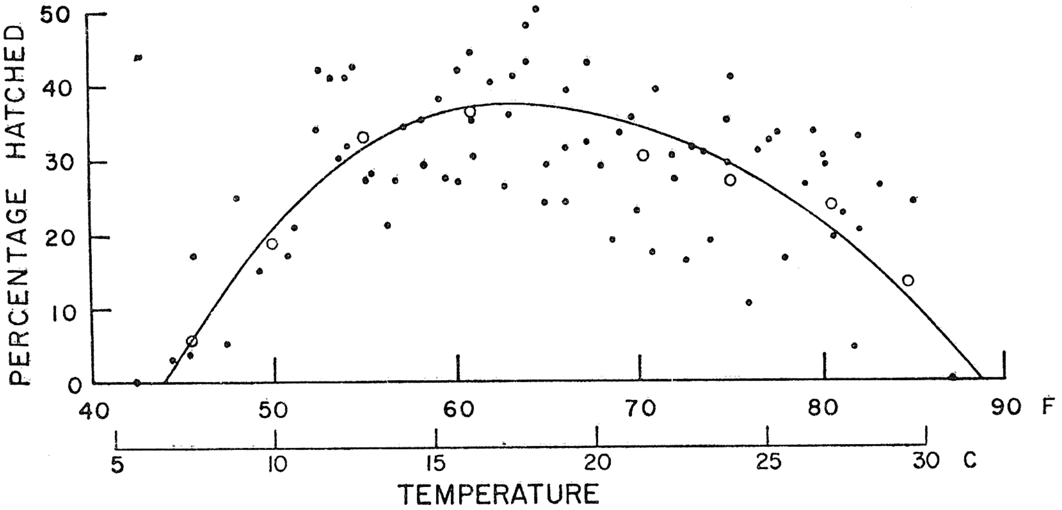

Figure PS-2. Percentage of alewife eggs hatched at various temperatures. Curve fitted by inspection. From Edsall, 1970.

For eggs incubated at temperatures from 42.1 to 87.0 F (5.1 to 30.6 C), Edsall (1970) found that hatching occurred between 44.4 and 84.9 F (6.9 and 29.4 C) and was optimal (38% hatched) at about 64 F (17.8 C). A considerable percentage survived only at incubation temperatures between 50 and 80 F (10 and 26.7 C). Edsall's (1970) data on egg survival are graphed in Figure PS-2.

Larvae

In laboratory tests (Edsall, 1970), survival of unfed larvae held at the above mentioned incubation temperatures increased from 3.8 days at 51 F (10.6 C) to 7.6 days at 58 to 59 F (14.4 to 15 C) and then decreased to 2.4 days at 80 to 82 F (26.7 to 27.8 C). At temperatures below 50 F (10 C) alewife larvae did not develop functional jaws, even though eggs hatched and larvae could live for a time at temperatures as low as 44.4 F (7.4 C) (Edsall, 1970).

Marcy (1971) examined survival of post yolk-sac larvae (97.5%) and early juveniles (2.5%) in the discharge canal of a nuclear plant in Connecticut. Two species of Alosa (A. aestivalis and A. pseudoharengus) composed 97.6% of the total catch. When taken into the plant at water temperatures of up to 22.2 C (72 F), survival was greatest for these two species, some of which were able to resist discharge temperatures of 28.2 C (82.8 F) for the 50-100 minute duration within the canal. From a similar intake temperature some fish were also able to resist 33.5 C (92.3 F) temperatures for about a fourth of the distance of down the canal (12.5-25 minutes?). However, when exposed to condenser temperatures of 35.5 C (95.9 F) and above, no speciments from intake temperatures of from 23.9 C to 30 C (75 to 86 F) survived even to the beginning of the discharge canal. The majority of dead specimens were mangled.

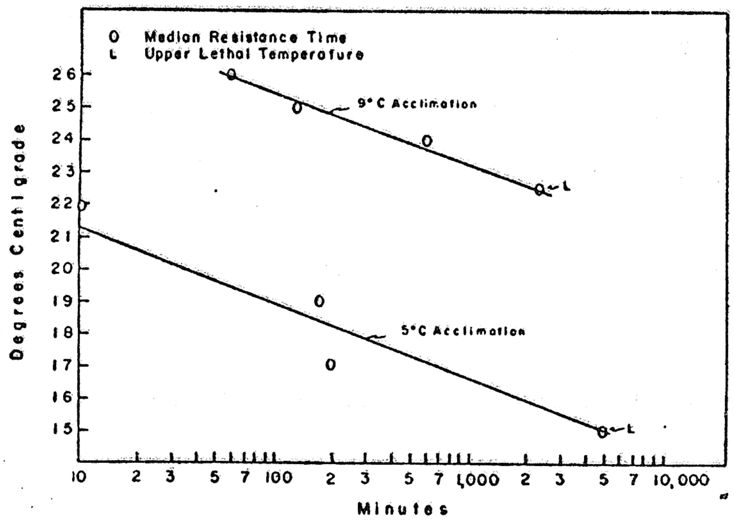

Figure PS-3. Lethal temperature relations of under-yearling alewives. From Graham, 1956.

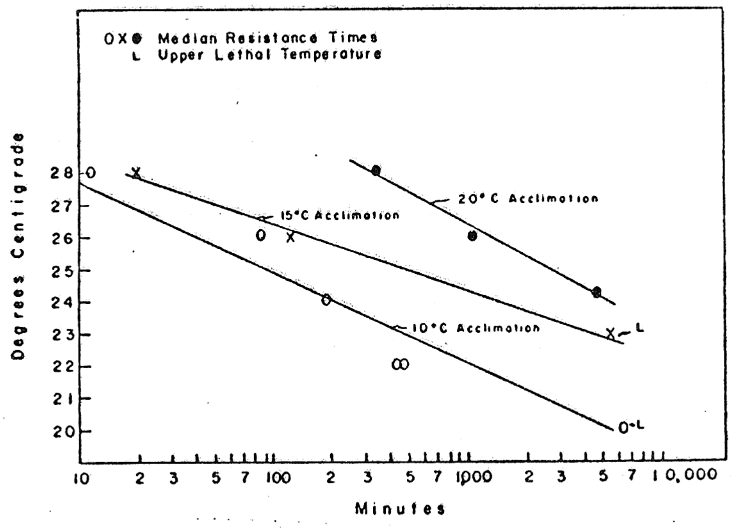

Figure PS-4. Lethal temperature relations of adult alewives. From Graham, 1956.

Juveniles

Dorfman and Westman (1970; cited in Coutant, 1971) report that in laboratory experiments some juveniles survived and fed at 94 to 95 F (34.4 to 35 C) and Commercial Fisheries Review (CFR) (1961) reports that in Lake Erie growth of young-of-the-year alewives terminates near the beginning of October when water temperatures are reduced to 65 F (18.3 C).

Young-of-year acclimated to 16 C (60.1 F) were exposed to stepwise temperature elevations of about 2.5 C (4.5 F)/day by Stanley and Colby (1971). The authors stated that within 24 hours alewives died in significant numbers regardless of the salinity of the water, when exposed to temperatures elevated to 31 C (87.8 F), though their data indicate some survival in one test lot at higher temperatures (31.2 C, 88.2 F). Test procedure precludes determination of temperatures producing various percent mortalities, and therefore the results cited here can only be used to approximate lethal temperatures as determined by conventional analyses.

Graham (1956) found that when under-yearling alewives were acclimated to 5 C (41 F), they had a resistance time of over three hours at 17 C (62.6 F) and a resistance time of 80 hours at 15 C (59 F); when acclimated to 9 C (48.2 F), they resisted 26 C (78.8 F) water for an hour and 22.5 C (72.5 F) water for 40 hours. Although not calculated exactly, the upper LT at acclimation temperatures of 5 and 9 (41 and 48.2 F) was felt to be about 15 C and 22.6 C (59 and 72.7F) respectively. Graham's (1956) data on under-yearlings are plotted in Figure PS-3.

Marcy (1971) examined survival of juveniles from higher ambient (acclimation?) temperatures. Because he failed to differentiate survival rates for the different life history stages, the discussion of this work given above (see Larvae section) must suffice.

Adult

Internal temperatures (mean of 20.8 to 21.8 C, 69.5 to 71.3 F) of (409) alewives collected in the discharge plume of Point Beach Nuclear Plant were found by Spigarelli et al. (1973) to be slightly lower (mean difference -0.3 to -1.1 C) than discharge water temperatures, indicating equilibrium had not occurred, and that the fish were at temperatures slightly above preferred levels.

Graham (1956) subjected adult alewives to lethal temperatures from acclimation temperatures of 10, 15 and 20 C (50, 59 and 68 F). At the lowest acclimation temperature the alewives resisted 24 C (75.2 F) water for about 3 hours, and at a 20 C (68 F) acclimation temperature, resistance was possible for over 5 hours at 28 C (82.4 E) and for about 80 hours at 24 C (75.2 F). His time-mortality curves for the adult alewives are given in Figure PS-4.

Graham (1956) also estimated that the alewives acclimated to 10, 15 and 20 C (50, 59 and 68 F) approached their upper incipient lethal temperatures at just above 20 C (68 F), just below 22.8 C (73 F), and about 22.8 C (about 73 F) respectively.

General and Unspecified

In Lake Cayuga, New York, Galligan (1962) found that alewives were most frequently collected at water temperatures between 42 and 65 F (5.6 and 18.3 C), while Wells (1968) found they were most abundant in

Lake Michigan water at temperatures from 8 to 22 C (46.4 to 71.6 F). Also in Lake Michigan, during summer, Reigle (1969:12) felt alewife distribution to be controlled by temperature, abundance decreasing with lowered temperatures. Few alewives were collected in areas where bottom temperatures were below 50 F (10 C).

Raney (1971), apparently elaborating on the findings of Meldrim and Gift (1971), has reported experiments testing preferred temperatures of alewives. In August, six specimens were acclimated at 77 F (25 C) for 48 hours. They were introduced into an experimental tank where the temperature was 74 F (23.3 C), and they were offered two alternatives, 74 or 82 F (23.3 or 27.8 C). They proceeded to the area and occupied water of 82 F (27.8 C). After a short period, these same six specimens were introduced into a similar experimental tank where the water temperature was 80 F (26.7 C), but where the alternative temperature of 86 F (30 C) was available. The latter temperature was avoided.

In another experiment (Raney, 1971), the results were similar. The fish were acclimated at 77 F (25 C), introduced into water of 75 F (23.9 C), and were attracted to water 83 F (28.3 C). A short time later the same fish were placed in water of 80 F (26.7 C). They avoided the alternative temperature which was 86 F (30 C).

Graham (1956) observed mortalities in Lake Ontario during spring when alewives moved from cool offshore waters onto shoals with surface temperatures between 17 and 19.6 C (62.6 and 67.3 F).

In May, Trembley (1960:IX-6) observed a school of alewives in 80 F (26.7 C) water in a heated water discharge on the Delaware River. When frightened into adjacent 83 F (28.3 C) water they proceeded to die of heat shock. Later in May the lagoon had a gradient of 83 to 92 F

(28.3 to 33.3 C) and alewives were in the coolest part of the lagoon (83 F, 28.3 C). They were tolerating (resisting?) the same temperature that had apparently brought heat death the previous week. This exemplified to Trembley the effect of sudden changes in temperature upon fish as opposed to gradual changes. When the alewives mentioned above were frightened into the hotter (92 F, 33.3 C) water, five of the 30 died, while others survived and regrouped in the 83 F (28.3 C) water (Trembley, 1960:IX-6).

In Canada's Maritime Provinces, Huntsman (1946) documented a fish kill, including alewives, when summer temperatures reached a daily maximum of 88.5 F (31.4 C).

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LAKE WHITEFISH

Distribution

The lake whitefish is widely distributed in North American fresh waters from Atlantic coastal watersheds in New England westward across Canada and the northern United States to British Columbia, the Yukon territory and Alaska (Scott and Crossman, 1973:270).

Spawning

Lake whitefish spawn between mid September and December (Table CL-1) at temperatures between 0.5 and 9.4 C (32.9 and 49.0 F) (Table CL-2). Based upon Lawler's (1965) study, the AEC (1972:A-47) concluded that spawning is in general delayed until water temperatures drop to approximately 46 F (7.8 C), with peak spawning at a somewhat lower temperature, though the U.S. Fish and Wildlife Service (USFWS) (1970:61; citing unpublished observations) stated that whitefish in the Great Lakes require a drop in temperature to 42 F (5.6 C) to initiate spawning.

According to Lawler (1965) spawning at temperatures above 43 F (6.1 C) is probably unsuccessful because of the slight chance for successful incubation as indicated by the observations of Wickliff (1933) and Price (1940) (both cited in Lawler, 1965).

Eggs

Wickliff (1933; cited in Carlander, 1969:122) found egg fertility (viability?) dropped significantly during mid spawning season when water temperatures rose from 5.5 to 8 C (41.9 to 46.4 F), and Price (1940) found that for eggs incubated at various constant incubation temperatures between 0 and 12 C (32 and 53.6 F), 6 C (42.8 F) was the maximum temperature at which normal development (10% abnormal embryos at

Table CL-1. Lake whitefish spawning times at various locations.

Date	Location	Comment	Author
September - October	Canadian "far north"		Van Oosten, 1956*
Mid September - Mid October	Great Slave Lake	Northern section	Rawson, 1947*
Beginning Early October	Great Slave Lake	Southern section	Rawson, 1947*
October	Bay of Quinte, Ontario	Spawning migration	Hart, 1930*
Late October - December	Montana		Bjorklund, 1953*
Late October - December	New York		Everhart, 1958*
Lake October - December	Lake Erie		Bean, 1903*
Early November	Bay of Quinte, Ontario	Spawning	Hart, 1930*
Early - Late November	Lake Erie		Faber, 1970
Early November - Early December	Lake Erie	Range	Lawler, 1965; and Wickliff,1933; cited in Lawler, 1965.
Mid November - Late December	Lake Michigan		Koelz, 1929
Late November	Lake Erie		Price, 1940

(continued)

*Cited in Carlander, 1969:121,122.

**Cited in Breder and Rosen, 1966:118.

Table CL-1. (Continued)

Date	Location	Comment	Author
November - Early December	Lake Erie		Fish, 1929a**, 1929b**, 1932; Van Oosten and Hile, 1947
November - December	Yukon Territory		Lindsey, 1963

Table CL-2. Lake whitefish spawning temperatures.

Temperature		
C F	Comment	Author
0.5 - 1.7 (32.9 - 35.1)		Eddy and Surber, 1947*, Katz, 1954*
0.5 - 4.5 (32.9 - 41.1)		Slastenenko, 1958*
(2.2 - 9.5) 36 - 49	Range	Wickliff, 1933; cited in Lawler, 1965
(3.9 - 9.4) 39 - 49	Range	Lawler, 1965
4.3 - 8.7 (39.8 - 46.7)		Faber, 1970
4.5 (40.1)		Bean, 1903*
4.5 - 10 (40.1 - 50)		Hart, 1930*
5.5 (41.9)		Qadri, 1955*

*Cited in Carlander, 1969:122.

hatching) characteristically occurs, with optimum being extremely close to freezing (Table CL-3). This finding has been repeated by Lawler (1965) and the AEC (1972:A-48).

According to Colby and Brooke (1970) the laboratory study by Price (1940) showed greatest egg mortality to occur during the early stages of egg incubation, and one study in Lake Erie (Lawler, 1965) found early and steady cooling followed by late and steady warming of waters to 40 F (4.4 C) enhanced year class success, though during one winter a possibly successful year class (of 1938) was produced when low November temperatures were followed by an average April water temperature of about 45.5 F (7.5 C). In addition, Faber (1970) found hatching to occur in Lake Erie between late April and early May at temperatures of 4.6 to 6.9 C (40.3 to 44.5 F).

It therefore appears that if spawning and early egg incubation temperatures are kept below 43 F (6.1 C), embryos in later stages of development might survive at slightly higher temperatures prior to hatching.

Price (1940) also found that temperature influenced the fry size at hatch, the lower the incubation temperature, the greater the fry length (Table CL-3). This was also observed of whitefish by Hall (1925; cited in Lawler, 1965), and was suggested by Colby and Brooke (1973) to increase feeding success.

Larvae

In Lake Erie, Faber (1970) found a surface temperature of 4 C (39.2 F) was present during all periods of larval abundance, and cites similar observations by Hart (1930) in Bay of Quinte.

Table CL-3. Mortality, hatching, duration of hatching, and length of lake whitefish embryos incubated at constant temperatures. From Lawler (1965) after Price (1940).

	Incubation temperature					
	F: 32.9 C: 0.5	35.6 2.0	39.2 4.0	42.8 6.0	46.4 8.0	50.0 10.0
Mortality, %						
(a) Prior to hatching stage	26	38	40	28	34	63
(b) During hatching stage	1	4	1	14	47	36
(c) Total	27	42	41	42	81	99
Eggs hatched alive, %	73	58	59	58	19	1
Percentage of abnormal embryos which hatched alive	0	0	1	10	25	50
Number of days to hatching	140	120	80	60	40	30
Length (mm) of newly-hatched whitefish incubated at constant temperature	12-14	11-13	-	11-12	-	8-9.5

For slightly older fish, Hart (1930; cited in Reckahn, 1970) notes growth of young (postlarval?) whitefish increased markedly in late May as water temperatures increased from 10 to 13 C (50 to 55.4 F).

Post-larvae were observed by Reckahn (1970) in the shallowest waters of South Bay, Lake Huron in late June and early July in close proximity to 17 C (62.6 F) water.

Juveniles

In early July Reckahn (1970) found young lake whitefish left the shallows for deeper water, though retaining their association with 17 C (62.6 F) water. For reasons not associated with the 17 C (62.6 F) isotherm, in mid August the fish descended into the upper hypolimnion.

Edsall and Yocom (1972:48) state 62.6 F (17 C) to be the preferred temperature of young-of-year whitefish, though Tompkins and Fraser (1950; cited in Ferguson, 1958) determined the final temperature preferendum of two-year-old lake whitefish to be 12.7 C (54.9 F).

Unpublished data of the Great Lakes Fishery Laboratory (cited in Edsall and Yocom, 1972:47-48) showed susceptibility to predation increased significantly when young-of-year whitefish acclimated to 64.4 F (18 C) were given a one-minute exposure at 84.2 F (29 C).

General and Unspecified

Cooper and Fuller (1945; cited in Ferguson, 1958) found lake whitefish to be associated with the 11.4 to 11.9 C (52.6 to 53.5 F) temperature interval in Moosehead Lake, Maine.

While Koelz (1929) described the general movements of whitefish in Lake Michigan, he stated that "nothing is known about [coregonid] reactions to the various physical and chemical factors of their environment " (p.333), and provided no temperature data himself.

Koelz data showed that fish moved off shoals into deeper water in mid June off Michigan City, and the first week of August off Grand Haven. Other observations on depth distributions of lake whitefish in southern Lake Michigan include those reported by Reigle (1969).

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BLOATER

Distribution

The bloater has generally been considered endemic in the Great Lakes basin where it occurs in all lakes, except Lake Erie (Scott and Crossman, 1973:247).

Spawning

Bloaters spawn between November (Progressive Fish Culturist, 1960) and into March (Wells, 1966) (Table HO-1).

Larvae

About 96% of the larval bloater collected by Wells (1966) in southeastern Lake Michigan were from strata in which maximum water temperatures were below 4.8 C (40.7 F).

Juveniles

Edsall et al. (1970) determined upper lethal temperatures for age-I bloaters by both rapid temperature rise and slow heating methods. In the former, Edsall et al. found the 7 day ultimate upper incipient lethal temperature to be 26.75 C (80.2 F). When exposed to gradually increasing temperatures at the rate of 0.5 C (0.9 F)/day until 22 C (71.6 F) and 1 C/day (1.8 F) thereafter, Edsall et al. found death occurred between 27 and 29 C (80.6 and 84.2 F) for fish acclimated to 8, 20 and 25 C (46.4, 68 and 77 F). When compared with the resistance data for constant exposure temperatures, it appears that for the lower acclimation temperature (8 C, 46.4 F), slow heating increased resistance to high temperatures.

Table HO-1. Bloater spawning times at various locations.

Date	Location	Author
November - January	Lake Ontario	Progressive Fish Culturist, 1960*
January - into March	Lake Michigan	Wells, 1966
February - March	Lakes Huron and Michigan	Jobes, 1949*; Koelz, 1929*
March	Lake Michigan	Koelz, 1929

*Cited in Carlander, 1969:128.

Adults

Edsall et al. (1970) also determined upper lethal temperatures for age-III bloaters by the slow heating method cited above, and acclimated to 8 C (46.4 F). The lethal temperature was found to be between 26 and 27 C (78.8 and 80.6 F). While the authors felt upper lethal temperatures of adults to be slightly lower than for the juveniles tested, it is not felt that adequate data were presented to substantiate such a statement.

General and Unspecified

Bloaters have been found to generally inhabit 4 to 11 C (39.2 to 51.8 F) water in summer in southern Lake Michigan, though greatest concentrations often were between temperatures of 6 and 10 C (42.8 and 50 F) (Wells, 1968). In another study in southern Lake Michigan (Reigle, 1969), a comparsion of chub (primarily C. hoyi) catch rates and bottom temperatures was made during July. Although some chubs were taken at temperatures between 39 and 63 F (3.9 and 17.2 C), most were collected between 41 and 59 F (5.0 and 10.0 C). Jobes (1949; cited in Reigle, 1969) collected bloaters in Lake Michigan at between 34.7 and 52.5 F (1.5 and 11.4 C) though greatest concentrations were in waters between 38.8 and 44.6 F (3.8 and 7.0 C).

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COHO SALMON

Effects of temperature on coho and other Pacific salmon have been recently reviewed by Schuytema (1969). In the following discussion when this review is used as the source of a reference an asterisk is placed following the publication date of the original article, e.g., (1953*).

Distribution

Coho occur naturally only in the Pacific Ocean and its tributary drainage. In natural systems it is known from Monterey Bay, California to Point Hope, Alaska (Scott and Crossman, 1973:159), though they have now been widely introduced in the Great Lakes, Alberta and elsewhere.

Spawning

According to Schuytema (1969:A-32) the majority of adult coho studies are reports of naturally occurring migration and spawning temperatures. Peak periods of upstream coho migration in Sand Creek, Oregon, occurred at temperatures from 40 to 52 F (4.4 to 11.1 C) (Sumner, 1952*) and Allen (1959*), in studies of influence of environmental factors on behavior, reported that coho runs did not occur until the water temperature dropped below 50 F (10 C).

Coho salmon spawned in various Columbia River Basin waterways at temperatures from 40 to 45 F (4.4 to 7.7 C) (Snyder et al., 1966; cited in Pacific Northwest Laboratories, 1967*). Russian studies revealed that the water temperatures at certain coho spawning grounds ranged from 0.8 to 7.7 C (33.4 to 45.3 F) throughout the year (Gribanov, 1962*). On the Pacific coast, spawning occurs between September (Schuytema, 1969:A-29) and January (Briggs, 1953) and has been observed at water temperatures of between 40.0 and 58 F (4.4 and

14.4 C) (Table KI-1).

Eggs

According to Shapovalov and Taft (1954*) coho eggs incubated at 51.3 F (10.7 C) hatched in 38 days, while eggs incubated at 48 F (8.9 C) hatched in 48 days. The temperature of advanced near-hatching eggs in some Russian coho nests in January ranged from 2.1 to 5.3 C (35.8 to 41.5 F) (Gribanov, 1962*).

Larvae

Hatchery epizootics of the myxobacterium Cytophaga psychrophilia in coho fry (and fingerlings) were influenced greatly by water temperature data cited in Rucker et al.,(1953*). The disease usually occurred at temperatures from 40 to 50 F (4.4 to 10 C) although the disease sometimes persisted in 60 F (15.6 C) water.

Juveniles

Over a three year period peak downstream migration of coho fingerlings in Sand Creek, Oregon, occurred at between 45 and 61 F (7.7 to 15.6 C) (Sumner, 1952*). In the Columbia River Basin, juveniles migrated at between 40 and 61 F (4.4 to 16.1 C) (Snyder et al., 1966; cited in Pacific Northwest Laboratory, 1967*).

Davis et al. (1963*) found sustained fingerling swim speeds were higher at 20 C (68 F) than at 10 C (50 F) at all levels of dissolved oxygen tested; and Brett (1957) stated that 20 C (68 F) was the optimum cruising speed for young coho, though they maintained a high level of performance even when approaching upper lethal temperatures. Brett felt that as a measure of metabolic performance, cruising speed provided

Table KI-1. Coho salmon spawning times and temperatures at various locations.

Date	Temperature C	F	Location	Comment	Author
	0.8-7.7	(33.4-45.3)	Russia		Gribanov, 1962*
September - December			Pacific Coast		Schuytema, 1969:A-29
October - January	(7.8-13.3)	46 - 56	Prairie Creek, California	Mid-day water temperatures	Briggs, 1953
	(5.6-14.4)	42 - 58	Toutle River, California		Burner, 1951: cited in Briggs, 1953.
	(4.4-7.7)	40 - 45	Columbia River Basin, Washington		Snyder et al., 1966; cited in Pacific Northwest Laboratories, 1967*
	(7.8)	46	Alaska		Chamberlain, 1907 ; cited in Briggs, 1953.

*Cited in Schuytema, 1969:A-33.

an index to the temperature at which fish are most likely to prosper. Brett et al. (1958) further indicated that this peak performance temperature (20 C, 68 F) related to both underyearlings and yearlings. Maximum sustained (1 hour) speeds were 1 fps for underyearlings and 1.5 fps for yearlings. In more elaborate studies, Griffiths and Alderdice (1972) expanded upon the results of Brett et al. (1958), finding an optimum (ultimate maximum) performance of 5.8 lengths/second for juveniles (7.5-9.5 cm TL) occurred at a combination of acclimation and test temperatures near 20 C (68 F). They noted an apparent shift in location of the acclimation temperature of maximum performance, indicative of seasonal performance compensation and improved capacity to perform at low acclimation temperatures in winter. The 20 C (68 F) temperature was also found by Brett (1952) to be the final temperature preferendum, though in the field shoal water temperatures of higher than 75 F (23.9 C) apparently had no inhibitory effect on coho in Granby Reservoir, Colorado (Klein and Finnell, 1969).

A growth study (Averett, 1969; cited in Coutant, 1970a) found optional efficiency of food utilization within consumption ranges believed to occur in nature to be at 14-17 C (57.2-62.6 F) in late summer, though maximum growth on excess rations occurred at a somewhat higher temperature range (17-20 C, 62.6-68 F) (Averett, 1969; cited in Griffiths and Alderdice, 1972). Another study (unpublished data cited in USFWS, 1970:56) found optimum growth on excess rations at 59 F (15 C) and efficient conversion (≥80% of maximum) up to 62 F (16.7 C). Edsall (cited in USFWS, 1970:58) suggested restriction of diet to within natural levels would reduce these optimal growth and conversion temperatures.

While data led Griffiths and Alderdice (1972) to presume a temperature of near 20 C (68 F) to represent the physiological optima for coho salmon, the study by Averett (1969; cited in Coutant, 1970a) and unpublished data cited in USFWS (1970:55-58) suggest a slightly lower maximum limit (17 C, 62.6 F) for efficient growth and conversion for fish fed rations similar to levels in nature.

Iwanage and Hall (1973; cited in Coutant and Pfuderer, 1974) found that in unlogged streams with (summer?) temperatures of between 10.8 and 14.5 C (51.5 and 58.2 F) growth of coho was poorer than in clear cut streams where warmer conditions prevailed (13.6 to 17.3 C, 56.5 to 63.2 F). However, in the laboratory, fish showed poorest growth at these latter temperatures. These findings apparently conflict with those cited above.

Sylvester (1972) found the yearling coho predation rates on sockeye salmon fry increased with acclimation temperatures of 7, 12 and 17 C (44.6, 53.6 and 62.6 F) though he was not able to determine whether this was due to increase in predator forage activity, decrease in prey swimming ability, or both. Based on other material presented in this review, increased predator forage activity would seem the likely cause.

Brett (1952) determined 7 day upper (4 day lower) lethal temperatures for young (4.8 cm FL, 1.4 g, 5.2 mo.) coho salmon at various acclimation temperatures. Brett found upper lethal temperatures rose with acclimation temperature to the ultimate upper incipient lethal temperature of 25 C (77 F) (Figure KI-1). The 24 hour ultimate upper incipient LT_{50} was 26 to 26.5 C (78.8 to 79.7 F). Below upper incipient lethal temperatures, Dean (1969) found a difference of 5 C (9 F) in acclimation temperature resulted in a 1 C (1.8 F) shift in incipient lethal temperature. Resistance times given for exposures of fish to

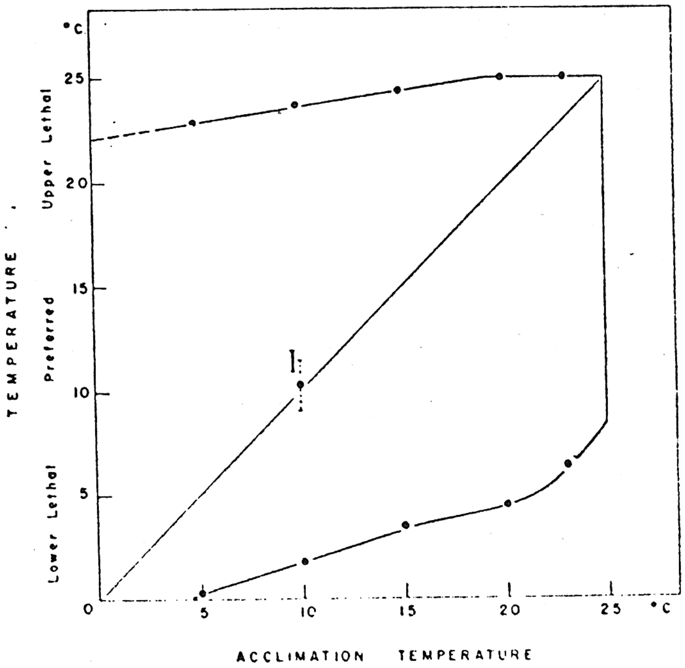

Figure KI-1. Lethal temperature polygon for young coho salmon. The preferred temperature is represented by a central point for the mean, with limits for 1 S.D. dotted above and below. The degree C in which the mode occurred is represented by a solid vertical line. From Brett (1952).

sublethal doses at potentially lethal temperatures were calculated by Brett (1952) and are presented in Figure KI-2.

Dean (1969) determined times to equilibrium loss as well as time to death in his experiments with juvenile coho, but no data were presented. However, Dean (1969) found that while fish experienced loss of equilibrium prior to death, there was no significant difference between time to equilibrium loss and death, because of the wide range over which the two responses occurred.

Dean (1969) also found that for juvenile fish acclimated to 15 C (59 F), and cycled between 15 C (59 F) and 27 C (80.6 F), cumulative lethal effects of exposure to 27 C (80.6 F) were essentially eliminated during the recovery period.

"Cold-water disease" in young coho salmon is found generally in spring when water temperatures are low (Ordal and Pacha, 1963*). The infectious organism, Cytophaga psychrophila may cause heavy fish losses. The disease is self limiting, however, and disappears as the water temperature increases. An incidence of the disease persisted in young cohos held at 43 F (6.1 C). After two days no additional mortality occurred in a group of fish placed and held at 55 F (12.8 C).

McCoy (1973; cited in Coutant and Pfuderer, 1974) injected juvenile coho salmon with Aeromonas salmonicida and A. hydrophila. He found that water temperatures above 15 C (59 F) produced high mortality and moderate mortality at 15 C (59 F) in the former and high

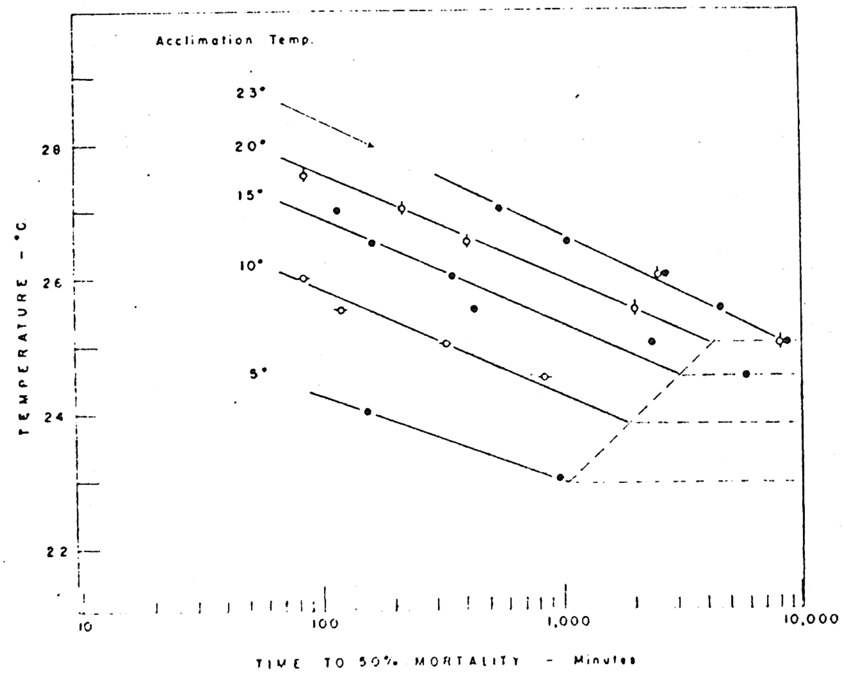

Figure KI-2. Median resistance times to high temperatures among young coho salmon acclimated to the temperatures indicated. From Brett (1952).

mortality at 18 C (64.4 F) in the latter.

Templeton and Coutant (1971) state that laboratory and field studies have shown that the infection of fish with columnaris becomes evident when water temperatures rise above 10 C (50 F), and declines when temperatures decrease. Becker (1973) states the appearance of the organism normally coincides with a temperature rise of approximately 12 to 15 C (53.6 to 59 F) in spring. Nakatani (1969) notes that in a hatchery the disease is well established when water temperatures reach 63 to 64 F (17 to 18 C) in early July. Fingerlings were reported to suffer mortalities for a few weeks, but losses then tapered off sharply, and few deaths occurred, despite the continual rise in river water temperatures to about 70 F (21 C) in late August.[1]

Adult

According to Borgeson (1970; cited in USFWS, 1970:58) optimum temperatures for feeding of adult coho in Lake Michigan are between 50 and 55 F (10 and 12.8 C).

While thermal resistance of juvenile salmon have been extensively studied, resistance of large salmon has not. In one of the few studies, Coutant (1969) held adult coho at between 16.1 and 18.2 C (61 and 64.8 F) and found them to have significantly shorter resistance times at 28 C (82.4 F) (corrected to 28.5 C, 83.3 F in Coutant, 1970b) and below than did juveniles held at 15 C (59 F) and tested previously by Dean (unpublished).

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[1] According to Fujihara et al. (1971) many complex factors other than temperature are involved in mortality of fish from columnaris. Some of these factors are crowding, probable immunity of previously exposed fish, differences in resistance to columnaris according to species, age

Insufficient data are available from Columbia River studies to estimate incipient lethal temperatures for adult coho salmon (Templeton and Coutant, 1971; Becker, 1973).

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and condition of fish, differences in strain virulence of columnaris, and interrelations with other fish diseases.

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RAINBOW TROUT

Distribution

The native range of the rainbow trout (including all varieties) was the eastern Pacific Ocean and the fresh water, mainly west of the Rocky Mountains, from northwest Mexico (including extreme northern Baja California), to the Kuskokwim River, Alaska. It is probably native in the drainages of the Peace and Athabasca rivers east of the Rocky Mountains. This species, under all its names, has been so widely introduced in North America outside its natural range as to suggest it occurs throughout the United States in all suitable localities (Scott and Crossman, 1973:186).

Spawning

Spawning in rainbow trout has been observed between November and July (Agersborg, 1934; cited in Carlander, 1969:191) at temperatures ranging from 0.3 C (32.5F) (Dodge and MacCrimmon, 1971) to 15.5 C(60 F) (Scott and Crossman, 1973:187) (Table GA-1).

Eggs

Embody (1934) determined the incubation period for rainbow trout eggs at temperatures between 3.2 and 15.5 C (37.8 and 59.9 F). Incubation periods ranged from 101 to 18 days respectively (Table GA-2). Others (Knight, 1963; cited in Carlander, 1969:192; Garside, 1966; and Lagler, 1956:31) have cited similar incubation times within this temperature range. Embody (1934) found egg loss at the highest temperature (15.5 C, 59.9 F) was 10%.

Timoshina (1972; cited in Coutant and Pfuderer, 1974) found optimum egg development at 5 to 7 C (41 to 44.6 F), and from a review

Table GA-1. Rainbow trout spawning times and temperatures at various locations.

Date	Temperature C	F	Location	Comment	Author
November into February			Wytheville, Virginia	Dec. and Jan. best	Agersborg, 1934
Nov. - Early Mar.			Neosho, Missouri		Agersborg, 1934
Nov. - April			McConaughy Reservoir, Nebraska	Dec.-peak, fall run Mar.-peak, spring run	Van Velson, 1974
Late Nov. - Mid June			Pittsford, Vermont		Agersborg, 1934
Dec. - Apr.			Sacramento River, California		Hallock et al., 1961**
Late Dec. - Late Apr.	0.3-10	(32.5-50.0)	Bothwells Creek, Ont.	Range	Dodge MacCrimmon, 1971
Late Mar. - Early Apr.	6-8,	(42.8-46.4)		Maximum spawning	
January			Little Manistee River, Michigan	During mild winter began spawning early	Greeley, 1932
January - February			Mexico	*S.g. nelson*	Needham, 1937*
January - March			Cowichan River, British Columbia		Carl & Clemens, 1948**
Early Winter - Beginning of Summer				Range due to climate, elevation and genetic strain	Agersborg, 1934

Table GA-1. (Continued)

Date	Temperature		Location	Comment	Author
	C	F			
Feb. - Apr.			McCloud R., Cal.		Agersborg, 1934
Feb. - Late May			Finger Lakes, N.Y.	Range	Rayner, 1941*
April	5.5-13	(41.9-55.4)		Peak month and temperatures	
Feb. - June			Maine		Bond, 1958*
Late Feb. - Late Apr.	(7.8-8.3)	46-47	Prairie Creek, Cal.	Mid-day March temperatures	Briggs, 1953
Late Winter - Early Spring			Frazier River, British Columbia		Larkin, 1950*
March			Chilliwack River, British Columbia	Peak	Maher & Larkin, 1954*
Mar. - Apr.			Coastal Watersheds, Oregon	Peak	Bali, 1959*
Mar. - Jul.	(2.8-7.8)	37-46		According to review date depends upon water temperature patterns; desirable temperature range	Dunham, 1968:36
Spring				On rising temperature	Breder & Rosen, 1966:108

Table GA-1. (Continued)

Date	Temperature C	 F	Location	Comment	Author
Mid April			Little Manistee River, Michigan		Greeley, 1932
Mid Apr. - Early June			Montana		Agersborg, 1934
Throughout May	(3.3-3.9)	38-39	Central Alaska		Evermann & Goldsborough, 1907**
Early May - July			Colorado		Agersborg, 1934
	(10-15.5)	50-60		Usual spawning range	Scott & Crossman, 1973:187
	(12.8)	55		Maximum temperature compatible with spawning	NTAC, 1968:33, 43
	6-10	(42.8-50)	Europe		Privol 'nev and Brizinova, 1964***

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*Cited in Carlander, 1969:191.

**Cited in Briggs, 1953.

***Cited in European Inland Fisheries Advisory Commission, 1969.

Table GA-2. Incubation times of rainbow trout eggs held at various temperatures*

Temperature C	F	Days
3.23	37.8	101
4.80	40.7	75
6.1	43.0	61
8.0	46.4	41
10.35	50.7	28
12.45	54.4	24
15.5	59.5	18

*Adapted from Embody, 1934

of the literature Dunham (1968) indicates 42 to 54 F (5.6 to 12.2 C) as desirable, with extremes of 35 and 61 F (1.7 and 16.1 C). Markus (1962) states that at 55 F (12.8 C) rainbow trout eggs develop normally, the NTAC (1968:33, 43) recommended 55 F (12.8 C) as a provisional maximum temperature compatible with rainbow trout egg development, and Moore (1940; cited in Altman and Dittmer, 1966:78) found 13 C (55.4 F) to be the upper tolerance limit of rainbow trout embryos. However, Embody (1934) notes that at certain federal hatcheries eggs were incubated at temperatures above 60 F (15.6 C) with "highly satisfactory results," and Garside (1966) makes no mention of mortality at incubation temperatures of up to 17.5 C (63.5 F).

Larvae

Morton (1962) found fry reared in a heated pond 56 F (13.3 C) were easier to start on dry food, had lower mortality, and were more uniform in size than those reared as controls in 50 F (10 C) water. Russian laboratory and fish culturing activities, summarized in Table GA-3 (from Mantelman, 1958), indicate 12 to 20 C (53.6 to 68 F) to be most favorable for young rainbow trout, and Dunham (1968) indicates 55 to 66 F (12.8 to 18.9 C) as desirable for development of young.

Olson et al. (1973) held steelhead fry (and as the experiments continued, juveniles as well) for 18 months at increments of 2, 4 and 4.7 F (1.7, 2.2 and 2.6 C) above normal Columbia River temperatures. Mortalities were well within hatchery standards despite temperatures in the warmest lot reaching 21.1 C (70 F). Calderon (1967; cited in Coutant, 1970a) successfully cultured rainbow trout (larvae?) at temperatures above 22 C (71.6 F).

Table GA-3. Russian studies of temperatures favorable for young rainbow trout*.

Temperature			
C	F	Comment	Author
12-14	(53.6-57.2)	Most favorable	Data cited by Buschkiel, 1931
12-20	(53.6-68.0)	Most favorable	Buschkiel, 1931 (?)
15	(59)	Maximum food consumption	
13-18	(55.4-64.4)	Most rapid growth, greatest food intake	Mekhanik, 1956
14-18	(57.2-64.4)	Most favorable during first independent feeding	Gracheva, 1955
15-18	(59.0-64.4)	Most intensive feeding and development	Kornilova, 1949 (?)
~20	(~68.0)	Most favorable	Sukhoverkhov, 1953 (?)
20	(68.0)	Grew well and readily consumed food	Gracheva, 1955

*Adapted from data cited in Mantelman (1958:21,22)

Mantelman (1958) found that prior to adopting an active mode, alevins (up to 13 days old) did not respond in a horizontal gradient to temperatures of even 24 C (72.5 F). However, following changeover to an active mode (15 to 18 days old) alevins were extremely sensitive to temperature, responding rapidly to changes in the positioning of the selected temperature. For these fish, previously held at between 12 and 16 C (53.6 and 60.8 F) and raised several days before initiation of experiments to between 14 and 18 C (57.2 and 64.4 F), the selected temperature interval was 13 to 20 C (55.4 to 68 F). Schmeing-Engberding (1953; cited in Mantelman, 1958) found that for 35 day old (and 4 month old) fish kept at 10 to 12 C (50 to 53.6 F) between experiments, the selected temperature was 10.4 C (50.8 F). Mantelman (1958) felt differences in holding temperatures might account for the selection differences.

Northcote (1962) observed that fry emerging from gravel were found to show a net downstream movement if water temperatures were below 13 C (55.4 F), though at higher temperatures ($>$14 C, $>$57.2 F) fish showed upstream movement. Similarly, from a review of the literature, Dunham (1968) found temperatures between 40 and 50 F (4.4 and 10 C) and long day length induced downstream migration, while temperatures greater than 59 F (15 C) inhibited migration, especially if accompanied by a decrease in flow.

Juveniles

Lawrence (1940) exposed fasting rainbow trout fingerlings to differing temperature regimes (46, 52 and 57 F) and, as might be expected, he found increasing temperatures increased the rate of weight loss. In natural populations in different sections of the W. Gallatin

River, Montana, Purkett (1950) found greatest growth occurred in the warmer sections. Purkett (1950) found that in all river sections studied, temperatures were within or exceeded the 55 to 60 F (12.8 to 15.6 C) range said by Davis (1946; cited in Purkett, 1950) to be optimal for trout, though the time these temperatures existed during the day and during the year was much less at higher elevations.

In laboratory studies, Morton (1962) found fingerlings grew more rapidly and had lower mortality in ponds heated to 56 F (13.3 C) than when kept at 50 F (10 C), and Markus (1962) reported fingerlings grew best at 55 F (12.8 C). In Britain, Aiken (1971) found for fish (age unspecified) fed on low fat diets, growth was maximum at between 12 and 16 C (53.6 and 60.8 F), but on a high fat diet the maximum growth rate probably lay between 16 and 20 C (60.8 and 68 F). According to unpublished data from Hokanson and Kleiner (cited in EPA, 1974) optimal temperatures for rainbow trout growth are between 17 and 19 C (62.6 and 66.2 F).

Jones (1971; cited in Coutant and Goodyear, 1972) found no significant difference between maximum cruising speeds for fish acclimated to test temperatures of 8 to 10 C (46.4 to 50 F) and 21 to 23 C (68.8 to 73.4 F), though Fry (1948) reported that yearling cruising speed (and metabolic scope) increased with acclimation temperatures of up to about 23 C (73.4 F) (Figure GA-1).

Mantelman (1958) conducted temperature selection experiments with fingerling rainbow trout. For one series of experiments he used fish from ponds in which water temperatures rose as high as 23 to 24 C (73.4 to 75.2 F), and where diurnal water temperature fluctuations were as high as 8 C (14.4 F). Combining results of various experiments,

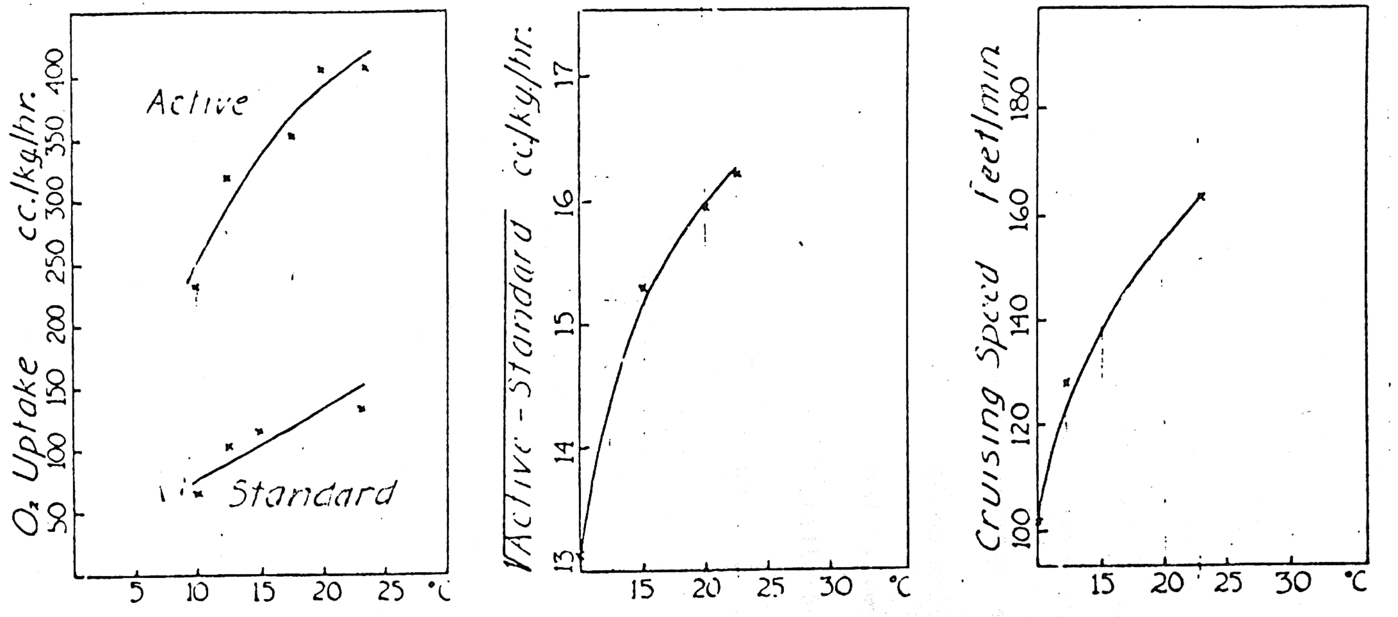

Figure GA-1. The relationship between temperature and metabolism in Rainbow trout. The square root of the difference between the active and standard metabolism is used to compare with the cruising speed since the resistance offered by the fluid to swimming varies with the square of the velocity. From Fry, 1948.

fish selected temperatures between 13 and 19 C (55.4 and 66.2 F), and temperatures of 21 and 22 C (69.8 and 71.6 F) were avoided. Based upon tests during summer, Mantelman concluded that the temperature selected by fingerlings during summer was independent of length of fish, size of sample, range of temperatures in the gradient, or rearing temperature. Mantelman noted a reduction of temperature selected in autumn to between 9 and 17 C (48.2 and 62.2 F), though this did not persist in specimens tested in winter. In further experiments, Mantelman examined influence of acclimation temperature on temperature selection in young rainbow trout. He concluded that while changes in selected temperature occurred rapidly when fish were exposed to temperatures above or below acclimation, the effect was transitory and within 80 days the fish re-established themselves in the 12 to 19 C (53.6 to 66.2 F) temperature range.

While the temperature selection experiments on rainbow trout conducted by Mantelman (1958) are the most extensive, other authors have studied selection temperatures as well. Fry (1971:Figure 37) plotted selected temperatures found by the various authors and stated (Fry, 1971:80) that while rainbow trout might not be genetically homogeneous, particularly with respect to various domestic stocks in different parts of the world, this fact could not completely explain how four of the groups of workers, experimenting within a few hundred miles of each other, reported differences in behavior. The data of these workers are presented in Figure GA-2. Except possibly for fish tested by Christie (cited in Fry, 1971:80), all data cited in Figure GA-2 were for young-of-year. Fry suggests the disparity in selection temperatures might be due at least in part to differences in experimental method or season. Javaid and Anderson (1967b) also found that starvation reduced temperature

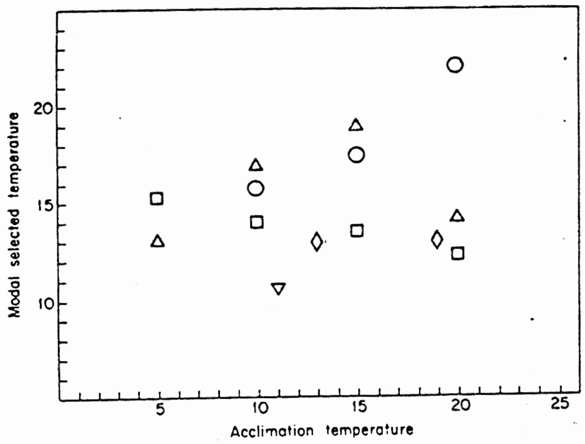

Figure GA-2. Various modal selected temperatures in relation to thermal history for rainbow trout, *Salmo gairdneri*. Data of W. J. Christie (personal communication) (Δ), Garside and Tait (1958) (□), Javaid and Anderson (1967a) (○), Mantelman (1958) (◇), and Schmein-Engberding (1953) (▽). From Fry, 1971:Figure 37 .

preference, but that it returned to previous levels following resumption of normal feeding.

Field studies by Spigarelli et al. (1973) around a Lake Michigan power plant indicated few small trout in the near field thermal plume; the two found (mean 75 gm) had mean body temperature of 19.3 C (66.8 F), a temperature 0.3 C (0.5 F) above the average water temperature. Similarly, one year old trout stocks in Hemlock Lake, Michigan, generally inhabited waters in summer of between 7 and 21 C (44.6 and 69.8 F) in 1969, and between 10 and 17 C (50 and 61.1 F) in 1970 (Fast, 1973). In both years trout avoided water warmer than 21 C (69.8 F).

Olson et al. (1973) held steelhead juveniles (also fry, see Larvae section) at increments of 2, 4 and 4.7 F (1.7, 2.2 and 2.6 C) above normal Columbia River temperatures. Though temperatures reached 21.9 C (71.5 F), mortalities were said to be well within hatchery standards.

Early experiments on effects of acute temperature shock upon equilibrium loss and susceptibility of juvenile rainbow trout to predation were conducted by Coutant (1969a). These and later experiments have been periodically reviewed (Coutant, 1969b; Templeton and Coutant, 1971; Becker, 1973) and only more recent results are reviewed here.

Coutant and Dean (1972) have found that for juvenile steelheads acclimated to 15 C (59 F), time to equilibrium loss and time of death appeared distinct at the 95% confidence levels at temperatures slightly above 29 C (84.2 F) (though for adult steelhead no statistical distinction was evident at this or other test temperatures; see Coutant, 1970b).

Coutant (1973) determined that thermally shocked juvenile rainbow trout were selectively preyed upon by larger unshocked trout in the laboratory when exposure time of juveniles exceeded 20% of the duration that caused body inversion of half a test population at that temperature. Selective predation occurred at an average exposure which was about 10.9% of the median death time for that temperature, or at a temperature of about 2.5 C (4. 5 F) lower than death for that same temperature (Figure GA-3).

At an acclimation temperature of 11 C (51.8 F), Black (1953) found a 24-hour LT_{50} of 24 C (75.2 F) for kamloops trout (Salmo gairdneri kamloops; 26.1 g average, 14 to 54 g range). Similarly, Angelovic et al. (1961) found that young rainbow trout (8-13 cm, 15-25 g) just reached the ULT at 75 F (23.9 C), the lethal limit normally falling, according to Angelovic et al., between 74 and 78 F (23.3 and 25.6 C). The latter authors also stated that rainbow trout which have been acclimated and then have their temperature raised at the rate of 1 F (0.6 C) per hour did not reach the ULT until about 80 F (26.7 C). Bidgood and Berst (1969) found no difference in tolerance to upper lethal temperature among juvenile (205 to 212 days old) progeny of wild rainbow trout homing to four widely separated watersheds in the Great Lakes (Lakes Erie, Huron, Ontario and Superior). All eggs had been incubated and juveniles reared under similar conditions and acclimated to 15 C (59 F). The upper incipient lethal temperature (exposure time unspecified) for the samples fell between 25 and 26 C (77 and 78.8 F). Size of fish (range 37 to 92 mm TL) did not affect resistance times. For slightly larger fish acclimated to the same 15 C (59 F) temperature in Great Britain, Alabaster and Downing (1966) determined a 100 minute ULT of 27.3 C (81.2 F), and a 1000 minute ULT of 25.3 C (77.6 F). When

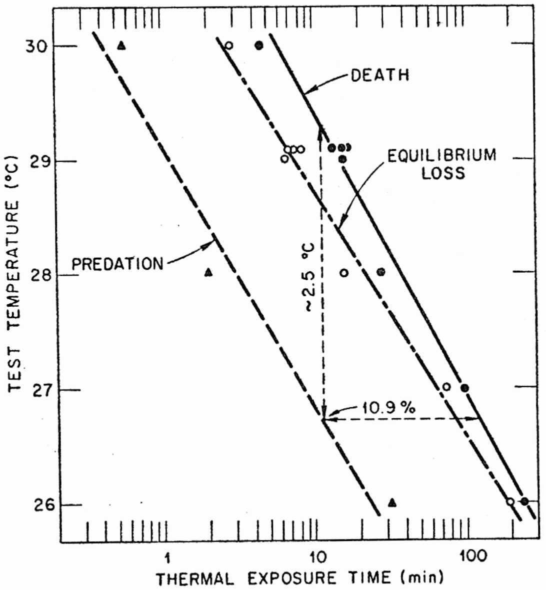

Figure GA-3. Relationship among three effects of acture thermal shock on a sibling group of juvenile rainbow trout acclimated to 15 C: (1) time to initial increase in vulnerability to predation, (2) median time to loss of equilibrium, and (3) median time to death. From Coutant (1973).

acclimated to 20 C (68 F), fish had a 100 minute ULT of 28.2 C (82.8 F), and a 1000 minute ULT of 26.6 C (79.9 F).

Craigie (1963) determined that hardness of water during embryonic development and early growth did not significantly influence thermal resistance of yearling trout to high temperatures, though hardness of water experienced immediately preceding exposure to lethal temperatures did, and Halsband (1953; cited in Angelovic et al., 1961) was able to increase the lethal temperature of rainbow trout at least 2 C (3.6 F) by increasing the calcium and magnesium content of water. McCauley (1968) observed that fingerlings exposed to thermal stress in the laboratory apparently altered the composition of the water such that survival of fish subsequently exposed to lethal temperatures in the same water was measurably increased.

Fujihara et al. (1971) found that survival of juvenile rainbow trout exposed to *Chondrococcus columnaris* disease was higher when held 2.2 C (4 F) below seasonal river temperatures of 17.7 to 21.7 C (63.9 to 71.1 F) than when held at 2.2 C (4 F) above seasonal river temperatures. However, many complex factors other than increased temperatures are involved in mortality of fish from this disease. Fujihara et al. (1971) list these factors as crowding, probable immunity of previously exposed fish, differences in resistance to *C. columnaris* according to age and condition of fish, differences in strain virulence of *C. columnaris*, and interrelations with other fish diseases.

Adults

At the end of a thermal discharge outfall into Lake Michigan 77 large trout (mean 2284 gm) were collected with a mean body temperature of 14.5 C (58.1 F), 4.4 C (7.9 F) below the mean water temperature.

In the near field, two large trout (mean 3000 gm) were collected with a mean body temperature of 17.2 C (63.0 F), 0.3 C (0.5 F) below the mean water temperature. This latter temperature is closer to the 18.9 to 21.1 C (66.1 to 70.0 F) temperature said to be preferred by adult trout in Horsetooth Reservoir, Colorado (Horak and Tanner, 1964; cited in Coutant, 1974).

Estimates of resistance times of adult rainbow trout to lethal temperatures were determined by Coutant (1970b). Incipient lethal temperatures for fish held at between 16 and 19 C (60.8 and 66.2 F) were 21 to 22 C (69.8 to 71.6 F). Relative resistances of large and juvenile fish varied with test temperatures; juveniles being more resistant at lethal temperatures up to about 28.5 C (83.3 F), while adults were more resistant above that temperature.

General and Unspecified

In a Colorado reservoir, rainbow trout were found most abundantly at 19 to 21 C (66.2 to 69.8 F), (Horak and Tanner, 1964; cited in Carlander, 1969:194), and hatchery reared trout showed a similar temperature range (18.5 to 21 C, 65.3 to 69.8 F) for maximum stamina (Horak, 1966; cited in Carlander, 1969:194).

Two papers examined effects of temperature on planting success of rainbow trout. Threinen (1958) found complete mortality at 73 F (22.8 C) for planted trout acclimated to 54 F (12.2 C). Threinen found that the trout could not withstand a temperature shock of 20 F (11.1 C) above an acclimation temperature of 54 F (12.2 C), but could tolerate a shock of 15 F (8.3 C) from an acclimation temperature of 51 F (10.6 C). Raising the acclimation temperature through a 24 hour period to 65 F enabled the trout to withstand a temperature of 74 F

(23.3 C) (the highest temperature tested) with only minor short term stress. Sharpe (1961) noted that after tempering, when 6-8 inch trout from 61 F (16.1 C) water were placed in 83 F (28.3 C) surface waters of Stone Lake, Tennessee, the fish exhibited severe stress symptoms and some died.

There are numerous discussions of limiting temperatures for rainbow trout. From a review of the literature, Dunham (1968) considers a good trout stream should have summer temperatures in the range of 55 to 60 F (12.8 to 15.6 C), with an upper limit of 68 F (20 C). It was also felt temperatures above 66 F (18.9 C) for an appreciable period might limit distribution. However, Burton and Odum (1945) stated that the variety of rainbow trout introduced into streams tributary to Mountain Lake, Virginia, occur largely in waters warmer than 19 C (66.2 F). Needham (1938; cited in Burton and Odum, 1945) stated that rainbow trout can do equally well in warm or cool waters, but varieties apparently differ in requirements. In their native range they are said (by Needham) to be most abundant in warm but swift water having a temperature between 24 and 27 C (75.2 and 80.6 F), with 28 C (82.4 F) as the limiting high temperature. Scott and Crossman (1973:189) state that rainbow trout are most successful in habitats with a temperature of 70 F (21 C) or slightly lower, but so long as there is cooler, well-oxygenated water into which they can retreat they can thrive in lakes in which surface waters reach temperatures well over 70 F (21 C) for long periods in summer. Van Velson (1974) stated that water temperatures exceeding 24 C (75.2 F) for a short duration in summer are common in many spawning streams tributary to the upper North Platte River, Nebraska. Eipper (1960; cited in Fast, 1973) indicates that rainbow trout can withstand temperatures as high as 26.7 C (80.1 F) for a few days, but that prolonged exposure to temperatures above 24 C (75.2 F) lead to high mortality. Wurtz (in Wurtz and Renn, 1965:39) observed sea run rainbow trout in July in 72 F (22.2 C) water and Tarzwell (1957) has observed them in a Michigan river in 83 F (28.3 C) water. However, the first author states that salmonids cannot be expected to maintain populations in waters which are commonly above 75 F (23.9 C), while the latter believes that for good trout production, water should not exceed 68 F (20 C). According to Embody (1934) limiting summer temperatures for habitation by apparantly thriving populations of rainbow trout in Tompkins County, New York, are 85 F (29.4 C). When exposed to naturally cycling stream temperature variations in the laboratory during summer, Embody found that steelhead became distressed only when maximum daily temperatures reached 84.2 F (29 C), and that 20% mortality occurred the following day at 85.5 F (29.7 C), and total mortality occurred one day later at 87 F (30.6 C). From Embody's account, it is not possible to determine whether fish suffered death due to accumulation of sublethal exposures to lethal temperatures or simply from exposure to maximum temperatures in the final days of the observations.

Three strains of rainbow trout were raised in experimental New Jersey farm ponds by Soldwedel and Pyle (1968; cited in Coutant, 1971) to test survival and growth under conditions of high natural temperatures. All three strains (Donaldson, New Jersey and Donaldson X New Jersey) survived maximum temperatures of 84.5 F (29.1 C) if other fish species were absent. Trout failed to survive less critical conditions when alewife and fathead minnows were competing species. The New Jersey strain seemed best adapted for survival in the test environment.

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ATLANTIC SALMON

Distribution

The Atlantic salmon is native to the basin of the North Atlantic Ocean, from the Ungava Bay region of northern Quebec south to the Connecticut River (Scott and Crossman, 1973:193).

Spawning

Sea run Atlantic salmon are said to usually spawn in October, but spawning may occur as late as December (Cutting, 1958; Elson, 1962; Jones, 1959; Newell, 1960; all cited in Carlander, 1969:205). Landlocked forms are said to spawn mostly from mid October to late November (Warner, 1958; cited in Carlander, 1969:212). In Canada, Atlantic salmon spawn in October and November (Scott and Crossman, 1973:194).

Jones (1959:111) stated that in observation tanks on a river bank in the British Isles, Atlantic salmon were seen to spawn to completion only at water temperatures of between 2 and 6 C (35.6 and 42.8 F), though spawning was observed in the river at temperatures up to 10 C (50 F). Atlantic salmon are said by Vernidub (1963, personal communication; both cited in European Inland Fisheries Advisory Commission, 1969) to spawn at temperatures between 6 and 8 C (42.8 and 46.4 F).

Eggs

Dumas (1966) incubated landlocked salmon eggs at constant temperatures of 47 and 53 F (8.3 and 11.7 C). Hatching occurred in 65 and 65 days respectively. At temperatures naturally fluctuating and rising between 33 and 48 F (0.6 and 8.9 C), Dumas found eggs hatched in 104 days. For eggs incubated at a constant 3.9 C (39.1 F), Power (1969; cited in Scott and Crossman, 1973:194) found hatching occurred in 110 days.

Spaas and Heuts (1958; cited in Spaas, 1960) found two optima for embryonic development rate, survival, and growth; one at 4.5 C (40.1 F) and the other at 10.5 C (50.9 F). Markus (1962) stated that Atlantic salmon eggs develop normally in water temperatures up to 50 F (10 C). At 54 F (12.2 C) Markus found about half the embryos died, and many that hatched were weak and deformed.

In addition, Vernidub (1963; cited in European Inland Fisheries Advisory Commission,1969) indicated that while development at 10 to 12 C (50 to 53.6 F) was normal, newly hatched larvae were smaller in size than those incubated at lower temperatures.

Larvae

Fisher and Elson (1950) determined that when acclimated to 4 C (39.2 F), fry with yolk sacs mostly absorbed selected 14 C (57.2 F) water.

While Dumas (1966) found fry raised in warm water (47 or 53 F, 8.3 or 11.7 C) had constricted yolk sacs which removed some yolk, it was felt the constriction served only to pinch off food in excess of that needed to carry the fry to the feeding stage. According to Markus (1962), growth of fry seemed best at between 60 and 65 F (15.6 and 18.3 C).

Bishai (1960) brought newly hatched larvae from an initial temperature of 6 C (42.8 F) to lethal temperatures over a six hour period. A temperature of 22 C (71.6 F) was resisted by 50% of the experimental population for almost 8 days, while 24 C (75.2 F) was resisted for over 2.5 days. Bishai (1960) also transferred 30 day old alevins from various acclimation temperatures directly into lethal temperature baths. At the highest acclimation temperature (20 C, 68 F), the 7-day ULT_{50} was 23 C

(73.4 F). Interpolating from the data presented, the 24-hour ULT_{50} was about 24.7 C (76.5 F). Spaas (1960) also determined upper lethal temperatures for Atlantic salmon alevins, initially held at 7 C (44.6 F) and raised at the rate of 1 C (1.8 F)/ day until death of all fish. The mean lethal temperature of 27.6 C (81.7 F) was felt to be nearly equivalent to the ultimate upper incipient lethal temperature.

Juveniles

Blair (1938; cited in Carlander, 1969:204) found growth of well fed fingerlings was more rapid at 12.2 C (54.0 F) than at 8.9 C (48.1 F), although when poorly fed there was little difference in growth rates at these temperatures. Nikiforov (1953; cited in European Inland Fisheries Advisory Commission, 1969) found Atlantic salmon feeding and growth were best at between 13 and 15 C (55.4 and 59 F), and Markus (1962) stated that water at temperatures between 60 and 65 F (15.6 and 18.3 C) seemed best for fingerling growth.

Maximum response to electrical stimulus by parr acclimated to 4 C (39.2 F) occurred at approximately 15 C (59 F) (Fisher and Elson, 1950), and Mantelman (1958; cited in European Inland Fisheries Advisory Commission, 1969) found the zone of preferred temperature for young Atlantic salmon was between 9 and 17 C (48.2 and 62.6 F). Javaid and Anderson (1967a) found that the temperature selected by fingerling Atlantic salmon increased with temperature over an acclimation range of 5 to 20 C (41 to 68 F), the final preferendum being about 17 C (62.6 F). In a companion paper, Javaid and Anderson (1967b) found that within 24 to 48 hours after cessation of feeding the selected temperature shifted upward 2 C (3.6 F). However within 24 hours after resumption of feeding, the selected temperature returned to the prestarvation level.

Peterson and Anderson (1969) found that underyearling activity peaks measured after one to six hours stabilization occurred at temperatures (12 to 15 C, 53.6 to 59 F) which were near, though slightly below, the selected temperature as determined by Javaid and Anderson (1967a). A second activity maximum occurred as temperatures approached lethal limits, a finding similar to that of Fisher and Sullivan (1958) for brook trout. Fry (1971:83-84) further discussed these findings stating that initial activity shown during a temperature change represented a response to temperature acting as a directive factor, while less pronounced changes observed after allowing stabilization at test temperatures approximated a response to temperature acting as a controlling factor.

Spaas (1960) determined that the ULT_{50} for Atlantic salmon yearlings was about 28.5 C (83.3 F) when exposed to temperature increases of 1 C (1.8 F)/ day until death. This temperature was felt to approximate the ultimate upper incipient lethal temperature. Parr exposed to a similar temperature rise had a ULT_{50} of 29.2 C (84.6 F). Huntsman (1942), working with parr of the same age and older, acclimated fish to 25 C (77 F) and raised the test temperature at the rate of 1 C (1.8 F)/ 5 minutes. Huntsman found that fish died at between 32.9 and 33.8 C (91.3 and 93.9 F), with larger parr dying first. Using fish of similar length, Alabaster (1967) determined that from an estimated acclimation temperature of 10.9 C (51.7 F), the 1000-minute ULT_{50} was 24.9 C (76.9 F) and the 100-minute ULT_{50} was 24.7 C (76.5 F).

General and Unspecified

Cooper and Fuller (1945; cited in Ferguson, 1958) found that landlocked salmon selected the 13.6 to 16.2 C (56.5 to 61.2 F) temperature range in Moosehead Lake, Maine. Similarly, Leggett and Power (1969;

cited in Coutant, 1974) found Atlantic salmon to prefer 14 C (57.2 F) water in Newfoundland lakes.

Huntsman (1942) found fish newly arrived from an adjacent estuary died in the Moser River at about 29.5 C (85.1 F), while those long in the river died at about 30.5 C (86.9 F), exemplifying to Huntsman the influence of acclimation. Larger salmon died before grilse, but no parr died.

Discussion of Lethal Temperatures

Lethal temperatures of Atlantic salmon found by the various researchers for larvae and juveniles vary by over 10 C. A brief discussion is needed to place these differences in context. While other variables also influence lethal temperatures, recognized variation occurred in age/size of fish, acclimation temperature, rate of temperature change, and test duration. However, the cited authors all used differing variable combinations, thereby making direct comparisons difficult.

Huntsman (1942) testing fish from the highest estimated acclimation temperature and using shortest exposure time, found the highest lethal temperatures. Bishai (1960) using the lowest acclimation temperature and longest exposure time, found the lowest lethal temperature. Lethal temperatures determined by Alabaster (1967) and Spaas (1960) fell in between.

While test methods differed it seems possible to assign relative temperature tolerances to the various life history stages which have been studied. It appears that tolerance increases with age from alevins to parr (Spaas, 1960), parr tolerance decreases with age (Huntsman, 1942), and smolt tolerance is below that of parr (Alabaster, 1967).

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BROWN TROUT

Distribution

A native of Europe and western Asia, brown trout has been widely introduced into other parts of the world. In North America brown trout is now found in almost all Canadian Provinces (Scott and Crossman, 1973:199), and in many eastern and western states.

Spawning

Brown trout have been observed to spawn between October (O'Donnell and Churchill, 1954; cited in Carlander, 1969:232) and January (Carl, 1938; cited in Scott and Crossman, 1973:199) (Table TR-1), and the NTAC (1968:33, 43) has provisionally recommended 55 F (12.8 C) as being the maximum temperature compatible with trout spawning. Several references to brown trout spawning temperatures are cited in European Inland Fisheries Commission (1969). *S. trutta* is said to spawn at between 1 and 2 C (33.8 and 35.6 F) (Vernidub, 1963), *s.t. lucustris* at between 0.5 and 9 C (32.9 and 48.2 F) (Sakowicz, 1961), and *s.t. caspius* at between 10 and 12 C (50 and 53.6 F) (Vernidub, 1963).

Eggs

Embody (1934) determined incubation periods for brown trout eggs held at various temperatures. Incubation times ranged from 148 days at 1.9 C (35.5 F) to 34 days at 11.2 C (52.2 F) (Table TR-2). Embody made no mention of mortality at the highest incubation temperature. Kowalska (1959; cited in European Inland Fisheries Advisory Commission, 1969) found that while eggs incubated in excess of about 7.5 C (45.5 F) yielded normal hatch, the resultant larvae were smaller in size than for eggs incubated at lower temperatures. According to Spaas and Heuts

Table TR-1. Brown trout spawning times and temperatures at various locations.

	Temperature				
Date	C	F	Location	Comment	Author
October			Brule River, Wisconsin		O'Donnell and Churchill, 1954*
October			Montana		Posewitz, 1962*
October-February			Maine		Fenderson, 1958*
Mid October - Early November	(6.7-8.9)	44-48	Southeastern Ontario		Mansell, 1966**
November			Sanborn Creek, Michigan		Greeley, 1932
	(12.8)	55		Provisional maximum compatible with spawning	NTAC, 1968:33, 43
Into January			British Columbia		Carl, 1938**

*Cited in Carlander, 1969:232

**Cited in Scott and Crossman, 1973:199

Table TR-2. Incubation times of brown trout eggs held at various temperatures*

Temperature C	Temperature F	Days
1.9	35.5	148
2.7	36.9	143
3.7	38.7	116
4.6	40.3	97.5
5.5	41.9	87
7.0	44.6	66
9.2	48.6	46
10.7	51.3	38.5
11.2	52.2	34

*Adapted from Embody, 1934

(1958; cited in Spaas, 1960), the embryonic development rate, survival, and growth in relation to temperature are characterized by two optima, below 4 C (below 39.2 F), and between 9 and 10 C (48.2 and 50 F), and Markus (1962) stated that observations indicated brown trout to develop normally in water temperatures up to 50 F (15 C). Optimum development of trout eggs is said by Frost and Brown (1967:73, 142) to occur between 45 and 53 F (7.2 and 11.7 C), though successful hatching is said to occur between temperatures of 5 and 13 C (41 and 55.4 F). The NTAC (1968:33, 43) also recommended 55 F (12.8 C) as being the maximum temperature compatible with trout egg development. Gray (1928; cited in Cocking, 1959) observed high mortality when brown trout were reared from eggs incubated at 15 C (59 F). However, Andersen (1929; cited in Altman and Dittmer, 1966:78) indicates 27 C (80 F) as the upper tolerance limit of brown trout embryos.

Larvae

Markus (1962) stated that once brown trout began to feed, growth seemed best at water temperatures of 55 F (12.8 C).

Two papers (Bishai, 1960; Spaas, 1960) have determined upper lethal temperatures for larval stages of brown trout (*Salmo trutta fario*) and sea trout (*S. trutta trutta*). For newly hatch larvae raised from 6 C (42.8 F) to the final test temperature over a 6 hour period, the 7-day ULT at the final test temperature was interpolated to be about 22.8 C (73.1 F) for brown trout, and was 22 C (71.6 F) for sea trout (Bishai, 1960). The interpolated 24-hour ULT was 24.7 C (76.5 F) for brown trout, and 23.9 C (75.1 F) for sea trout.

Spaas (1960) determined upper lethal temperatures for brown trout alevins by the slow temperature rise method at the rate of 1 C (1.8 F)/ day until death, and Bishai (1960) determined alevin upper lethal temperature by the rapid transfer method. Spaas found a ULT_{50} of 25.5 C (77.9 F) which he considered nearly equivalent to the ultimate upper incipient lethal temperature. Bishai found that at the highest acclimation used (20 C, 68 F), the 7-day ULT_{50} was 23 C (73.4 F) for both brown trout and sea trout, though brown trout showed a 24-hour ULT_{50} of 26 C (78.8 F), and sea trout an interpolated 24-hour ULT_{50} of 24.8 C (76.7 F). Rushton (1926; cited in Huntsman, 1942) found 80% fry mortality in waters with temperature no higher than 25 C (77 F).

Juveniles

In the area of a thermal discharge into Lake Michigan, small brown trout (mean 44 g) had a mean internal temperature of 19.9 C (67.9 F), a near correspondence with plume water temperatures. (Spigarelli et. al., 1973).

Contrary to results with some other species, Fry (1948) reports metabolic scope and cruising speed for yearling trout increased with temperature to the upper limit of their biokinetic range (according to Fry this limit is 25 C, 77 F) (Figure TR-1).

Based on their review of the literature (Table TR-3), Frost and Brown (1967:139) concluded 7 to 19 C (44.6 to 66.2 F) to be the range in which maximum growth occurs in brown trout. Studies evaluated used test fish ranging from age -0 to at least age IV. Several other investigators have also found best growth within this range (Eipper, 1963; cited in Carlander, 1969:230; Poston et al., 1969; cited in Coutant, 1970). Tarzwell (1957) and NTAC (1968:33,43) felt 68 F (20 C) to be the maximum temperature compatible with brown trout growth. However, Brynildson et al. (1963; cited in Scott and Crossman, 1973:199) state 65 to 75 F (18.3 to 23.9 C) to be the optimum temperature range

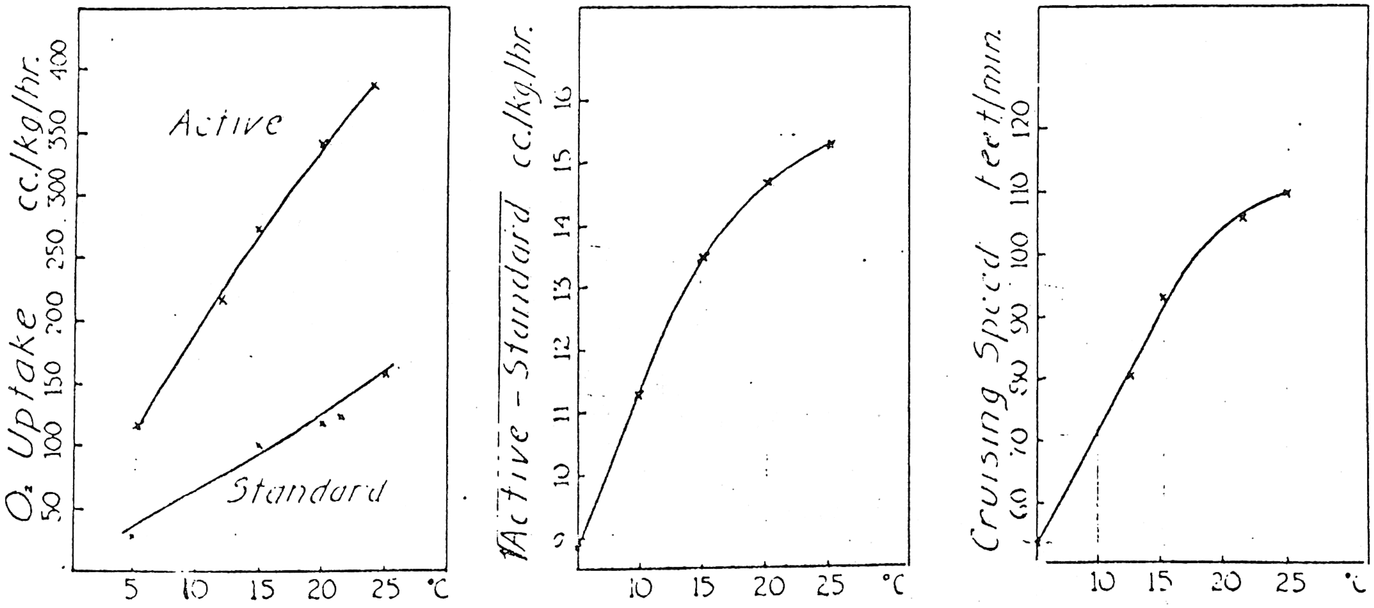

Figure TR-1. The relationship between temperature and metabolism in brown trout. The square root of the difference between the active and standard metabolism is used to compare with the cruising speed since the resistance offered by the fluid to swimming varies with the square of the velocity. From Fry, 1948.

Table TR-3. Optimum temperature ranges for growth and feeding of brown trout*

Age (years)	Growth Optima C	 F	Feeding Optima C	 F	Author
0 - 1/2	12 10	53.6 50			Brown, 1951
0 - 1			7 - 15	(44.6 - 59)	Myers, 1946
1/2 - 1 1/2	10 - 15	(50 - 59)	10	(50)	Pentelow, 1939
1/2 - 1 1/2	10 - 15	(50 - 59)			Wingfield, 1940
1 - 2	12	(53.6)			Swift, 1961
2 - 3	7 - 9 and 16 - 19	(44.6 - 48.2) and (60.8 - 66.2)	10 - 19	(50 - 66.2)	Brown, 1946
3 - 4	8 - 12 and 15 - 16	(46.4 - 58.6) and 59 - 60.8			Swift, 1955
All Ages (?)			5 - 13 and 16 - 19	(41 - 55.4) and (60.8 - 66.2)	Gerrish, 1935
All Ages (?)	15 - 19	(59 - 66.2)			Hewitt, 1943

*Adapted from Frost and Brown, 1967:139.

for brown trout.

Spaas (1960) determined the ULT for brown trout and sea trout yearlings by the slow temperature rise method described above (<u>Larvae</u> section). The ULT of 25.9 C (78.7 F) for brown trout, and 26.4 C (79.6 F) for sea trout were considered to be nearly equivalent to the ultimate upper incipient lethal temperature. For brown trout of similar length, Alabaster and Downing (1966) determined a 1000-minute ULT_{50} of 26.4 C (79.6F) for fish acclimated to 20 C (68 F). While the age of fish was not given, Alabaster and Downing (1966) cite Anonymous (1951) as finding a 26.6 C (79.9 F) ULT_{50} for fish tested with similar acclimation temperature and exposure time.

Alabaster (1967) determined the upper lethal temperature of sea trout parr and smolt held in ambient river water prior to testing. Based upon his earlier findings (Alabaster and Downing, 1966) that small and regular temperature fluctuations did not influence acclimation temperature in trout, Alabaster used the mean river temperature for the month preceding tests as the acclimation temperature (10.9 C, 51.7 F for May tests). Alabaster found a 100-minute ULT_{50} of 24.9 C (76.9 F) for parr tested in May. For smolts tested in May the 100-minute ULT_{50} was 24.8 C (76.7 F), and the 1000-minute ULT_{50} was 24 C (75.2 F). Smolts tested in April at a lower acclimation temperature were found to have slightly lower temperature tolerance.

According to Sullivan (1954) and Fry (1971:82), activity maxima, observed when fish are held at various constant temperatures, reflect temperature acting as a controlling factor, the increased random movement presumably representing the temperature preferendum--the area where the animal is reacting most vigorously to any stray stimuli

(Fry, 1971:83). Preliminary laboratory studies on trout 2 years and older (Tait, 1958; cited in Ferguson, 1958) indicate preferred temperatures within the range of 12.4 and 17.6 C (54.4 and 63.7 F); and field observations by Jammes (1931; cited in Sullivan, 1954) indicate trout stay within the 12 C (53.6 F) isotherm. However, field observations by Spigarelli et al. (1973) in the area of the Point Beach Nuclear Power Plant thermal plume indicated higher preferred temperatures as determined by the near correspondence of internal temperatures with plume water temperatures, large trout (mean 3000 g) having a mean internal temperature of 16.9 C (62.5 F).

General and Unspecified

Tarzwell (1957) cited an example where brown trout were able to tolerate (resist?) a peak temperature of 83 F (28.3 C) in a Michigan river, and Embody (1921) considered limiting temperatures for brown trout in New York to be 83 F (28.3 C). Embody also observed that when he placed brown trout into wooden races supplied with ambient creek waters, distress and loss of appetite occurred when temperatures reached 84.3 F (29.1 C). Fish seemed to recover during the next two days when maximum and minimum temperatures were 70.7 to 82.4 F (21.5 to 28 C) and 71.6 to 83.2 F (22 C to 28.4 C) respectively. However, the third day, 50% of brown trout died at 85.5 F (29.7 C), and despite a night decrease of 75. 2 F (24 C), all fish died the following day at 87 F (30.6 C). From Embody's account, it is not possible to determine whether fish suffered death due to accumulation of sublethal exposures to lethal temperatures, or simply from exposure to maximum temperatures on the final days of the observations. Frost and Brown (1967:136) state exposure to high temperature has a cumulative effect unless the fish can spend periods of several hours at temperatures below about 21 C (70 F).

Data cited in Frost and Brown (1967:136) indicate temperatures lethal to brown trout over several acclimation temperatures and exposure times. These data are given in Table TR-4. The 7 day upper lethal temperature for fish acclimated to 23 C (73.5 F) was 25.3 C (77.5 F), while 26.8 C (80 F) was resisted for 24 hours, and 27.8 C (82 F) was resisted for 12 hours. Working in Poland, Grudniewski (1961; cited in European Inland Fisheries Advisory Commission, 1969) determined upper lethal temperatures for _s.t._ _lacustris_ at various acclimation temperatures during the year and using a 4 C/hour temperature rise. Lethal temperatures ranged from 25 C (77 F) to 30 C (86 F), fish in the latter tests being acclimated to 22 or 23 C (71.6 or 73.4 F).

Schlieper et al. (1952; cited in McCauley, 1958) demonstrated that the ionic composition of the water affected the thermal resistance of brown trout, and Eipper (1963; cited in Carlander, 1969:230) found that retarded fish (reared at below optimum temperatures) had softer fat, and had lower survival rates when shocked, particularly at higher temperatures.

Table TR-4. The maximum temperatures at which half the brown trout survived for different periods.*

Acclimatization Temperature		DURATION OF TEST							
		12 hours		24 hours		48 hours		7 days	
C	F	C	F	C	F	C	F	C	F
5	41	22.5	72.5	22.5	72.5	22.5	72.5	22.5	72.5
10	50	24.5	76	24.2	75.5	24.2	75.5	24.2	75.5
15	59	26.2	79	25.6	78	25.1	77	24.5	76
20	68	26.5	80	26.3	79.5	25.8	78.5	24.8	76.5
23	73.5	27.8	82	26.8	80	26.4	79.5	25.3	77.5

*From data cited in Frost and Brown, 1967:136.

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LAKE TROUT

Distribution

The lake trout occurs in the Great Lakes and in colder lakes of the St. Lawrence, Hudson River and the Great Lakes drainages northwestward to northern British Columbia, Alaska and the Canadian northern provinces (Eddy, 1969:53; Scott and Crossman, 1973:221).

Spawning

There exists a large variation in spawning times reported for lake trout, ranging from between mid August (Rawson, 1961; cited in Carlander, 1969:291) and December (Eschmeyer, 1957b; cited in Carlander, 1969:290) (Table NA-1) Temperatures observed during spawning are less often reported but range from 37 to 58 F (Royce, 1951) (Table NA-1).

Eggs

Embody (1934) and Garside (1959) have determined incubation periods for lake trout eggs held at various temperatures between 1.5 and 10 C (34.7 and 50 F). In general their findings are similar (Table NA-2). The data of Garside in Table NA-2 are for eggs held in water saturated with oxygen. For those eggs held at oxygen levels permitting development but below saturation, incubation times were longer. While neither Embody or Garside report mortalities for eggs incubated under favorable conditions within the temperature range utilized, the Great Lakes Fishery Laboratory (1972, 1973) has reported many survivors for eggs incubated at 43 to 47 F (6.1 to 8.3 C), and 43% hatch at 50 F (10 C). Royce (1951) reported high mortalities for eggs incubated above 50 F.

Table NA-1. Lake trout spawning times and temperatures at various locations.

Date	Temperature C	F	Location	Comment	Author
Mid August			Great Bear Lake, Saskatchewan	66° N. Lat.	Rawson, 1961*
Mid September			Great Slave Lake, Sasketchewan	62° N. Lat.	
Early October			Lake LaRonge, Sasketchewan	55° N. Lat.	
	11-14	(51.8-57.2)	Lake Simcoe, Ontario		McCrimmon, 1958*
September-November			Great Lakes		Eschmeyer, 1957a*
October - November			New Hampshire		Newell, 1960*
October - November			Southern portion of range		Lagler, 1956:32
		37 - 58	New York		Royce, 1951
October - November			Southern Great Lakes		AEC, 1972:A-65, 67
Late Fall			Lake Erie		Trautman, 1957

Table NA-1 (Continued)

Date	Temperature C	F	Location	Comment	Author
Mid October - Early November	(10)	50	Maine		DeRoche, 1969
Mid October - Mid November			Maine		DeRoche, 1958*
Late October - Mid November			Watertown Lakes Alberta		Currier and Schultz, 1957
Early - Mid November			Southeastern Lake Michigan		Great Lakes Fishery Laboratory, 1972, 1973
Late October	13	(55.4)	Green Lake, Wisconsin	Peak, under age 10	Hacker, 1962*
Late November	7	(44.6)		Peak, older fish	
Into December			New York		Eschmeyer, 1957b*
	(8.9)	48		Maximum compatible with spawning	NTAC, 1968:33, 43

*Cited in Carlander, 1969:290, 291

Table NA-2. Incubation times of lake trout eggs held at various temperatures*

Temperature		Days	
C	F	Garside	Embody
1.8	35.2		162
2.5	36.5	141	
4.5	40.1		106
5.0	41.0	(91)**	
5.1	41.2		86.3
5.7	42.3		92
6.7	44.1		80.5
7.5	45.5	67	
8.5	47.3		59
10.0	50.0	50	49

*From data in Embody (1934) and Garside (1959)
**Accidently lost on day 91

Juveniles

Eschmeyer (1956) noted that in Lake Superior, young-of-year lake trout were found most often at temperatures between 42 and 63 F (5.6 and 17.2 C) while those in age groups I and II were found in somewhat cooler water (39 to 53 F; 3.9 to 11.7 C). However, off Isle Royale, Eschmeyer (1956) felt it possible the water temperatures in the depths at which most small lake trout were caught did not exceed 43 F (6.1 C). Martin (1951) found small lake trout had a deeper distribution than did larger fish in two Algonquin Park, Ontario, lakes during mid summer. The 8 C (46.4 F) isotherm separated those above and below 12 inches in length. The Great Lakes Fishery Laboratory (1972) also reported that some size-depth relation was evident in southeastern Lake Michigan in June, with average length of fish decreasing with depth. Overall best catches were reported for the 44.8 to 53.8 F (7.1 to 12.1 C) temperature range. The size-depth relation was not as conspicuous during other samplings. Galligan (1962) could find no distinct differences in depth distribution of different age groups in Cayuga Lake, New York, trout being captured more frequently in the 45 to 55 F (7.2 to 12.8 C) isothermal range.

In laboratory studies of preferred temperature of yearling lake trout in a vertical gradient, McCauley and Tait (1970) found that the acclimation temperature had virtually no effect on the preferred temperature, and that the final preferendum was 11.7 C (53.1 F), a temperature which they considered to be about 2 C (3.6 F) warmer than the temperature at which lake trout are most often caught in thermally stratified lakes. Similarly, laboratory studies by Goddard et al. (1974; cited in Coutant, 1974) found young lake trout to prefer 11.5 C

(52.7 F) water and found 14 C (57.2 F) to be the upper avoidance temperature.

The temperature preferences cited above are lower than the 17 to 18 C (62.6 to 64.4 F) reported by Fry (1948) as being the optimum for peak cruising speed and metabolic scope in yearling (?) lake trout. In a later paper, Gibson and Fry (1954) found maximum swimming speed for one and two year old trout in the region of 16 C (60.8 F), and estimated (apparently) the 7-day ultimate upper lethal temperature to be 23.5 C (74.3 F).

General and Unspecified

Additional field data (cited in Ferguson, 1958) indicated a lake trout preference for water between 8 and 15.5 C (46.4 and 59.9 F). These and other field data are presented in Table NA-3, more recent data tending to reaffirm earlier findings.

Table NA-3. Field observations of lake trout and associated temperatures.

Temperature				
C	F	Location	Comment	Author
13.9-15.0	57 - 59	Redrock Lake, Ontario	Moved into deeper water	Martin, 1951
	up to 64	Redrock Lake, Ontario	frequently penetrated	
14	(57.2)	White Lake, Ontario	Peak migration from this to a deeper lake	Kennedy, 1940; cited in Ferguson, 1958
(7.2-12.8)	45 - 55	Lake Cayuga, New York	More frequently during alewife inshore movement	Galligan, 1962
(18.3)	up to 65			
		Lake Ontario	Noted same inshore movement as did Galligan, 1962	Dymond, 1928; cited in Galligan, 1962
5.0 - 10.0	41 - 50	Several lakes in Saskatchewan	Preferred rather than warmer surface water (55-59)	Rawson, 1960
10 - 13	(50 - 55.4)	Moosehead Lake, Maine	Especially abundant	Cooper and Fuller, 1945; cited in McCauley and Tait, 1970
5 - 13	(41.0 - 55.4)	Lac LaRonge, Saskatchewan	Range	Rawson, 1961; cited in McCauley and Tait, 1970
8 - 10.9	(46.4 - 51.7)		Largest concentrations	
10.0	(50)	Algonquin Park Lakes, Ontario	Found in shallow water	Fry, 1940; cited in Carlander, 1969:291

Table NA-3 (Continued)

Temperature C	F	Location	Comment	Author
(7.8-12.2)	46 - 54		Most abundant from previous experience, all but very young	Great Lakes Fishery Laboratory, 1972, 1973
(7.1-12.1)	44.8 - 53.8	Southeast Lake Michigan	Largest catches reported, summer	Great Lakes Fishery Laboratory, 1972

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RAINBOW SMELT

Distribution

The original range of the (Atlantic) rainbow smelt appears to have been restricted to the Atlantic coastal drainage from about New Jersey to Labrador and indigenous landlocked populations in many parts of northeastern North America; introductions have greatly extended inland populations (Scott and Crossman, 1973:313).

Spawning

Spawning season for rainbow smelt varies with location, and is reported from early spring (AEC, 1972:A-71) to late July (McKenzie, 1958, 1964; both cited in Carlander, 1969:315) (Table MO-1). Spawning runs have been observed at temperatures ranging from 37 to 59 F (Greene, 1930), and spawning observed at between 2.2 and 14.5C (36 and 58.1 F) (Hale, 1960; cited in Carlander, 1969:315) (Table MO-1).

Eggs

Incubation of smelt eggs has been observed to take between 19 and 20 days at 5 to 8 C (41 to 46.4 F), and 10 days at 15 C (59 F) (studies cited in Carlander, 1969:314).

Juveniles

In Lake Erie, young were common in shallow water and in the epilimnion at temperatures over 21 C (69.8 F) in summer (Ferguson, 1965; cited in Carlander, 1969:314).

Growth in Lake Erie ends in early to mid October when temperatures drop to 65 F (18.3 C) (Commercial Fisheries Review, 1961).

Table MO-1. Rainbow smelt spawning times and temperatures at various locations.

	Temperature				
Date	C	F	Location	Comment	Author
Early spring					Lagler, 1956:25
Early spring	(3.9-5.6) (10)	39 - 42 50		Spawning run Spawning	AEC, 1972:A-71
Spring		40.0 - 42.0	Maine	Sea-run forms enter streams	Bigelow & Shroeder, 1953, cited in Breder & Rosen, 1966:127
		37.0 - 59.0 37.0 - 54.0	Canadaiqua and Oswego Lakes, New York	Range, spawning run Frequent, spawning run	Greene, 1930
April-May			New Hampshire		Newell, 1960; cited in Carlander, 1969: 315
Mid-Late April	2.2-14.5	(36.0 - 58.1)	Lake Superior		Hale, 1960; cited in Carlander, 1969:315
April - late July			New Brunswick		McKenzie, 1958, 1964; both cited in Carlander, 1969:315

Adults

In Lake Erie, adults were restricted in summer to water cooler than 15.5 C (59.9 F) and were more abundant at temperatures below 7 C (44.6 F) (Ferguson, 1965; cited in Carlander, 1969:314).

Huntsman and Sparks (1924) found that in 19 specimens (15 to 21 cm, length measure unspecified) held within the range of 10.2 and 15 C (50.4 and 59.0 F), the range of lethal temperatures was 21.5 to 28.5 C (70.7 to 83.3 F) when water was elevated from ambient at the rate of about 1 C (1.8 F)/5 minutes. While the authors felt laboratory conditions produced death before those to be expected in nature, it must also be noted that time to death at any exposure temperature was within 5 minutes, and therefore these temperatures were within the area commonly designated the zone of resistance. These data suggest that for fish exposed to high temperatures for any prolonged period (e.g., 24 hours) the lethal temperatures would have been lower.

General and Unspecified

According to Galligan (1962) smelt occur chiefly below the 55 F (12.8 C) isotherm in Lake Cayuga, New York, and Greene (1930) found that in Lake Champlain they preferred 55.4 F water and avoided water at temperatures greater than 59 F. Wells (1968) found that during summer, smelt in southeastern Lake Michigan were most abundant in waters between 6 and 14 C (42.8 and 57.2 F).

Hart and Ferguson (1966; cited in Scott and Crossman, 1973:315) suggested most of the smelt population in Lake Erie occupied water of about 45 F (7.2 C) although they would enter 60 F (15.6 C) water for brief periods.

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STONEROLLER MINNOW

Distribution

The stoneroller minnow, in its various subspecies, is found from southern North Dakota to Texas east to the Appalachians and to western New York (Trautman, 1957; cited in Carlander, 1969:364).

Spawning

Nest building usually begins at temperatures between 55 and 60 F (12.8 and 15.6 C) in June in New York (Miller, 1964), and spawning may occur from mid-April to early June in water temperatures of between 58 and 75 F (14.4 and 23.9 C) (Miller, 1962; cited in Miller, 1964).

In Illinois, one study (Smith, 1935; cited in Carlander, 1969:365) nest building was found to start in mid-April at 12 C (53.6 F) and spawning continue to early June at water temperatures of 24 to 27 C (75.2 to 80.6 F). Also in Illinois, Hankinson (1919) found stonerollers to spawn from late March to late May when water temperatures were between 65 and 80 F (18.3 and 26.7 C).

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ROSY DACE

Distribution

The rosy dace is found in headwater streams from Chesapeake Bay and W. Virginia south to North Carolina and Tennessee (Eddy, 1969; Trautman, 1957).

General and Unspecified

No temperature related life history data have been found for this species.

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CARP

Distribution

Originally Asiatic in distribution, carp have been introduced into many parts of the world, including some waters in most parts of the United States (Carlander, 1969:369).

Spawning

Carp spawn between March (Swingle, 1956; cited in Carlander, 1969: 388) and late August (Cross, 1951; cited in Carlander, 1969:388) depending on location (Table CA-1). Spawning has been reported to begin at 14.5 C (Sigler, 1958; cited in Carlander, 1969:388), and extend to 25 C (Shikhshabekov, 1969; cited in Coutant, 1971), though optimum spawning conditions apparently occur at more restrictive intermediate temperatures (Table CA-2).

Eggs

In field studies of carp in Lake St. Lawrence, Ontario, incubation time for eggs was 4 to 8 days at 16.7 C (62.1 F) (Swee and McCrimmon, 1966).

Burns (1966; cited in EPA, 1974) states 17 to 22 C (62.6 to 71.6 F) to be the range of successful incubation, and Tatarko (1965; cited in European Inland Fisheries Advisory Commission, 1969) reports hatch is less than 60% at temperatures above 22 C (71.6 F). Abnormalities in those hatching were greater than 20% at 27 C (80.6 F) and above (Tatarko, 1965; Shuliak, 1965; both cited in European Inland Fisheries Advisory Commission, 1969). Shuliak (1965; cited in European Inland Fisheries Advisory Commission, 1969) also found that carp embryos survived a change from 20 to 30 C (68 to 86 F) better than embryos transferred from 30 to 20 C

Table CA-1. Carp spawning times at various locations*

Date	Location	Author
March	Alabama	Swingle, 1956
April - June	Illinois	Richardson, 1913
May and June (two spawnings)	South Dakota	Fogle, 1961a
May and Late July (two spawnings)	South Dakoa	Fogle, 1961b
May - July	Nevada	LaRivers, 1962
May - Late August	Oklahoma	Cross, 1951
Mid May - Mid August	Wisconsin	Black, 1948; data cited in Carlander, 1969:388
Late May - Late June	South Dakota	Sprague, 1959
Early June	South Dakota	Shields, 1956; Sprague, 1961; Walburg, 1964
Early June	Michigan	Data cited in Carlander, 1969:388

*From data cited in Carlander, 1969:388

Table CA-2. Carp spawning temperatures.

Temperature			
C	F	Comment	Author
14.5 - 17	(58.1 - 62.6)	Begin	Sigler, 1958*
17 - 20	(62.6 - 68)	Spawning	Kryzhanovskii, 1949**
17 - 25	(62.6 - 77)	Spawning	Shikhshabekov, 1969***
18.5 - 20	(65.3 - 68)	Most active	Sigler, 1958*
19 - 23	(66.2 - 73.4)	Optimum	Swee and McCrimmon, 1966****

*Cited in Carlander, 1969:388

**Cited in European Inland Fisheries Advisory Commission, 1969

***Cited in Coutant, 1971

****Cited in EPA, 1974

(86 to 68 F), though percentage success in each case was not reported. Frank (1973; cited in EPA, 1974) reported abnormal larvae after embryos received a shock to 35 C (95 F).

Tatarko (1968) subjected artificially fertilized spawn acclimated to 20 C (68 F) to the effects of high temperature during different periods in their embryology. The embryos in the period from the beginning of division to beginning of gastrulation, and from the formation of the tailbud to hatching were the stages most sensitive to test temperatures of 30 and 31.5 C (86 and 88.7 F). In the first stages 82 - 93% of the fertilized spawn died and in 30 - 76% of those surviving, various defects in structure were found; in the latter stages about 23% of the spawn died, with 23 - 27% of the surviving hatch showing anomalies.

Larvae

For the early fry stages, growth per day was found by Timmermans (1962; cited in Carlander, 1969:386) to be positively correlated with water temperature between 14.5 and 18.5 C (58.1 and 65.3 F), while after feeding started the effect was less evident. Increased growth and development of larvae with increasing temperatures 16 to 30 C (60.8 to 86 F) was also seen by Tatarko (1966). The best temperature for development of carp would be situated, according to Huet (1953; cited in Meuwis and Heuts, 1957), between 20 and 25 C (68 and 75 F), while according to Schaeperclaus (1949; cited in Meuwis and Heuts, 1957), the optimum is nearer to 27 C (80.6 F).

For larvae and fry grown at a constant temperature of 23 C (73.4 F) and then subjected to the effects of high temperatures (36 and 38 C, 96.8 and 100.4 F), Tatarko (1970) reports that those at 36 C

(96.8 F) experienced "stable" development at all stages, while those exposed to 38 C (100.4 F) showed a "high sensitivity" during the earliest post embryonic stages, sensitivity gradually decreased with age (in the abstracted article "stability" and "high sensitivity" are not defined).

Coutant et al. (1974: 25-26 briefly report investigations of the thermal sensitivity of various stages of carp larvae (0.5 to 30 days old), acclimated to 25 C (77 F), to a 10 minute thermal shock of between 35 and 38 C (95 and 100.4 F). Mortality after 24 hours was reported and indicated that the per cent mortality was not only related to shock temperature, but apparently also to nutritional state (Table CA-3). As yolk was exhausted the thermal sensitivity of the larvae increased. Larvae were approximately two weeks old before they assimilated enough food to promote growth, at which time susceptibility to thermal shock again decreased. A temperature of 35 C (95 F) was survived by even the most sensitive stages.

Carp were among the young fish (post-sac larvae and early juveniles) passing through the condensers of a nuclear plant in Connecticut studied by Marcy (1971). Few fish survived the trip down the discharge canal at water temperatures at 28.2 C (82.8 F) and no carp survived the trip down the discharge canal when temperatures reached 33.5 C (92.3 F). None survived even the passage through the condenser when temperatures reached 35.5 C (95.9 F). The majority of dead fish were mangled.

Table CA-3. Effects of an acute thermal shock on the survival of *Cyprinus carpio* larvae incubated at 25 C. From Coutant et al. (1974:26)

25 larvae were used in each treatment

Age of larvae at time of shock (days)	Number of larvae that died within 24 hr following a 10-min thermal shock (from 25°) at -				
	25 C	35 C	36 C	37 C	38 C
0.5	0	0	0	0	0
1	0	0	0	0	0
2	0	0	0	1	8
3	0	0	0	10	22
4	0	0	0	7	24
5	0	0	3	23	25
6	0	1	6	25	25
7	0	0	2	25	25
8	0	0	8	25	a
9	0	1	13	25	a
10	0	1	9	25	a
11	0	0	9	25	a
12	0	0	4	25	a
19	0	0	0	5	12
30	0	0	0	0	0

[a] No larvae shocked at this temperature.

Juveniles

In one study greatest food intake was observed at between 23 and 27 C (73.4 and 80.6 F) (Mantelman, 1958; cited in European Inland Fisheries Advisory Commission, 1969), and in another (Shkorbatov, 1954; cited in European Inland Fisheries Advisory Commission, 1969) a marked reduction in feeding intensity was recorded at 29 to 30 C (84.2 to 86 F). In Israel where water temperatures are between 11 and 19 C (51.8 and 66.2 F) carp may grow even in winter (Yashouv, 1954, 1958; Wirszubski and Ivri, 1954; all cited in Carlander, 1969:386).

Carp within their first year (2-3 inches in length) were tested for their temperature preference by Pitt et al. (1956). The preferred temperature rose with the acclimation temperature (Figure CA-1). No unusual behavior was noted at any acclimation temperature except at the extremes. At 10 C (50 F) the carp fed poorly and movements were slow. In the 35 C (95 F) acclimation environment the fish were extremely active and moved rapidly around the experimental tank. The final temperature preferendum was 32 C (89.6 F).

According to Beamish (1964) the final preferendum found by Pitt et al. (1956) was suggestively close to the 25 to 30 C (77 to 86 F) range of maximum spontaneous activity which he found for 100 gm carp, the suggestion being for a physiological optima in this temperature region. As further evidence for this possibility, Neill and Magnuson (1974) found that young carp concentrated in 29 C (84.2 F) water and the midpoint of the preferred temperature range was 31.8 C (89.3 F) in the laboratory.

Meuwis and Heuts (1957) examined, among other variables, the effects of size upon lethal temperatures in a small sample of carp

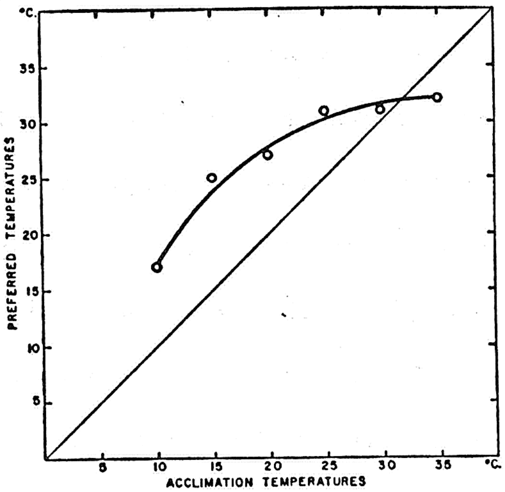

Figure CA-1. The relation of preferred temperature of carp to acclimation temperature. From Pitt et al., 1956.

ranging in age from one-third year to four years. For carp between one-third and one-half year old, the lethal temperature ranged between 38 and 39 C (100.4 and 102.2 F).

Adults

During the summer body temperatures of large fish (323-586 mm) around a thermal discharge were approximately 30.6 C (87.1 F) during the day, while at night their body temperatures were slightly lower (29.8 C, 85.7 F) (Neill and Magnuson, 1974). Spigarelli et al. (1973) found large carp off the Point Beach Nuclear Power Plant had lower body temperatures, the mean ranging from 20.7 to 24.8 C (69.3 to 76.7 F).

Two to four year old carp tested by Meuwis and Heuts (1957) had a lethal temperature of between 35 and 36 C (95 and 96.8 F).

General and Unspecified

In Lewis and Clark Lake, bordering South Dakota and Nebraska, Walburg (1969) found catch per unit effort was greatest (66% of total) at temperatures between 15.6 and 26.1 C (60.1 and 79 F) (the highest temperature recorded).

Several authors, including Gammon (1973), Neill and Magnuson (1974), Proffitt (1969), Proffitt and Benda (1971), and Trembley (1960, 1961) have recorded observations on carp in heated water discharges. Neill and Magnuson's observations have already been noted (see Juvenile and Adult sections).

In one observation, Trembley (1961:IX-11 to IX-12) reports carp showing no temperature preference in a heated water lagoon ranging in temperature from 73 to 90 F (22.8 to 32.2 C), and on another date carp were seen swimming in 94 to 96 F (33.4 to 35.6 C) water with no (apparent) ill effects (Trembley, 1960:IX-8). Gammon (1973:44) reported carp showed a preference for water between 33 and 35 C (91.4 and 95 F). Proffitt (1969) observed carp in effluent water at temperatures up to 93 F (33.9 C) and more recently (Proffitt and Benda, 1971:38) in water up to 97 F (36.1 C).

Heat death was noted by Trembley (1960:IX-8) when fish were frightened from 83 to 92 F (28.3 into 33.3 C) discharge water, a lethal temperature within the 24-hour upper LT_{50} of 31 to 34 C (87.8 to 93.2 F) 24 hour upper LT_{50} range reported by Black (1953) for fish acclimated to 20 C (68 F). For fish acclimated to 26 C (78.8 F) the 24-hour upper LT_{50} was 35.7 C (96.4 F).

European studies testing lethal (and disturbing) temperatures in carp are summarized in Table CA-4 (from European Inland Fisheries Advisory Commission, 1969). The highest lethal temperature reported (by Horoszewicz, 1966) was 40.6 C (105.0 F) for fish acclimated to 26.3 C (79.4 F) and slowly heated at the rate of 3 C/hour.

Table CA-4. European studies of disturbing and lethal temperatures in carp.*

Locality	Temp. (C)	Time	Increase in temp. (C/hr)	Disturbing temp. (C)	Lethal temp. (C)	Author
	5 - 15	180 hr	Immediate	26.3		Kempinska (1960)
(Kharkov)	Ambient			30.7-31.3	35.1-36.3	Shkorbatov (1954)
(Kharkov)	3 - 10	2 months	6		29.1	Shkorbatov and Kudriavtseva (1964)
	8 - 12				28.1	
	13 - 15				30.2	
	18 - 20				3.22	
	24 - 26				28.2	
(Kharkov)	15 - 17	30-40 days	6		35.4	Shkorbatov (1964)
(Leningrad)	15 - 17	30-40 days	6		34.0	Shkorbatov (1964)
(Warsaw)	Ambient to 22.5	1-1 1/2 mos.	6	28.3	39.0	Opuszynski (1965)
(Heated lake - Poland	26.3		3	34.8	40.6	Horoszewicz (1966)

*From European Inland Fisheries Advisory Commission, 1969

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TONGUETIED MINNOW

Distribution

The tonguetied minnow is found in the Kanawha River drainage of Virginia, West Virginia, and the Allegheny River system (Eddy, 1969), and in the Ohio River system in Ohio (Hubbs and Lagler, 1958; Trautman, 1957). Two subspecies are located in three disjunct eastern and east central areas.

Spawning

Raney (1939; cited in Carlander, 1969:436) reports nesting of this species in June in Pennsylvania, at a temperature of 20.5 C (68.9 F) (Raney, 1939; cited in Breder and Rosen, 1966:190).

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CUTLIPS MINNOW

Distribution

The cutlips minnow is found from Lake Ontario and the St. Lawrence south into Virginia (Eddy, 1969).

Spawning

In Maryland spawning occurs in May (Schwartz, 1963; cited in Carlander, 1969:391), while in New York nest building begins in mid (Hankinson, 1922) to late May (Miller, 1964; Van Duzer, 1939), and may extend until mid July (Van Duzer, 1939). In one study (cited in Van Duzer, 1939), spawning activity peaked before mid June.

On one occasion (Hankinson, 1922), nest building was seen, but on the following day when the water temperature was taken (57 F), the fish had stopped working. Examined fish had large gonads, but eggs could not be stripped. On another occasion (Van Duzer, 1939), breeding was observed between water temperatures of 62.6 and 70.7 F.

General and Unspecified

On two occasions in winter, Trembley (1961:IX-12) reports collecting several cutlips minnows in heated discharges in the Delaware River when temperature gradients were 32 to 65 F (0 to 18.3 C) and 50 to 67 F (10 to 19.4 C).

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BLUEHEAD CHUB

Distribution

The bluehead chub has an extensive distribution extending from the Potomac River drainage along the Atlantic coast to the lower Mississippi drainage on the Gulf coast (Lachner and Wiley, 1971). Three recognized subspecies exist according to Lachner and Wiley (1971).

General and Unspecified

Generally, the species of *Nocomis* prefer clear, moderate to warm streams of moderate gradient (Lachner and Jenkins, 1971).

A publication by Lachner on the nesting, reproduction and behavior of the genus *Nocomis* is in preparation.

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RIVER CHUB

Distribution

The river chub is native to a large portion of the northeastern United States and does not occur west of the Mississippi River. Its range on the Atlantic slope is southward from the Susquehanna drainage in New York to the James drainage in Virginia, absent southward except for a population in the upper Savannah drainage. The only known population on the Gulf of Mexico slope occurs in one river system in the Mobile Bay drainage. West of the Appalachian divide it occurs from the Tennessee drainage tributaries of northern Alabama and southwestern Tennessee, and from the Wabash drainage of Illinois up throughout most of the Ohio River drainage. It is found in the Great Lakes drainage of the Lower Peninsula of Michigan eastward to Lake Ontario tributaries in New York and Ontario. (Lachner and Jenkins, 1971a).

Spawning

In New York the river chub has been recorded nest building between late May and early June at water temperatures between 53.5 and 69 F (11.9 and 20.6 C)(Miller, 1964). During one year, most nests built in early June as the water temperatures gradually increased from 60 to 67 F (15.6 to 20.6 C) (Miller, 1964). In Illinois, nest building occurred in the wider seasonal interval of from late May to early July at temperatures of between 67 and 82 F (19.4 and 27.8 C)

53.5 and 69 F.

(Hankinson, 1919)*. A spawning time of late May to early June given for Hybopsis kentuckienis in southern Michigan (Forbes and Richardson, 1908; cited in Hankinson, 1919) is not considered here to describe the river chub.

More information on river chub spawning should be forthcoming when a study by Lachner on the nesting, spawning and behavior within the genus Nocomis, currently in preparation, is published.

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*The inclusion of this data for river chub is provisional. Hankinson (1919) made his observations of Hybopsis kentuckiensis (Rafinesque) in the Kaskaskia and Embarrass River drainages near Charleston, Illinois. The species H. kentuckiensis has since been dissolved and specimens incorporated into at least six species of the genus Nocomis (Lachner and Jenkins, 1971a, 1971b), however, based on species ranges given in Lachner and Jenkins (1971a, 1971b), Hankinson's descriptions could only refer to N. micropogon (river chub) or, more probably, N. biguttatus (hornyhead chub). According to Trautman (1957), before 1925 literature records for these two species were a composite; thus further complicating early literature.

The distributional range of N. biguttatus given by Lachner and Jenkins (1971b) includes the Kaskaskia River drainage, but not the Embarrass River drainage, in Illinois. Neither drainage is within the distributional range of N. micropogon as given by Lachner and Jenkins (1971a).

The discussion by Lachner and Jenkins (1971a) (and apparently their distributional map) is based on the 1965 paper by Smith which presents an annotated list of the lampreys and fishes of Illinois. In that paper, Smith states that Hybopsis (Nocomis) micropogon is known only from the Wabash River in Lawrence and Clark Counties.

The Kaskaskia River drainage thus appears to be within the range of only N. biguttatus, and the Embarrass River drainage within the published range of neither N. biguttatus nor N. micropogon. Nevertheless, the inclusion of Hankinson's data under Carlander's (1969) discussion of the river chub has tentatively dictated its inclusion here under that species.

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BIGMOUTH CHUB

Distribution

The bigmouth chub is a western Appalachian slope species confined to, and widely distributed in the New River drainage of West Virginia, Virginia, and North Carolina (Lachner and Jenkins, 1971).

General and Unspecified

Generally, the species of *Nocomis* prefer clear, moderate to warm streams of moderate gradient (Lachner and Jenkins, 1971).

A publication by Lachner on the nesting, reproduction and behavior of the genus *Nocomis* is in preparation.

References Cited

Lachner, E. A., and R. E. Jenkins 1971. Systematics, distribution, and evolution of the chub Genus Nocomis Girard (Pisces, Cyprinidae) of eastern United States, with descriptions of new species. Smithsonian Contr. Zool. No. 85, 97 p.

GOLDEN SHINER

Distribution

The golden shiner has a wide ranging distribution from Saskatchewan to Quebec and southward to Florida and south central Texas (Pflieger, 1971). It is unclear from the literature whether subspecies are generally recognized. Several authors (Eddy, 1969; Hart, 1952; Hubbs and Lagler, 1958; Trautman, 1957) recognize several, while more recently Pflieger (1971), based on the work of Bailey et al. (1954; cited in Pflieger, 1971) seems to feel this splitting unwise.

While Hart (1952) found a considerable geographic variation in morphological characters in specimens from Ontario, Ohio and Florida, he found an absence of physiological variation. For the present purposes then, the species is treated as a unit.

Spawning

Spawning has been reported between May (e.g., Forbes and Richardson, 1908; cited in Carlander, 1969:412) and August (e.g., Hubbs and Cooper, 1936; cited in Breder and Rosen, 1966:214) at temperatures between 15.6 C (60 F) (Wojtalik, unpublished; cited in NAS, 1973) and 21 C (69.8 F) Forney (1957; cited in Carlander, 1969:412) (Table CR-1).

Eggs

Hatching occurs in 4 days at 15.6 C + (60.1 F^{+})(Wojtalik, unpublished; cited in NAS, 1973).

Juveniles

Trembley (1960:IX-8) reports young-of-the-year golden shiners

Table CR-1. Golden shiner spawning times and temperatures at various locations.

Date	Temperature C	F	Location	Comment	Author
Late spring - Early summer					Breder and Rosen, 1966:213
May and July			Illinois		Forbes & Richardson, 1908*
May - July			New York		Scott and Crossman, 1973:436
May - August	20 - 21	(68-69.8)		Most spawning at these temperatures	Forney, 1957*
June - August			Michigan	Some evidence begins in May	Hubbs and Cooper, 1936***
June - August			Michigan		Scott and Crossman, 1973:436
Mid June			Eastern Ontario		Toner, 1943*
Mid June			Wisconsin		Cahn, 1927***
Early August			Nova Scotia	Midst of spawning	Smith, 1939**
	(20)	68		Spawning commences	Dobie et al., 1956**
	15.6	(60)			Wojtalik, unpublished****

*Cited in Carlander, 1969:412
**Cited in Scott and Crossman, 1973:436
***Cited in Breder and Rosen, 1966:214
****Cited in NAS, 1973

killed in a Delaware River heated water discharge though the date and the temperature of the water were unreported.

Adults

Brett (1944) documented the seasonal variation in lethal temperatures for several fish species in Algonquin Park, Ontario, including the golden shiner (3.49 in. mean length) (Figure NE-3). The maximum lethal temperature recorded was 33.4 C (92.1 F) when the average water temperature was about 22 C (71.6 F).

More recently, Alpaugh (1972) describes superficial tests on three golden shiners (ranging in length between 7-8 cm, and weight between 2.2-3.5g). For fish acclimated to 22 C (71.6 F) he found that by raising the temperature by 0.75 C (1.35 F)/day two fish died at 39.5 C (103.1 F), and the third fish at 40 C (104 F).

General and Unspecified

Trembley (1961:II-12 to IX-13) reports temperature preference observations for golden shiners. On one occasion in a heated discharge temperature gradient of 75-90 F (25 to 32.2 C), shiners were present and observed swimming throughout the maximum temperature levels. On another occasion in a gradient of 84 to 99 F (28.9 to 37.2 C) the shiners present tended to crowd toward the cooler zone. In a final observation in waters from 75 to 100 F (23.9 to 37.8 C), all individuals avoided the 100 F (37.8 C) water and milled about in the cooler area.

Nickum (1966) investigated the effects of rapid temperature changes upon small (1.5-2.5 inch) and large (3 to 4.5 inch) golden shiners within the normal temperature extremes found in the animals environment. He found no particular differences in responses to temperature for the two size ranges. Eighty degrees (26.7 C) was the highest exposure temperature used. Fish tested at this temperature showed seasonally varied responses. In the spring a temperature rise of 20 F (11.1 C) to 80 F (26.7 C) produced 90% mortality after one week, while in winter a rapid change of 29 F (16.1 C) yielded no mortality and a 39 F (21.7 C) change produced only 5% mortality after one week. Changes of 20 F (11.1 C) or less produced mortality only with diseased fish and during the spring and early summer. Though the fish which died during these seasons were found to have nearly mature gonads, Nickum did not determine whether this was actually a determining factor or merely coincidental. No temperature elevation resulted in more than 5% mortality within the first 6 hours. However, it was also observed that mortality was not confined to an immediate reaction to the temperature change, but occasionally continued until termination of the test trial (1 week).

Based on the work of Hart (1952), Nickum's (1966) contention that 80 F (26.7 C) was within the tolerable limits for the species certainly seems valid. According to Hart (1952), only at an acclimated temperature of 0 C (32 F) would 26.7 C (80 F) approximate the lethal temperature (Figure CR-1). Although not determined, Hart (1952) estimated the upper incipient lethal temperature to be approximately 35 C (95 F). Hart (1952) also determined the resistance characteristics of this species (Figure CR-2). Using this figure, it would be predicted that 50% of the fish acclimated to 25 C (77 F) would be able to survive in 35 C (95 F) water for 100 minutes. Field observations by Trembley (1960:IX-8) confirm that resistance is possible

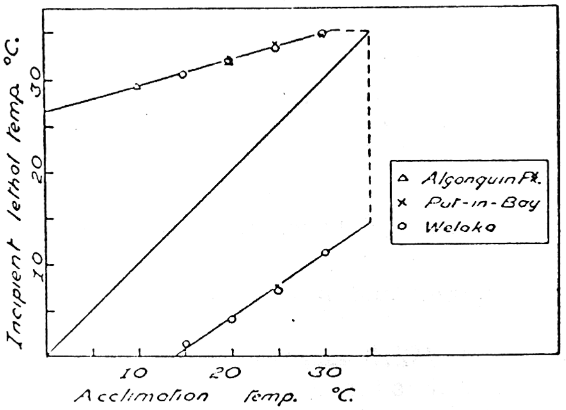

Figure CR-1. Relation between incipient upper and lower lethal temperatures and acclimation temperature for golden shiner from the same localities as in Figure CR-2.From Hart, 1952.

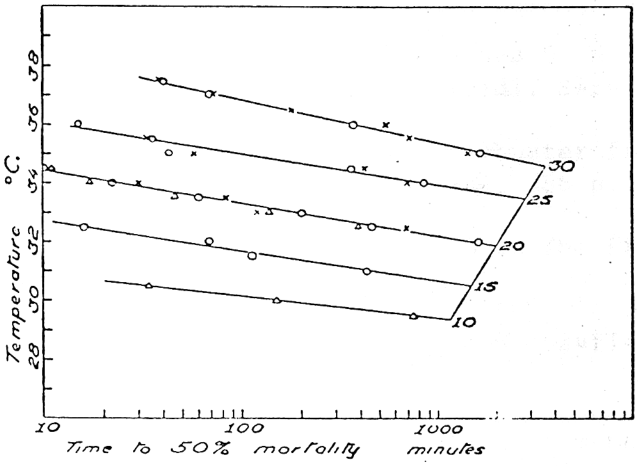

Figure CR-2. Upper lethal time-temperature relationships of golden shiner from Algonquin Park, Ontario (acclimated to 10 C and 20 C), Put-in-Bay, Ohio (acclimated to 20 C, 25 C and 30C) and Welaka (acclimated to 15 C, 20 C, 25 C and 30 C). From Hart, 1952.

under these conditions. He noted that when a school of shiners was frightened from water between 77 and 80 F (25 and 26. 1 C) into 95 F (36 C) water, two died (body temperatures of 92 and 93 F ;(33.3 and 33.9 C), while the others eventually regrouped at the lower temperatures.

On other occasions, Trembley (1960:IX-8) observed and netted specimens in 86 F (30 C) water and netted two specimens with body temperatures of 91 and 95 F (32.8 and 35 C).

Bailey (1955) observed dead and dying golden shiners in a Michigan lake when water temperatures reached 38 C (100.4 F) for several hours.

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WHITE SHINER

Distribution

The white shiner is distributed along the Atlantic coastal drainage of the Roanoke River in Virginia and southward, and on the west side of the Appalachian divide in West Virginia (Eddy, 1969).

General and Unspecified

No temperature related life history data have been located for this species.

References Cited

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SATINFIN SHINER

Distribution

The satinfin shiner has a distribution reportedly (Eddy, 1969) including only the Atlantic coastal drainage from the St. Lawrence to North Carolina.

Spawning

In New York (?), satinfin shiners spawn from late May to mid August at water temperatures between 18 and 27 C (64.4 and 80.6 F) (Stone, 1940; cited in Carlander, 1969:414). Stout and Winn (1958) and Stout (1959; both cited in Breder and Rosen, 1966:185) also described satinfin shiner as spawning from May to August.

According to Trembley (1960:IX-9) adult satinfins[1] were successful in spawning in a Delaware River heated effluent in mid May. On the first day of observations, the water temperature gradient was between 77 and 95% (25 and 35 C).

Larvae

Satinfin fry have been observed (Trembley, 1960:IX-9) swimming in 95 F (35 C) water.

General and Unspecified

Trembley (1961:IX-13) observed that satinfins avoid 102 F (38.9 C) water in August, but were seen swimming and maintaining themselves in 98 F water. From lower acclimation temperatures of 45 and 52 F (7.2 and 11.1 C), Trembley (1961:VIII-7) found upper ULT_{50}'s (obtained using a 1 or 2 F/hour temperature rise) of 90 F (32.2 C) and 94 F (34.4 C), respectively.

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[1] It should be noted that Trembley (1961:IX-13) stated that his study area on the Delaware River was an integration area between the satinfin shiner and the spotfin shiner (N. spilopterus), and that all specimens were lumped together as satinfins, although some individuals tended toward the spotfin complex.

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ROSEFIN SHINER

Distribution

The rosefin shiner occurs in the Roanoke River in Virginia and in the upper and central Ohio River drainage (Eddy, 1969). Several subspecies are known.

General and Unspecified

No temperature related life history data have been located for this species.

References Cited

Eddy, Samuel 1969. How to know the freshwater fishes, 2nd ed. William C. Brown Comp., Dubuque, Iowa, 286 p.

POPEYE SHINER

Distribution

While Eddy (1969) reports distribution of several subspecies in the Ohio River drainage and west into Missouri, Gilbert (1969; cited in Pflieger, 1971) has recently shed doubt on the validity of records west of the Mississippi.

General and Unspecified

No temperature related life history data have been located for this species.

References Cited

Eddy, Samuel 1969. How to know the freshwater fishes, 2nd ed. William C. Brown Comp., Dubuque, Iowa, 286 p.

Gilbert, C. R. 1969. Systematics and distribution of the American cyprinid fish *Notropis ariommus* and *Notropis telescopus*. Copeia 1969 (3):474-492.

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EMERALD SHINER

Distribution

The emberald shiner occurs in large open lakes and rivers in many parts of Canada, and in the Mississippi valley south to the Gulf coast in Alabama and Trinity River, Texas (Scott and Crossman, 1973:441).

Spawning

Females ready to spawn have been taken in mid May (Forbes and Richardson, 1908; cited in Carlander, 1969:416), with spawning extending through August (Fish, 1932; cited in Scott and Crossman, 1973:441) (Table AT-1). The range of spawning temperatures is said to be from 20 C (68 F) (Campbell and MacCrimmon, 1970; cited in EPA, 1974) to 27.0 C (80.6 F) (Gray, 1942; cited in EPA, 1974).

Eggs

In Lake Erie emerald shiners generally hatch in early to mid July at 75 F (23.9 C), less than twenty four hours after being laid (CFR, 1961).

Juveniles

McCormick and Kleiner (1970; cited in EPA, 1974) reported 29 C (84.2 F) as the optimum for juvenile growth, though the range was between 24 and 31 C (75.2 and 87.8 F). In Lake Erie growth of young-of-year shiners terminated during the latter part of September when water temperatures dropped to 70 F (21.1 C) (CFR, 1961).

Wells (1914) subjected young emerald shiners and other fish to high temperatures. In general he observed that individuals resisted higher temperatures when the heating was gradual rather than instantaneous, and that large fish were considerably more resistant to high

Table AT-1. Emerald shiner spawning times at various locations.

Date	Location	Comment	Author
Late Spring - Early Summer	Most Canadian lakes		Scott and Crossman, 1973:441
Mid May - Early June	Illinois	Ready to spawn	Forbes and Richardson, 1908*
June - August	Oneida Lake, N.Y.		Adams and Hankinson, 1928**
Late June - Mid August	Lake Erie		Gray, 1942*
July - August	Lake Erie		Fish, 1932***
Mid July	Des Moines R., Iowa	Females spent	Starrett, 1951*
Until Mid August	Lake Erie	Suggested	Langlois, 1954***

*Cited in Carlander, 1969:416
**Cited in Breder and Rosen, 1966:186
***Cited in Scott and Crossman, 1973:441

temperatures than were small individuals. In addition, he found a greater resistance to temperature in March and April, prior to spawning, than in the latter part of June and early July, following breeding. Unfortunately Wells did not specify the relation of these variables to his reported lethal temperature of between 27 and 28 C (80.6 and 82.4 F).

Lethal temperatures for juvenile emerald shiners have been more recently evaluated by Hart (1947). For specimens acclimated to 25 C (77 F), Hart found a 7-day upper LT_{50} of 30.7 C (87.3 F), though 34 C (93.2 F) was resisted for 35 minutes. Hart's temperature tolerance polygon is given as Figure AT-1, and the resistance times for temperatures beyond lethal limits in Figure AT-2.

General and Unspecified

The preferred temperature of emerald shiner in a Canadian lake was found to be 25 C (77 F) (Campbell and MacCrimmon (1970; cited in EPA, 1974), though Proffitt and Benda (1971:38) observed emerald shiners in waters up to 88 F (31.1 C) around a heated discharge into the White River, Indiana.

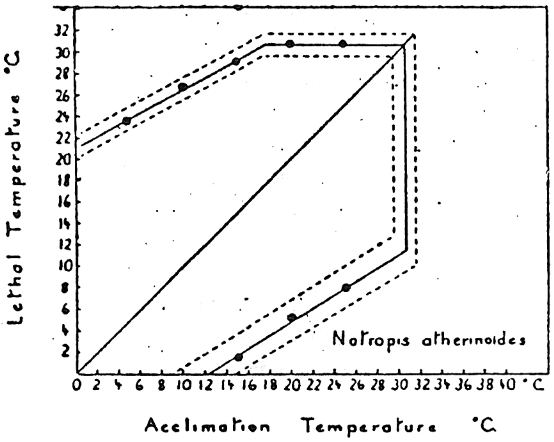

Figure AT-1. Lethal temperature polygon for emerald shiner. Dotted lines indicate approximate range for 10 per cent and 90 per cent mortality. From Hart, 1947.

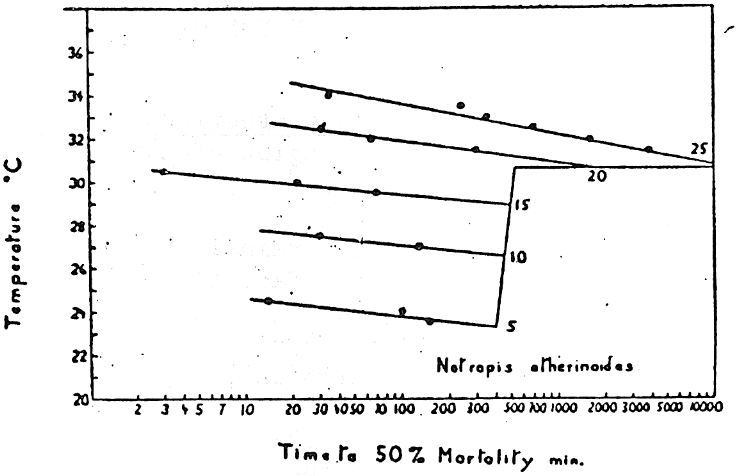

Figure AT-2. Resistance times to high temperature among emerald shiners acclimated to the temperatures indicated. From Hart, 1947.

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CRESCENT SHINER

Distribution

The crescent shiner is found in the upper Roanoke and Kanawha River drainages, in Virginia and West Virginia (Eddy, 1969).

Spawning

Raney (1947; cited in Carlander, 1969:418) has observed spawning in this species in June in Virginia.

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STRIPED SHINER

Distribution

Until recently (Gilbert, 1964; cited in AFS, 1970) a subspecies of the common shiner *N. cornutus*, the striped shiner is found in the southern Great Lakes and the St. Lawrence drainage south to Oklahoma, northern Alabama and Georgia (Eddy, 1969). The range of the striped shiner overlaps that of the common shiner in Illinois, Indiana, Michigan, and Missouri (Carlander, 1969:419).

Spawning

No data on striped shiner spawning per se have been located; however, in an observation for the common shiner located within its Michigan overlap with the striped shiner, spawning was recorded by Hubbs and Cooper (1936; cited in Carlander, 1969:421) to occur between late May and June.

In another study (location not specified in title) Nurenberger (1931; cited in Carlander, 1969:421) noted initiation spawning of the common shiner at 19 and 21 C (66.2 and 69.8 F).

General and Unspecified

As part of his studies to determine possible geographic differences in lethal temperatures among subspecies, Hart (1952) examined the effects of temperature upon *N. chrysocephalus* (then *N. cornutus chrysocephalus*). He found that with acclimation temperatures of 25 and 30 C (75 and 86 F), upper incipient lethal temperatures of 32.3 C (90.1 F) (5000 minute resistance) and probably 35.5 (92.3 F) greater than 4000 minute resistance); large fish died first.

The resistance characteristics of this species for the 25 and 30 C (75 and 86 F) acclimation temperatures are given in Figure CH-1 (Hart, 1952).

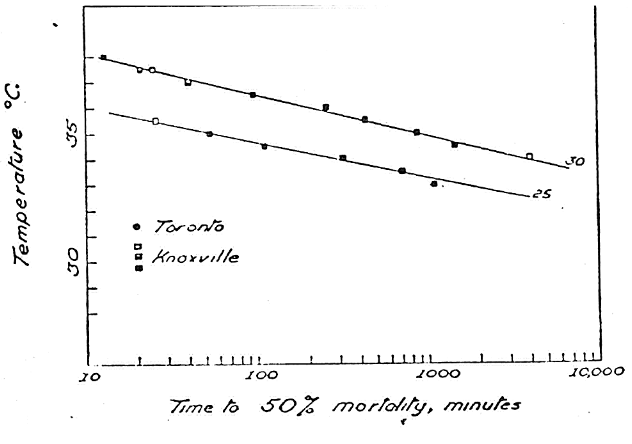

Figure CH-1. Upper lethal temperature relationhips of striped shiner from Knoxville, Tennessee. Samples from three local sources are included: solid squares, Willow Fork; half solid squares, Freeway Branch; open squares, Bull Run. From Hart, 1952.

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WHITETAIL SHINER

Distribution

The whitetail shiner is distributed in Ozark streams in Missouri and Arkansas and the headwaters of the Cumberland and Tennessee Rivers (Eddy, 1969).

Spawning

Outten (1958; cited in Carlander, 1969:423) observed spawning of the whitetail shiner from late May to late June in water temperatures ranging from 24 to 28 C (75.2 to 82.4 F).

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SPOTTAIL SHINER

Distribution

The spottail shiner is found in Alberta, Hudson Bay and Quebec south along the Atlantic coast to northern Georgia, and in the Mississippi valley to Missouri and Kansas (Trautman 1957; cited in Carlander, 1969:424). According to several authorities (Eddy, 1969, Hubbs and Lagler, 1958) subspecies occur.

Spawning

Spottail shiners have been seen to spawn between early May (McCann, 1959; cited in Carlander, 1969:426) and early August (Griswold, 1963; cited in Carlander, 1969:426). Table HU-1 gives reported spawning dates and localities.

Although neither date nor water temperatures were reported, Trembley (1960:IX-9) noted that spawning apparently occurred in the warm water areas below a heated water discharge on the Delaware River.

Eggs

In Lake Erie, hatching has been reported in early to mid June at water temperatures of 68 F (20 C) (CFR, 1961).

Larvae

Fry have been collected in 95 F (35 C) heated effluent water and successfully raised to adults by Trembley (1960:IX-9).

Juveniles

In Lower Red Lake, Minnesota, Smith and Kramer (1964) found growth of young-of-year and yearling spottail shiner to be significantly correlated with degree-days above 50 F (10 C) between mid June and

Table HU-1. Spottail shiner spawning times at various locations*

Date	Location	Author
Early May - Mid June	Clear Lake, Iowa	McCann, 1959; Griswold, 1963
Late June - Early July	Red Lake, Minnesota	Smith and Kramer, 1964
Late June - Early July	Lake Erie	Fish, 1932
Early August**	Clear Lake, Iowa	Griswold, 1963

*Cited in Carlander, 1969:426

**Second spawning

early August. From that time until the end of August, when growth slowed, correlations were not significant. Growth in Lake Erie ended in early to mid October when temperatures drop to 65 F (18.3 C) (Commercial Fisheries Review, 1961).

Adult

Meldrim and Gift (1971:27) found that adults (110-116 mm TL) acclimated to 59 F (15 C) (6 o/oo salinity) preferred 57 F (13.9 C) water.

General and Unspecified

Wells (1968) found spottail shiners to distribute themselves in Lake Michigan waters ranging in temperature from 13 C (55.4 F) to at least 22 C (71.6 F). Individuals were found in summer congregating in the cooler sections (93 to 94 F, 33.9 to 34.4 C) of a heated water lagoon ranging in temperature from 93 to 104 F (33.9 to 40 C) (Trembley, 1961:IX-13 to IX-14).

During winter, Trembley (1961:VIII-6 to VIII-7) determined upper lethal temperature for spottail shiners using a slow temperature rise of 1 or 2 F (0.6 to 1.1 C)/hour. He found that while shiners acclimated to 45 F (7.2 C) had an LT_{50} of 87 F (30.6 C), specimens acclimated to 52 F (11.1 C) had an LT_{50} of 88 F (31.1 C).

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SILVER SHINER

Distribution

While Eddy (1969) reports the distribution of the silver shiner to include the Ozark region of Missouri and Arkansas, and most of the Ohio River drainage, including systems of major tributaries, Pflieger (1971) does not report this species from Missouri, and Trautman (1957) includes neither Missouri nor Arkansas in its distributional range.

General and Unspecified

No temperature related life history data have been located for this species.

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Trautman, M. B. 1957. The Fishes of Ohio. Ohio State Univ. Press, 683 p.

SWALLOWTAIL SHINER

Distribution

The swallowtail shiner is reportedly restricted to the Atlantic coastal drainage from the Delaware River to South Carolina (Eddy, 1969).

Spawning

According to Raney (1947; cited in Carlander, 1969:428), spawning occurs in June and July.

General and Unspecified

In August, Trembley (1961:IX-13) collected specimens in waters heated to at least 93 F (33.9 C).

In November, Trembley (1961:VIII-6 to VIII-7) determined upper lethal temperatures for swallowtails using a slow temperature rise (1 to 2 F/hour). He found a LT_{50} of 88 F (31.1 C) at an acclimation temperature of 45 F (7.2 C), and a LT_{50} of 90 F (32.2 C) with an acclimation temperature of 52 F (11.1 C).

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ROSYFACE SHINER

Distribution

The rosyface shiner is distributed in waters from North Dakota and Manitoba to the St. Lawrence and Hudson Rivers, and south to Virginia, and much of the Ohio River drainage (Eddy, 1969). A disjunct population is also found in the Ozarks (Pflieger, 1971).

Spawning

Depending upon location, spawning occurs between May (Pfeiffer, 1955; Reed, 1957; both cited in Miller, 1964) to late June (Reed, 1957; cited in Miller, 1964; Miller, 1964) at water temperatures above 68 F (20 C) (Reed, 1957; cited in Miller, 1964) and up to 84 F (28.9 C) (Pfeiffer, 1955; cited in Miller, 1964). Recorded dates, temperatures, and locations are given in Table RN-1.

Eggs

Reed (1958; cited in Scott and Crossman, 1973:465) found hatching occurred in 57 to 59 hours at 70 F (21.1 C).

Table RN-1. Rosyface shiner spawning times and temperatures at various locations.

	Temperature			
Date	C	F	Location	Author
May-June	(24.4-28.9)	76-84	New York	Pfeiffer, 1955**
Late May - Late June	(20-22.2)	68-72	Pennsylvania	Reed, 1957***
Early - Late June	(>21.1)	>70	New York	Miller, 1964
June			Michigan	Hankinson, 1920*

*Cited in Carlander (1969:429)

**Cited in Miller (1964)

***Cited in Scott and Crossman (1973:465)

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Scott, W. B., and E. J. Crossman 1973. Freshwater fishes of Canada. Fish. Res. Board Can., Bull. 184, 966 p.

NEW RIVER SHINER

Distribution

The New River shiner is restricted to the upper drainage of the Kanawha River in Virginia and West Virginia (Eddy, 1969).

General and Unspecified

No temperature related life history data have been found for this species.

References Cited

Eddy, Samuel. 1969. How to know the freshwater fishes, 2nd ed. William C. Brown Comp., Dubuque, Iowa, 286 p.

SPOTFIN SHINER

Distribution

The spotfin shiner is distributed from Minnesota and Missouri to Lake Champlain and the Potomac River (Eddy, 1969; Pflieger, 1971).

Spawning

Spotfins spawn between early June to late August (Stone, 1940; cited in Carlander, 1969:431) (Table SP-1).

General and Unspecified

According to Trembley (1961:IX-13) the Delaware River system is a zone of integration between the spotfin and its close relative, the satinfin shiner (*N. analostanus*). In recording his observations, Trembley (1960, 1961) grouped his observations on these species under the satinfin shiner (Trembley, 1961:IX-13), although he recognized that some individuals tended toward the *N. spilopterus* complex.

The maximum temperature at which spotfin shiners were collected in a White River heated water discharge was 88 F (31.1 C) (Proffitt and Benda, 1971:38).

Table SP-1. Spotfin shiner spawning times at various locations.*

Date	Location	Author
Early June to Late August	New York	Stone, 1940
June	Maryland	Schwartz, 1963
Late July and August	Iowa	Starrett, 1951

*From data cited in Carlander (1969:431)

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TELESCOPE SHINER

Distribution

The telescope shiner has a restricted and disjunct distribution, being found in the Ozark uplands of Missouri, and from the Mississippi to the western sections of Virginia and North Carolina (Pflieger, 1971).

General and Unspecified

No temperature related life history data have been located for this species.

References Cited

Pflieger, W. L. 1971. A Distributional study of Missouri fishes. Univ. Kansas, Mus. Nat. Hist. Publ. 20 (3):225-570.

MIMIC SHINER

Distribution

This species ranges from southern Canada through Minnesota to central Texas (Eddy, 1969), and several subspecies exist (e.g., see descriptions in Hubbs and Lagler, 1958).

Spawning

In Indiana, spawning occurs between late June and early July (Black, 1945; cited in Carlander, 1969:434), though Bailey and Gilbert (1960; cited in Breder and Rosen, 1966:184) considered spawning to occur between mid May and late July.

General and Unspecified

In Ontario and Manitoba the mimic shiner reaches its northern limit between the 60 and 65 (15.6 and 18.3 C) July isotherm (Scott and Crossman, 1973:474).

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BLUNTNOSE MINNOW

Distribution

This species is widespread from North Dakota and Manitoba through southern Canada and the Great Lakes southward to Virginia, Louisiana and Oklahoma (Pflieger, 1971; Trautman, 1957).

Spawning

Spawning in this species has been observed between early April (Trautman, 1957) and late August (Hubbs and Cooper, 1936; cited in Breder and Rosen, 1966:193, 194) at water temperatures between 70 and 79 F (21.1 and 26.1 C) (Hankinson, 1919) (Table NO-1).

Juveniles

Bailey (1955) reports survival of several young (17-23 mm) bluntnose minnows in a Michigan lake when waters reached 38 C (100.4 F) for several hours, and remained as nearly high for several additional hours. No deaths for young were reported.

Adult

One dead adult was found by Bailey (1955) in the 38 C (100.4 F) water of the Michigan lake cited above.

General and Unspecified

The maximum temperature at which bluntnose minnows were collected in a heated discharge into the White River was 88 F (31.1 C) (Proffitt and Benda, 1971:38).

Hart (1947) examined the response of the bluntnose minnow to high temperatures. He found that the upper lethal temperature rose with increasing acclimation temperatures to an ultimate upper incipient

Table NO-1. Bluntnose minnow spawning times and temperatures at various locations.

Date	Temperature C	F	Location	Comment	Author
Early April - Early Spetember			Ohio	Range	Trautman, 1957
May - July			Ohio	Most	
May - Late August			Illinois	Eggs found	Hankinson, 1919
	(21.1-26.1)	70-79	Illinois	Temperatures for breeding waters	
Late May or June - August	(>20)	>68			Scott and Crossman, 1973:478
June - Late July			Indiana	Eggs found	Eigenmann, 1896*
June - July			Wisconsin		Cahn, 1927***
Late May - Late August	>21	(>69.8)	Michigan		Hubbs and Cooper, 1936**, ***

*Cited in Hankinson, 1919
**Cited in Carlander, 1969:439
***Cited in Breder and Rosen, 1966:193,194

LT_{50} of 33.3 C (92.0 F). This point was reached at acclimation temperatures of 25 C (77 F) (Figure NO-1).

The resistance characteristics of this species above the upper incipient lethal limit were also investigated (Figure NO-2). At the highest acclimation temperature tested 25 C (77 F), the fish could resist 35 C (95 F) water for 21 minutes.

Extensive work has been done on the fathead minnow subspecies, Pimephales p. promelas Rafinesque, e.g., Brett (1944), Hart (1947), Trembley (1961), Nickum (1966) and Brungs (1971). Although this work will not be discussed at this time, it shows that fathead minnow, like the bluntnose minnow, is tolerant of high temperatures.

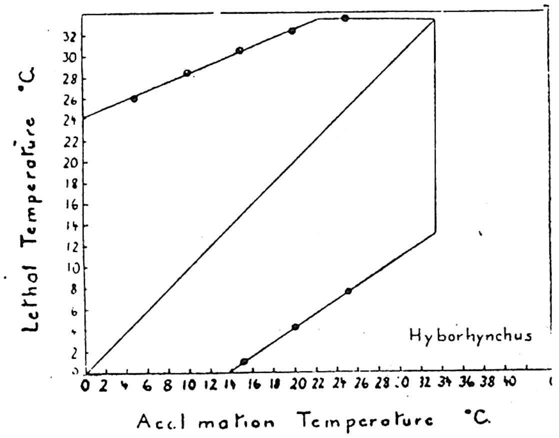

Figure NO--1. The relation between acclimation temperature and upper and lower incipient lethal temperatures for bluntnose minnow. From Hart, 1947.

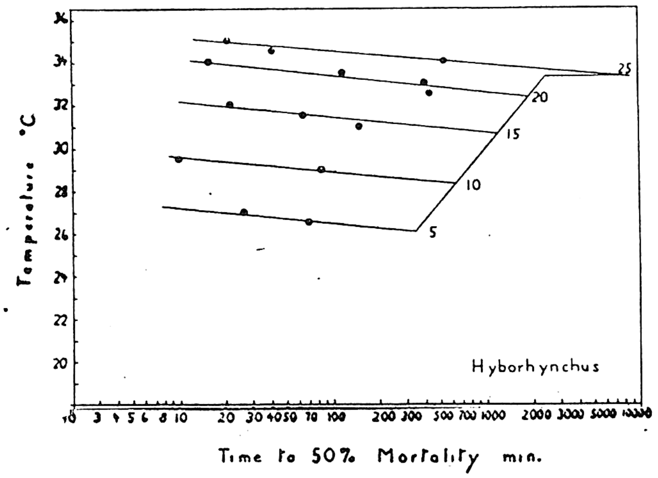

Figure NO-2. The relation between temperature and time to death (resistance time) at various acclimation temperatures for bluntnose minnow. From Hart, 1947.

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BLACKNOSE DACE

Distribution

The blacknose dace is found in streams from North Dakota to the St. Lawrence drainage and south to Nebraska and North Carolina (Eddy, 1969). According to Hubbs and Lagler (1958) four subspecies occur.

Spawning

Scott and Crossman (1973:493) state that spawning occurs in spring when water temperatures reach about 70 F (21.1 C), usually in May or June. Spawning of the three more northern subspecies occurs from late May (Raney, 1940) to early September (Coker, 1927), at water temperatures between 60 F (Schwartz, 1958) and 72 F (22.2 C) (Traver, 1929). Spawning data recorded for each subspecies are given in Table AU-1.

General and Unspecified

Hart (1947, 1952) has studied the temperature relations of the longnose dace subspecies, *R. a. meleagris* Agassiz and *R. a. obtusus*. Although significant geographic differences were found to exist in morphology, no differences were noted in the upper lethal temperatures or in the resistance times (Hart, 1952). Therefore Hart's 1947 data, which is only for *R. a. meleagris*, will be used with confidence in also considering *R. a. obtusus*.

The ultimate upper incipient lethal temperature is 29.5 C (85.1 F) (Hart, 1952). The thermal tolerance polygon developed for this species in winter (Hart, 1947) is presented in Figure AU-1, and resistance times in Figure AU-2 and Figure AU-3.

Table AU-1. Spawning data for three blacknose dace subspecies.

Date	Temperature C	 F	Location	Subspecies	Author
Late May			Ohio	?	Data cited in Breder & Rosen, 1966:174.
Late May			Pennsylvania	*R.a. meleagris*	Raney, 1940
Mid June	21.1	70	Upstate N.Y.	*R.a. meleagris*	Raney, 1940
Late June	(15.6-17.8)	60-64	W. Virginia	*R.a. obtusus*	Schwartz, 1958
Late May - Early June	(~ 22.2)	~72	New York	*R.a. atratulus*	Traver, 1929*
Early September			North Carolina	*R.a. atratulus*	Coker, 1927*

*Coker (1927) and Traver (1929) both reported their data for *R. atronasus* (Mitchill). The AFS (1948, 1960, 1970) has not listed this species, but Trautman (1957) stated that in Ohio the current name for *R. atronasus*, *R. atronasus meleagris*, and *R. atronasus obtusus*, is *R. atronasus meleagris*. However, more recently, Schwartz (1958) stated that the behavior of the species which Traver described in 1929 was that of *R. atratulus atratulus* (Hermann). Because of the more recent date of the Schwartz (1958) paper, it is the latter designation which is given here for the descriptions of Coker and Traver.

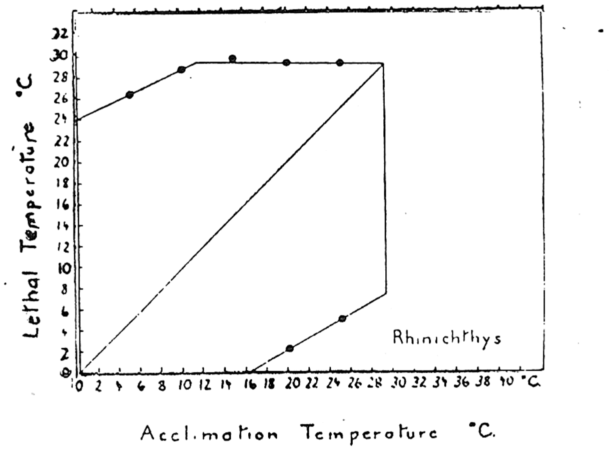

Figure AU-1. The relation between acclimation temperature and upper and lower incipient lethal temperatures for blacknose dace. From Hart, 1947.

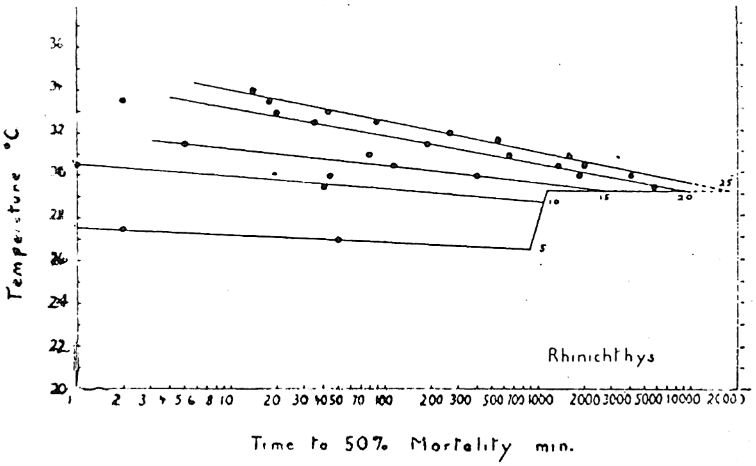

Figure AU-2. The relation between temperature and time to death (resistance time) at various acclimation temperatures for blacknose dace. From Hart, 1947.

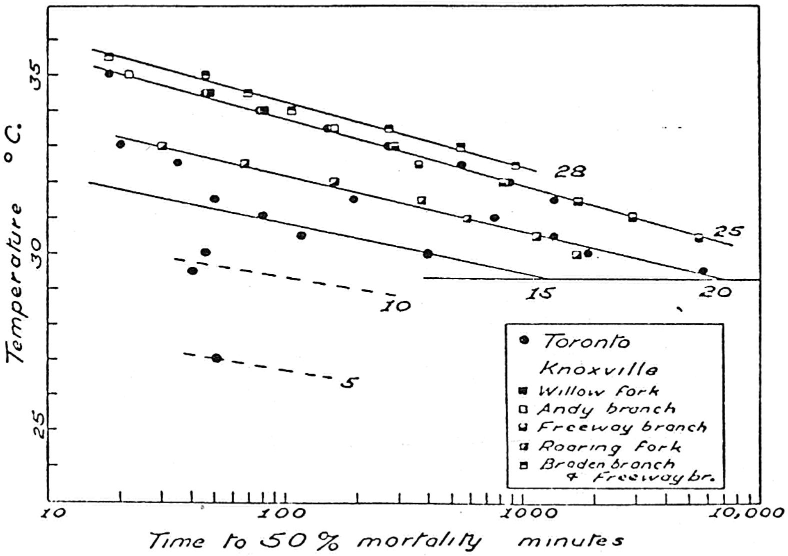

Figure AU-3. Upper lethal of blacknose dace from Toronto, Ontario and Knoxville, Tennessee. Acclimation temperatures are 5 C (41 F), 10 C (50 F), 15 C (59 F), 20 C (68 F), 25 C (77 F) and 30 C (86 F). Knoxville fish from various local sources as indicated. From Hart, 1952.

The eastern blacknose dace, R. a. atratulus, was studied by Trembley (1961:VIII-7). Using a slow temperature rise (2 F/hour), he found that from an acclimation temperature of 45 F (7.2 C), the upper LT_{50} was 89 F (31.7 C).

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Trembley, F. J. 1961. Research project on effects of condenser discharge water on aquatic life, progress report 1960. Institute of Research, Lehigh Univ., Bethlehem, Pennsylvania.

LONGNOSE DACE

Distribution

The longnose dace is found from British Columbia to Newfoundland, south to Pennsylvania and Oregon, except for extension in the Appalachians to South Carolina; and in the Rockies to New Mexico and west Texas (Trautman, 1957; cited in Carlander, 1969:447). According to Eddy (1969) and Hubbs and Lagler (1958) several subspecies exist.

Spawning

The longnose dace has been reported to spawn between May (e.g., Schwartz, 1963; cited in Carlander, 1969:448) and August (e.g., Kuehn, 1957; cited in Carlander, 1969:448) (Table CT-1).

Eggs

McPhail and Lindsey (1970; cited in Scott and Crossman, 1973: 497) noted eggs in Manitoba hatched in 7 to 10 days at 60 F (15.6 C).

General and Unspecified

In February Trembley (1961:IX-12) collected a single specimen in the heated water zone below a power plant on the Delaware River when the temperature gradient was between 50 and 67 F (10 and 19.7 C).

Table CT-1. Longnose dace spawning times at various locations.

Date	Location	Comment	Author
May	Maryland		Schwartz, 1963*
May - Early July		Spawning begins	Scott and Crossman, 1973:496
June and July	Ontario		Dymond, 1926**
Late June - August	S.E. Minnesota		Kuehn, 1957*
Into Late August	Alberta		McPhail and Lindsey, 1970**

*Cited in Carlander, 1969:448

**Cited in Scott and Crossman, 1973:496, 497

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CREEK CHUB

Distribution

The creek chub is distributed from Montana and Manitoba to eastern Canada and south to the Gulf of Mexico (Eddy, 1969). All but the southeast section of the range is occupied by the northern creek chub, S. a. atromaculatus (Mitchill).

Spawning

Spawning runs begin in late March (Paloumpis, 1958; cited in Carlander, 1969:454) and extend to July (Reighard, 1910; cited in Carlander, 1969:455), with nesting observed at temperatures between 55 and 80 F (12.8 and 26.7 C) (Table AO-1).

General and Unspecified

Bardach and Bjorklund (1957) found creek chubs (6-10 cm length) to have an average response level of 0.25 C (0.45 F).

Hart (1952) examined upper temperature tolerances for Toronto and Knoxville populations of the northern creek chub. He found no differences between the two populations (Figure AO-2), so that results from studies in both areas will be considered together.

Brett (1944) showed that not only did the upper lethal temperature rise in summer (also shown by Hart, 1947, 1952) in an Ontario lake, but that it was also sensitive to more short term water temperature fluctuations (Figure NE-3). He found that at maximum ambient water temperatures of 25 to 26 C (77 to 78.8 F) (to which the fish were probably acclimated), the creek chub had a 12-hour upper LT_{50} of 32.6 C (90.7 F). This upper lethal temperature is outside of the

Table AO-1. Creek chub spawning times and temperatures at various locations.

Date	Temperature C	F	Location	Comment	Author
Late March - June			Iowa		Paloumpis, 1958*
April - Mid May	(12.8-26.7)	55-80	Illinois		Hankinson, 1919
Late April - July			Michigan		Reighard, 1910*
May into July	(12.8)	55	Canada	Beginning spawning temperature	Scott and Crossman, 1973:508
Late May	>14 C	(>57.2)	Manitoba	Most spawning	Moshenko and Gee, 1973
June			Wisconsin		Cahn, 1927**

*Cited in Carlander, 1969:454, 455

**Cited in Breder and Rosen, 1966:200

temperature tolerance polygon developed by Hart (1947) (Figure AO-1), and above the ultimate upper incipient lethal temperature of about 31.6 C (88.9 F) reported later (Hart, 1952).

Resistance times to temperatures above lethal limits are plotted in Figure AO-2 and Figure AO-3.

For Delaware River specimens acclimated to 45 F (7.2 C), Trembley (1961:VIII-7) found an LT_{50} of 88 F (31.1 C) when temperatures were raised at the rate of 2.0 F/hour.

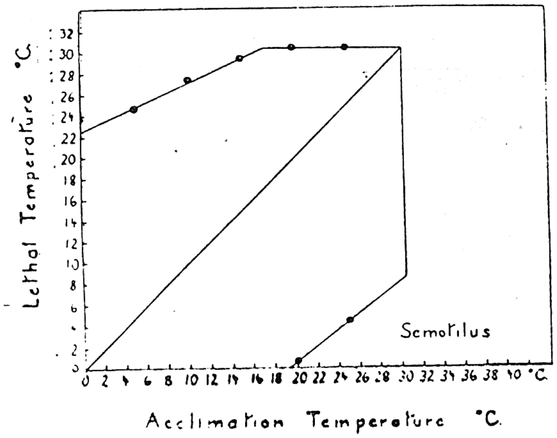

Figure AO-1. The relation between acclimation temperature and upper and lower incipient lethal temperatures for creek chub. From Hart, 1947.

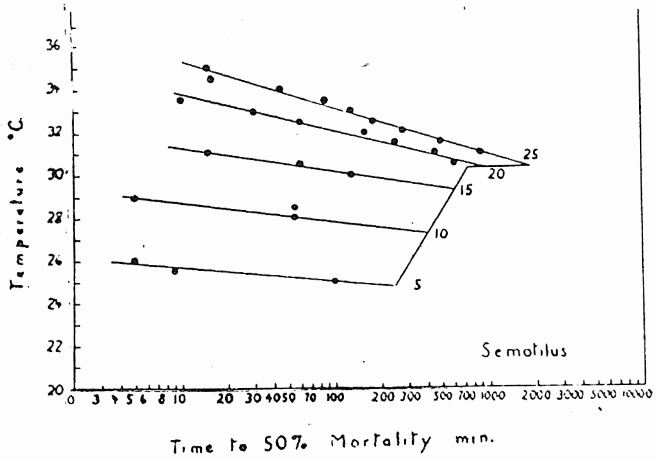

Figure AO-2. The relation between temperature and time to death (resistance time) at various acclimation temperatures for creek chub. From Hart, 1947.

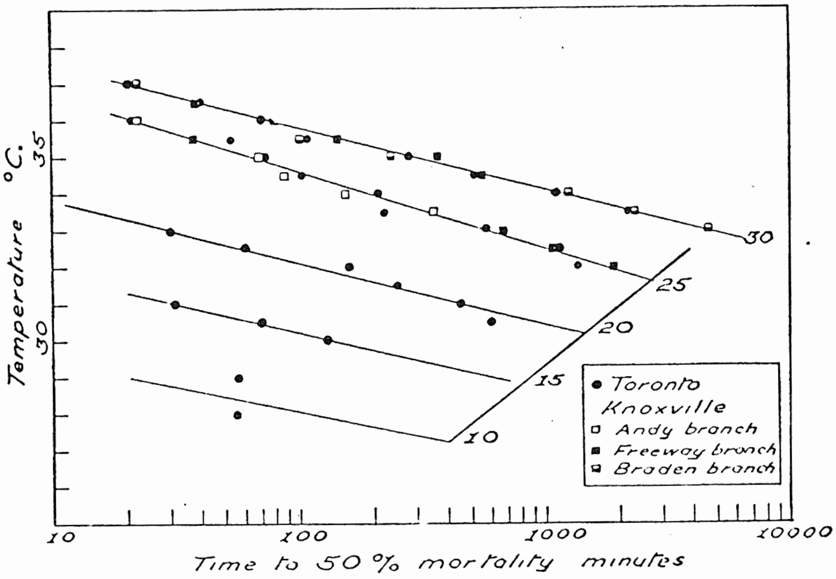

Figure AO-2. Upper lethal temperature relationships of creek chub from Ontario and Knoxville, Tennessee. Toronto fish acclimated to 10 C (50 F), 15 C (59 F), 20 C (68 F), 25 C (77 F) and 30 C (86 F). Knoxville samples from various local sources as indicated. From Hart, 1952.

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LONGNOSE SUCKER

Distribution

In North America, the longnose sucker occurs from Central Quebec and western Labrador south to Maryland, west through Pennsylvania, north to Minnesota, absent from all but the upper Mississippi in Minnesota, to northern Colorado, north through Washington to Alaska, and is generally distributed in Canada (Scott and Crossman, 1973:532).

Spawning

Spawning migrations have been reported by Geen et al. (1966) to begin during mid April when water temperatures reached 5 C (41 F), and spawning has been observed between mid May (Geen et al., 1966) and July (Elsey, 1946; cited in Carlander, 1969:473) at temperatures up to 59 F (15 C) (Harris, 1962) (Table CM-1).

Eggs

Eggs incubated in the laboratory by Geen et al. (1966) hatched in 11 days at 10 C (50 F), and 8 days at 15 C (59 F).

Juveniles

Black (1953) determined 24-hour ULT for longnose suckers (average 44 g) at two acclimation temperatures (11.5 and 14 C, 52.7 and 57.2 F). He found a similar ULT for the two (27 and 26.9 C, 80.6 and 80.5 F), perhaps indicating the 24-hour UUILT.

General and Unspecified

In a Maine lake, Cooper and Fuller (1945; cited in Ferguson, 1958) found longnose suckers to be associated with temperatures between 11.0 and 11.6 C (51.8 and 52.9 F).

Table CM-1. Longnose sucker spawning times at various locations.

Date	Location	Comment	Author
Mid April-May	British Columbia	Migration, critical temperature 5 C (41 F)	Geen et al., 1966
Mid May		Spawning	
Mid May-Mid June	Great Slave Lake	Temperatures below 59 F (15 C)	Harris, 1962
Late May-Early June	Lake Nipigon, Ontario		Dymond, 1926**
Lake May and June	Colorado		Hayes, 1956*
Mid June-Early July	Pyramid Lake, Saskatchewan		Elsey, 1946*
Mid June-Early July	Pyramid Lake, Saskatchewan	Migration 52-57 F (11-14 C)	Rawson and Elsey, 1948**
Late June	Yellowstone	Greatest migration 50-59 F (10-15 C)	Brown and Graham, 1953**
Through July	Yellowstone	Run continued	Brown and Graham, 1953**

*Cited in Carlander, 1969:473

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WHITE SUCKER

Distribution

The white sucker is widely distributed in North America, from the Pacific coast in Canada, and east of the Rockies in the United States, north to Hudson Bay and south to New Mexico, Oklahoma, and Georgia. It occurs throughout the east coast (Pflieger, 1971). Several subspecies occur (Hubbs and Lagler, 1958; Trautman, 1957) though in other than the Adirondack Mountains of New York, the subspecies occurring in the east is the common white sucker, *Catostomus commersoni commersoni* (Lacepede).

Spawning

Spawning occurs between March (Trautman, 1957) and mid June (Spoor, 1938; cited in Carlander, 1969:483) (Table CO-1) at temperatures between 43 and 74 F (Trautman, 1957). Most other observers have reported spawning to occur at temperatures well below 74 F.

Eggs

The incubation time for white sucker eggs has been found to be 11 days at 13.6 C (56.5 F), 7 days at 15.5 to 16. 1 C (59.9 to 61.0 F), and 5 days at 18 C (64.4 F) (Bassett, 1957; cited in Carlander, 1969:483). Scott and Crossman (1973:541) state that eggs hatch in 8 to 11 days at 50 to 59 F (10 to 15 C) in the laboratory.

According to McCormick et al. (1972; cited in EPA, 1974) the optimum incubation temperature is 15 C (59 F), though the range extends from 8 to 21 C (46.4 to 69.8 F).

Table CO-1. White sucker spawning times and temperatures at various locations.

	Temperature				
Date	C	F	Location	Comment	Author
March - June		43 - 74	Ohio	Range of spawning temperature	Trautman, 1957
		50 - 68		Usual spawning temperature	
Late March			Illinois		Hankinson, 1919
April			Wisconsin	Spawning just after ice leaves	Cahn, 1927**; Spoor, 1938**
April - May			Illinois		Hokanson, 1969
Late April - Early May			Michigan		Reighard, 1920*
May			Upstate N.Y.	Most spawning	Raney and Webster, 1942**
Early May - Early June					Scott and Crossman, 1973:540
Mid May			Saskatchewan		Campbell, 1935*
Late May - Mid June			Wisconsin		Spoor, 1938*

Table CO-1 (Continued)

Date	Temperature C	F	Location	Comment	Author
	~10	(~50)	Connecticut	Optimum	Webster, 1941***
	12-13	(53.6-55.4)			Wojtalik, unpublished****

*Cited in Carlander, 1969:483

**Cited in Breder and Rosen, 1966:237

***Cited in EPA, 1974

****Cited in NAS, 1973

NOTE: Carlander and Breder and Rosen both cited observations by Spoor. However, as noted, interpretation differs.

Larvae

Optimum growth of larvae in the laboratory has been found by McCormick et al. (1972; cited in EPA, 1974) to occur at 27 C (80.6 F), though growth occurred in the range of 24 to 27 C (75.2 to 80.6 F). The upper lethal temperature was found to be 30 C (86 F) for larvae acclimated to 21 C (69.8 F). Trembley (1960:IX-11) collected fry in waters of up to 83 F (28.3 C).

Juveniles

Huntsman (1942) made lethal temperature determinations on young suckers, raising the ambient (maximum 80 F, 26.7 C) water temperature 1.8 F every five minutes. He found a "dying period", beginning with a decrease in swimming ability and ending with cessation of breathing, at between 35.1 and 36.1 C (95.1 and 96.9 F). In later field observations, Huntsman (1946) noted young suckers dead in a Nova Scotia river in water 88.5 F (31.4 C).

Adults

In a Colorado reservoir, adult suckers were most abundant at 19-21 C (66.2 to 69.8 F), and retreated into deeper waters as summer progressed (Horak and Tanner, 1964; cited in Carlander, 1969:483; and in EPA, 1974).

General and Unspecified

Rawson (1960; cited in Wurtz and Renn, 1965) found white suckers to be part of the fauna located in the cooler (41-50 F, 5-10 C) bottom water of four Canadian lakes. However, in several lakes in Wisconsin, Hile and Juday (1941; cited in Ferguson, 1958) found white suckers between 11.8 and 20.6 C (53.2 and 69.1 F). Cooper and Fuller (1945; cited in Ferguson, 1958) found C. c. commersonnii having preference for 14.1 to 18. 3 C (57.4 to 64.8 F) water.

Van Vliet (1957) reported that white sucker populations diminished in a heated water discharge into the Delaware River as the waters cooled in fall. Further observations around this same discharge have been reported by Trembley (1960:IX-7, 1961:IX-10 to IX-11). In May when normal water temperature was 63 F (17.2 C) white suckers were concentrated in the cooler end (75 F, 23.9 C) of a heated lagoon where temperatures reached 90 F (32.2 C). When frightened into the warmer areas, a number died. However on another occasion when lagoon temperatures ranged from 64 to 83 F (17.8 to 28.3 C) no deaths were noted when fish were frightened from the cool end into the warmest zone. Body temperatures of suckers taken throughout the year in the heated open river ranged up to 82 F (27.8 C), and they were observed in the heated lagoon at temperatures up to 85 F (29.4 C) without exhibiting outward signs of irritation. Body temperatures of fish undergoing heat death after being frightened into warmer waters ranged from 86 to 92 F (30 to 33.3 C).

Several authors have examined the lethal temperature relations of the white sucker at various acclimation temperatures (Table CO-2). Depending upon the author, acclimation temperature, and rate of temperature rise, lethal temperature ranges from 26.8 C (69.4 F) at an acclimation temperature of 5 C (41 F) (5-1/6 hour resistance time) (Hart, 1947) to 95 F (35 C) at an acclimation temperature of 90 F (32.2 C) (Trembley, 1961:VIII-6).

Table CO-2. Summary of results of lethal temperature determinations using white sucker.

Acclimation Temperature		Lethal Temperature	Rate of Change	Resistance Time	Author
C	F				
5	(41)	79.3	instantaneous	310 min. (5-1/6 hrs.)	Hart, 1947
(7.2)	45	86.0	2.0F/hr.	600 min. (10 hrs.)	Trembley, 1961:VIII-7
10	(50)	81.9	instantaneous	310 min. (5-/16 hrs.)	Hart, 1947
(11.1)	52	88.0	1.0F/hr.	2160 min. (36 hrs.)	Trembley, 1961:VIII-6
15	(59)	84.7	instantaneous	310 min. (5-1/6 hrs.)	Hart, 1947
20	(68)	84.7	instantaneous	2000 min. (33-1/3 hrs.)	Hart, 1947
25	(77)	84.7	instantaneous	8000 min. (116-2/3 hrs.)	Hart, 1947
25-26	(77 - 77.8)	88.2	instantaneous	720 min. (12 hrs.)	Brett, 1944
(32.2)	90	95.0	0.5F/hr.	600 min. (10 hrs.)	Trembley, 1961:VIII-6

While not extending up to the upper incipient lethal temperatures found by Brett (1944) and Trembley (1961:VIII-6 to VIII-7), Hart's (1947) lethal temperature polygon is presented as Figure CO-1, and the resistance data for temperatures beyond incipient lethal temperatures are given in Figure CO-2.

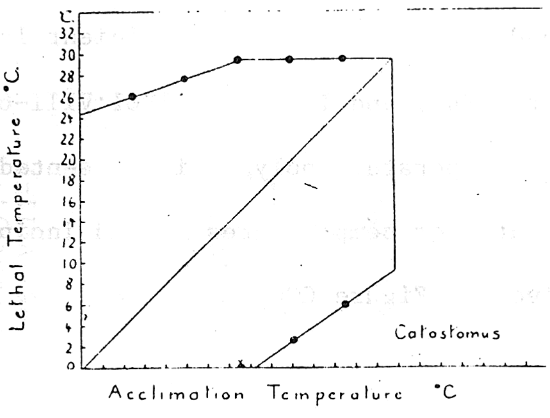

Figure CO-1. The relation between acclimation temperature and the upper and lower lethal temperature for white sucker. From Hart, 1947.

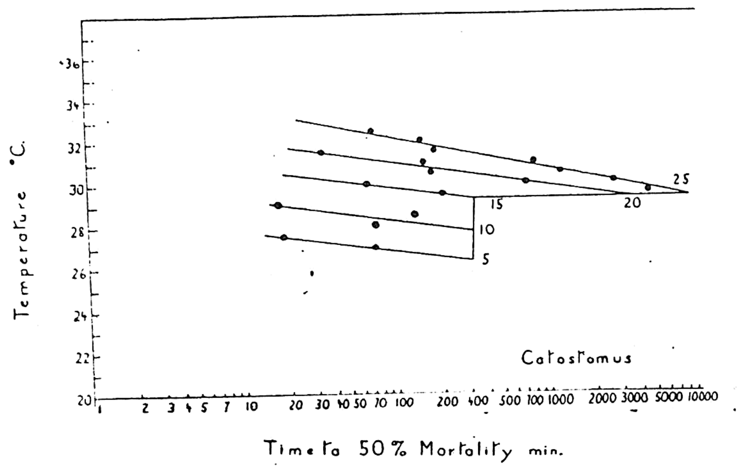

Figure CO-2. The relation between temperature and time to death (resistance time) at various acclimation temperatures for white sucker. From Hart, 1947.

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HOG SUCKER

Distribution

The hog sucker is distributed from Minnesota to New York, and south to Oklahoma and central Mississippi (Pflieger, 1971).

Spawning

Spawning occurs from late March (Trautman, 1957) to early June (Trautman, 1957), but depends on location (Table NI-1). According to Scott and Crossman (1973:555) spawning occurs in spring, usually in May or when water temperatures reach 60 F (15.6 C).

General and Unspecified

Gammon (1971) found no hog suckers were below a discharge into the Wabash River, and the few found above the discharge were in summer water temperatures averaging 25.2 C (77.4 F).

Below 50 F (10 C) hog suckers are said to be quite inactive, and annuli are formed by mid May when water temperatures reach 56 to 60 F (13.3 to 15.5 C) (Scott and Crossman, 1973:555, 556).

Table NI-1. Hog sucker spawning times at various locations.

Date	Location	Author
Late March - Early June	Ohio	Trautman, 1957
Mid April	Illinois	Hankinson, 1919
April - May	New York	Wright and Allen, 1913*
Early May	Michigan	Reighard, 1920*
May		Scott and Crossman, 1973:555

*Cited in Breder and Rosen, 1966:237

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BROWN BULLHEAD

Distribution

The brown bullhead is distributed from Saskatchewan to Nova Scotia and south to Louisiana and Florida (Plfieger, 1971).

Spawning

Spawning has been reported from March (Moody, 1957; cited in Carlander, 1969:537) through September (Swingle, 1957; cited in Carlander, 1969:537) (Table NE-1). According to Breder (1935; cited in Breder and Rosen, 1966:256) a slow rise in temperature to about 21 C (69.8 F) evidently permits spawning which might otherwise take place after a relatively rapid rise to about 25 C (77 F). Scott and Crossman (1973:601) state spawning to occur in Canada when water temperatures reach 70 F (21.1 C).

Eggs

Hatching is said to occur in 9 to 6 days when eggs are incubated at 69 to 74 F (20.6 to 23.3 C) (Scott and Crossman, 1973:601), and 5 days when incubated at 25 C (77 F) (Wojtalik, unpublished; cited in NAS, 1973). In Alabama first hatch was noted when temperatures reached 27 C (80.6 F) (Swingle, 1952; cited in Carlander, 1969:537).

Juveniles

Meldrim and Gift (1971:27, 34) found that young specimens acclimated to 79 F (26.1 C) had a preference for 88 F (31.1 C), and specimens acclimated to 77 F (25 C) actively avoided water 97 F (36.1 C).

One juvenile brown bullhead was seen dying in a Michigan pond

Table NE-1. Brown bullhead spawning times at various locations.

Date	Location	Author
March - May	Florida	Moody, 1957*
Early April - Late July	California	Neale,1915**
May - June	Maine	Everhart, 1958*
May - June	Canada	Scott and Crossman, 1973:601
May - June	Illinois	Richardson, 1913*
June	Wisconsin	Gill, 1907*
June	Michigan	Gill, 1907*
Mid August		Breder, 1935**
"Through" September	Alabama	Swingle, 1957*

*Cited in Carlander, 1969

**Cited in Breder and Rosen, 1966:257

which had reached 38 C (100.4 F) for several hours, though another survived these conditions (Bailey, 1955).

Trembley (1961:IX-14) reported a single young-of-the-year brown bullhead during a collection within a heated water lagoon. No temperature data were given.

General and Unspecified

On a number of instances Trembley (1960:IX-10, 1961:IX-14) observed brown bullheads in a heated water discharge entering the Delaware River. While the bullheads struck at worms thrown into 104 F (40 C) water, they would rapidly retreat into cooler water. In June of one year when water temperatures ranged from 75 to 100 F (23.9 to 37.8 C) in the adjacent heated lagoon, bullheads avoided the 90 - 100 F (32.2 to 37.8 C) water, and in July of another year when waters ranged from 89 to 106 F (31.7 to 41.1 C), they concentrated at between 89 and 90 F (31.7 and 32.2 C). On this latter occasion one sluggish fish was collected by hand which had an internal temperature of 96 F (35.6 C). Most body temperatures reported by Trembley (1960:IX-10) below the discharge were between 48 and 89 F (8.9 and 31.7 C).

Brett (1944) conducted lethal temperature determinations using brown bullhead. Brett noted that the lethal temperature varied not only with season, but also with more short term temperature fluctuations (Figure NE-3). He also observed what he referred to as "summation in acclimation", the acclimation of the fish not to the average water temperature, but to a temperature closer to the maximum. The highest 12-hour LT_{50} recorded was 37.5 C (99.5 F). Brett's lethal temperature polygon is included in Figure NE-1 (from Hart, 1952).

Hart (1952) also examined the upper lethal temperatures of this species from Ontario, Ohio, and Florida (Figure NE-1 and Figure NE-2). The different populations showed no appreciable geographic difference in the upper lethal temperature. Incipient lethal temperatures extended up to 34.7 C (94.6 F) for several days exposure when acclimated to 30 C (86 F). Based upon his findings Hart commented that the 12-hour exposure time used by Brett (1944) was insufficient to determine incipient lethal temperatures at acclimation levels above 15 C (59 F). However the differences in lethal temperature (see Figure NE-1) were felt to be greater than those expected from duration of the experiment alone.

Using a slow temperature rise of 1-2 F/hour, Trembley (1960: VIII-4, 1961: VIII-7) found upper LT_{50}'s which ranged from 93 to 99 F (33.9 to 37.2 C) for specimens acclimated at 45 and 73 F (7.2 and 22.8 C) respectively.

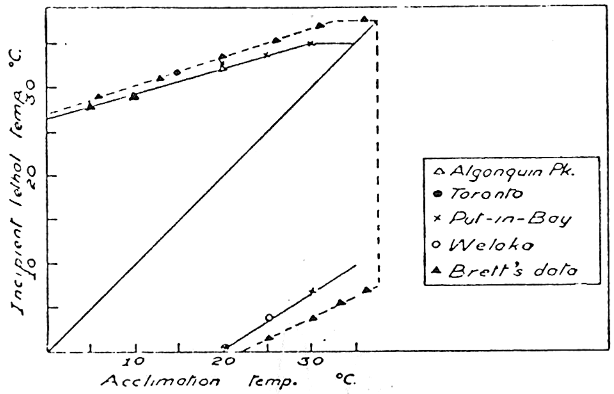

Figure NE-1. Relation between incipient upper and lower lethal temperatures for brown bullhead from the same localities as in Figure NE-2. Brett's (1944) data for Algonquin Park fish are also shown. From Hart, 1952.

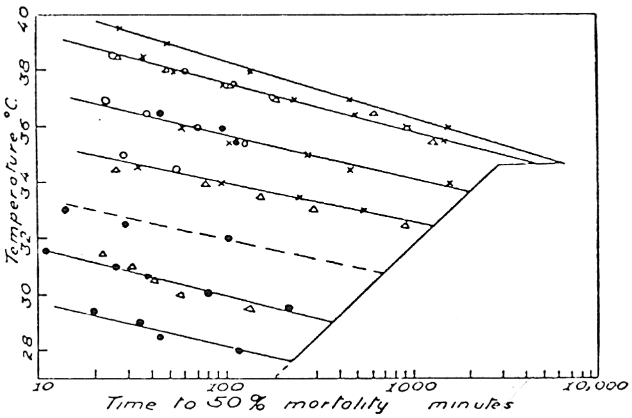

Figure NE-2. Upper lethal time-temperature relationships of brown bullhead from Algonquin Park, Ontario (acclimated to 20 C (68 F), 25 C (77 F) and 30 C (86 F), Toronto, Ontario (acclimated at 5 C (41 F), 10 C (50 F), and 25 C (77 F), Put-in-Bay, Ohio (acclimated to 20 C [68 F], 30 C [86 F], and 34 C [93.2 F]), and Welaka, Florida (acclimated to 20 C [68 F], 25 C [77 F], and 30 C [86 F]. From Hart, 1952.

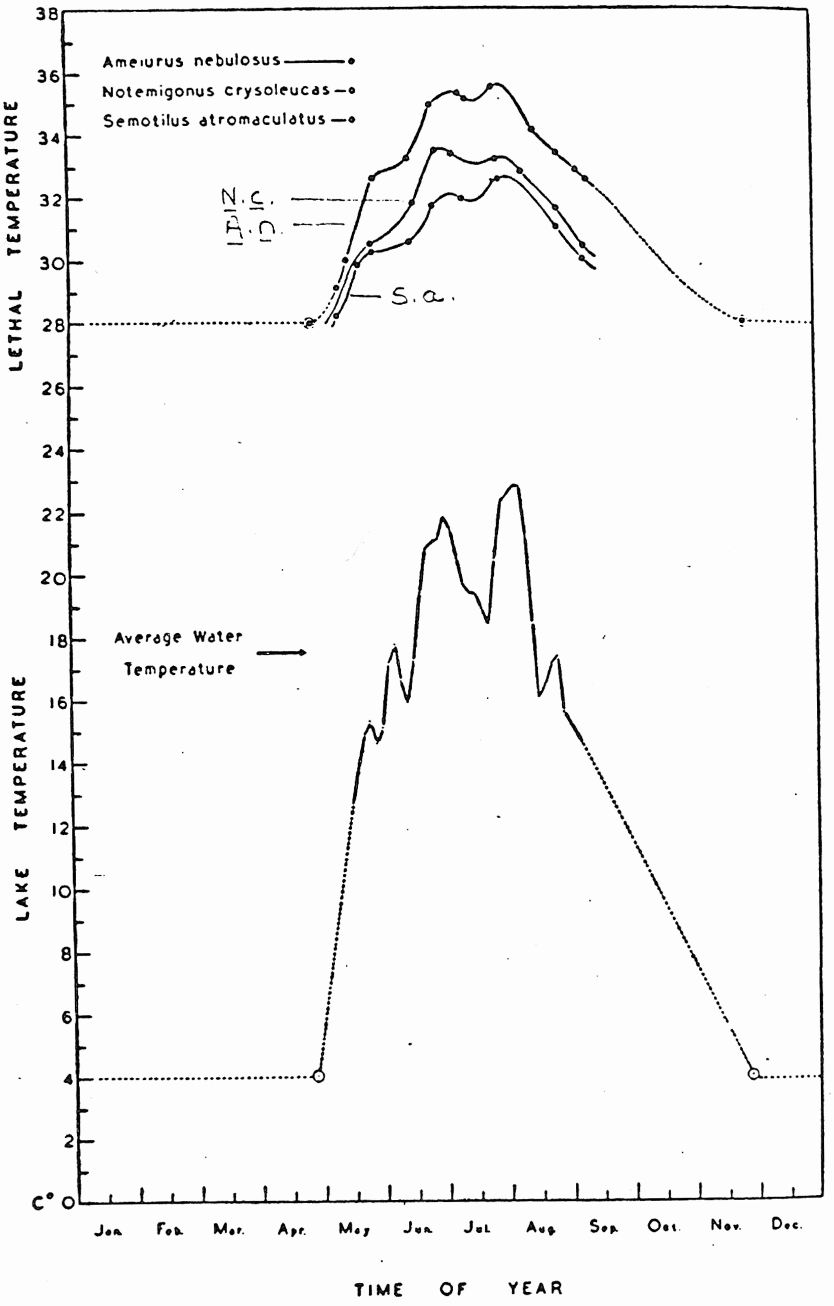

Figure NE-3. Seasonal variation in the lethal temperature of three species from Lake Opeongo, and the variation in the average temperature of the lake water. From Brett, 1944.

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CHANNEL CATFISH

Distribution

The channel catfish is distributed from the Saskatchewan River and the Great Lakes southward to the Gulf of Mexico and to Mexico and has been introduced elsewhere (Eddy, 1969).

Spawning

Spawning has been observed from March (Stevens, 1959; cited in Carlander, 1969:551) through July (Cross, 1951; cited in Carlander, 1969:551) (Table PU-1). In Texas spawning was observed predominantly between 21 and 27 C (69.8 and 80.6 F) though some spawning occured at 15.5 C (59.9 F) after temperatures had been over 21 C (69.8 F) (McClellan, 1954; cited in Carlander, 1969:552). According to Katz (1954; cited in Carlander, 1969:552) spawning usually occurs at 23.9 C (75.1 F). The NTAC (1968:33,43) and Sneed (personal communication; cited in Hokanson, 1969) consider 80 F (26.7 C) as the maximum temperature for channel catfish spawning.

Eggs

Hatching occurs in between 7 and 10 days for eggs incubated at between 75 and 82 F (23.9 and 27.8 C) (Table PU-2). Optimum hatch of normal larvae has been reported to occur at 22 C (71.6 F) (Hubbs and Allen, 1944; cited in EPA, 1974), and while 82 F (27.8 C) is considered the maximum successful incubation temperature (Sneed, personal communication; cited in Hokanson, 1969), Allen and Strawn (1971) hatched eggs in 28.4 C (83.2 F) water with no reported mortality.

Table PU-1. Channel catfish spawning times at various locations.

Date	Location	Comment	Author
March - April	South Carolina	Some spawning	Stevens, 1959*
April - July			Brown, 1942**
Mid May - June	Arkansas		Hokanson, 1969
June	Ohio		Data cited in Breder and Rosen, 1966:257
June - July	Oklahoma		Cross, 1951*
June - Early July	?		Data cited in Breder and Rosen, 1966:261
June - July	South Carolina	Most spawning	Stevens, 1959*
Prior to mid June	South Dakota		Shields, 1957a, 1957b Sprague, 1961

*Cited in Carlander, 1969:550

**Cited in EPA, 1974

Table PU-2. Incubation times for channel catfish eggs held at various temperatures.

Temperature C	F	Incubation Time (Days)	Author
(23.9)	75	8 - 10	Canfield, 1947*
(23.9)	75	Close to 7	Clemens and Sneed, 1957
(25.6)	78	8	Murphree, 1940*
(26.7)	80	7 - 9	Lenz, 1947*
(26.7)	80	6 - 7	Clemens and Sneed, 1957
(27.8)	82	6	Clemens and Sneed, 1957

*Cited in Clemens and Sneed, 1957.

Larvae

Citing laboratory studies by West (1966), Strawn (1970) stated that when fry were raised for 68 days at temperatures between 21 and 36 C (69.8 and 96.8 F), best growth occurred at 29 and 31 C (84.2 and 87.8 F), with good growth occurring between 27 and 34 C (80.6 and 93.2 F). Food conversion was best at 29 C (84.2 F) but was also very good at 27 and 31 C (80.6 and 87.8 F). West (1966; cited in Strawn, 1970) determined the preferred temperature for fry to be between 28 and 29 C (82.4 and 84.2 F). West (1966; cited in Allen and Strawn, 1968) also observed increased deformities for fry raised to fingerlings in 36 C (96.8 F) water.

Allen and Strawn (1968) investigated lethal temperature relationships for fish ranging in age from 6 days to 11.5 months. Heat resistance in fry changed rapidly at first but leveled off by about 10 days of age. Resistance times of fry were more variable than older fish, and fingerlings were slightly more resistant at a high acclimation temperature (30 C, 86 F). The more detailed analyses of older fish are discussed below.

Juveniles

In addition to studies by West (1966; cited in Strawn, 1970) a number of other papers have discussed growth of channel catfish. For convenience these papers are summarized in Table PU-3 and discussed here. From these data it appears that below 60 F (15.6 C) catfish do not feed, (Gaucher, 1968?), and that growth is suboptimal until 75 F (23.9 C) (Drew and Tilton, 1970), and is more commonly optimal at between 28 C (82.4 F) (Andrews et al., 1972) and 32 C (89.6 F) (Kilambri et al., 1970; cited in Coutant and Goodyear, 1972).

Table PU-3. Summary of growth studies using channel catfish.

Temperature			
C	F	Comment	Author
Below 15	(Below 60)	Growth ceases	Data cited in Gaucher, 1968 (?)
(18.3-21.1)	65-70	Poorer growth conversion	Tiemeier and Deyoe, 1967**
Below 21.1	Below 70	Poor production	Simco and Cross, 1966
Above 21	(Above 70)	Responds best	Data cited in Gaucher, 1968 (?)
(23.9)	75	Maximum growth	Drew and Tilton, 1970
(26.7-29.4)	80-85	Better growth and conversion	Tiemeier and Deyoe 1967**
29	84.2	Best growth and conversion	West, 1966***
(30)	86	Optimum	Hokanson, 1969
30	(86.0)	Best growth and conversion	Andrews and Stickney, 1972***
32.0	(89.6)	Optimum	Kilambri et al., 1970*
(33.9)	93	Maximum	NTAC, 1968:33, 43
28-30	(82.4-86)	Best fingerling growth	Andrews et al., 1972

*Cited in Coutant and Goodyear, 1972.

**Cited in Drew and Tilton, 1970.

***Cited in Strawn, 1970

Plumb (1973) reported that channel catfish fingerlings injected with virus showed significantly higher mortality when incubated at 28 C (82.4 F) rather than 19 C (66.2 F).

Allen and Strawn (1968) determined temperature tolerance in young channel catfish (6 day-old to 11.5 month-old). Fingerlings (44-57 day-old, 13-39 mm SL) acclimated to 26.0, 30.0, and 34.0 C (78.8, 86.0, and 93.2 F) had upper incipient lethal temperatures of approximately 36.6, 37.3 and 37.8 C (97.6, 99.2 and 100.1 F) (Table PU-4). These fingerlings had the highest upper lethal temperatures of the size groups tested, though at "quickly lethal" temperatures older fish had greater resistance (Figure PU-1). Death occurred for up to 13.75 days after initial exposure, and it was said high temperatures might indirectly cause mortalities over a still longer period of time by increasing metabolic rate beyond the fishes ability to consume food (see also General and Unspecified section for additional findings of delayed mortality).

Allen and Strawn (1971) further evaluated acclimation rates in juvenile (20-42 mm TL) channel catfish. Fish transferred from lower to higher temperatures were nearly reacclimated (in terms of resistance to high temperatures) in 1 to 3 days, though 12 days were needed for complete reacclimation. Acclimation rate was accelerated at higher temperatures.

General and Unspecified

Walburg (1969) found that catch/effort was uniform between 10 and 26.1 C (50.0 to 79 F)(the highest temperature recorded).

For fat and lean catfish acclimated to 25 C (77 F), a rapid temperature rise to 30 C (86 F) caused a brief though substantial increase in metabolic rate (Moss and Scott, 1964). Fish tested at 35 C (95 F) were not reported to experience mortality.

Table PU-4 Summary of results of lethal temperature determinations using channel catfish.

Acclimation Temperature	Rate of Change	ULT$_{50}$ C F	Resistance Time	Author
(7.2) 45	1 F/hr.	(32.8) 91	1 hr.	Trembley, 1961: VIII-7
(11.1) 52	2 F/hr.	(35.0) 95	1 hr.	Trembley, 1961: VIII-7
20 (68.0)	Instantaneous	32.8 (91.0)		Hart, 1952
25 (77.0)	Instantaneous	33.5 (92.3)	Ultimate ULT	Hart, 1952
25 (77.0)	20 min. rise, then 20 min. cool	35 (95.0)	96 hrs. (4 days)	Cairns 1956
Initial temp 26	Instantaneous	36.6		Allen and Strawn, 1968
30 (86.0)	20 min.	35 (95.0)	216 hrs. (9 days)	Cairns, 1956
? ?	2 C/day	35 (95.0)	438 hrs. (18.25 days) at the LT	Cairns, 1956
30 (86.0)		37.3 (99.2)		Allen and Strawn, 1968
34 (93.2)		37.8 (100.1)		Allen and Strawn, 1968

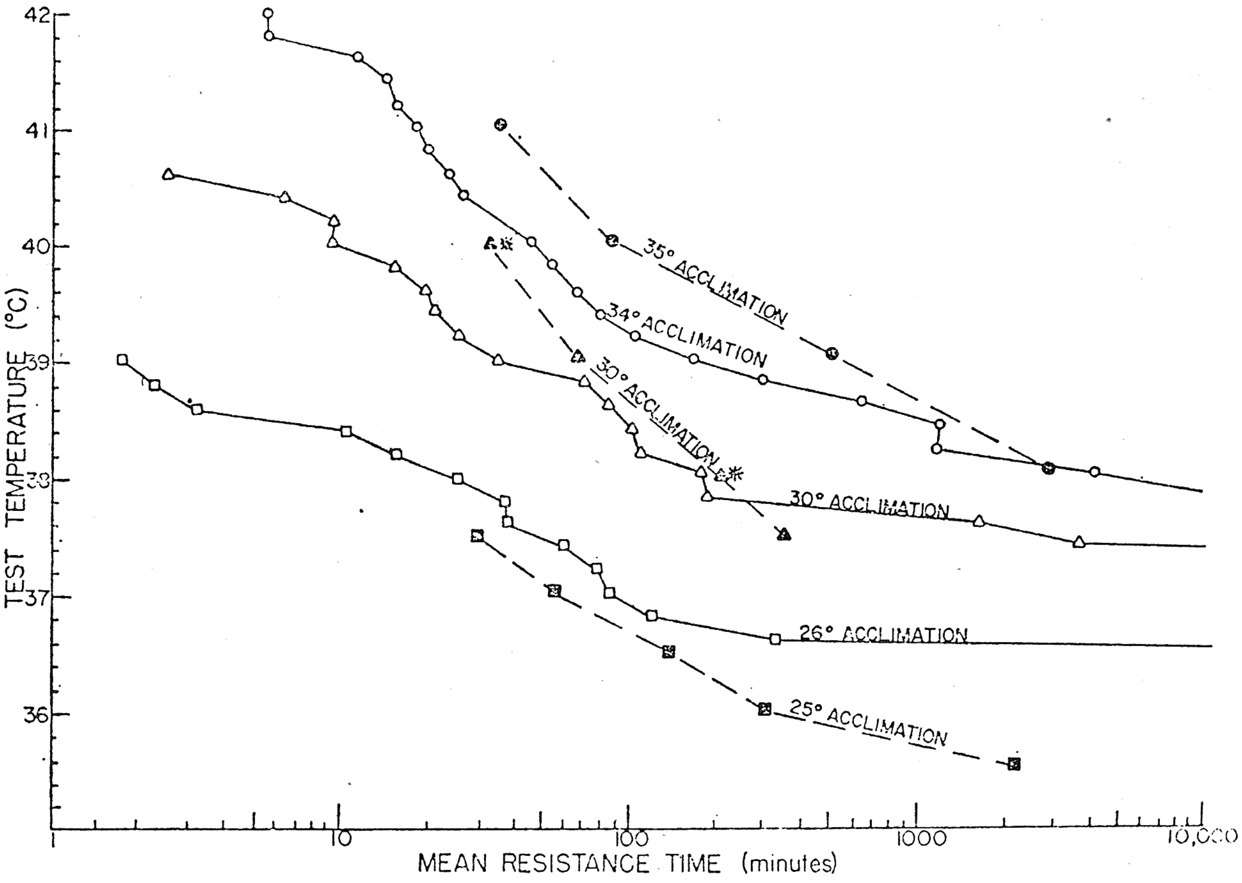

Figure PU-1. A comparison of the Mean Resistance Times of the Lonoke (73-120 mm SL) (dashed lines) and Centerton (13-39 mm SL) juvenile channel catfish (solid lines). Means of two samples of the West fish (79-119 mm SL) are represented by * (The West fish were acclimated to 30.0 C for 31 days) From Allen and Strawn, 1968.

Several studies around thermal discharges have commented upon the relationship between channel catfish distributions and discharge temperatures. Trembley (1960:IX-10) determined 86 F (30 C) as the maximum internal body temperature for fish around a discharge into the Delaware River, and Gammon (1973:44) found catfish in Wabash River to prefer water between 30 and 32 C (86 to 89.6 F), though Proffitt (1969) collected them in White River in water up to 95 F (35 C), and more recently (Proffitt and Benda, 1971:38) in water of 100 F (37.8 C). When frightened from the cooler into warmer sections of a lagoon ranging in temperature from 82 to 95 F (27.8 to 35 C), no deaths occured, though fish regrouped in the cooler zone (Trembley, 1960:IX-10).

In addition to determinations using juveniles (Allen and Strawn, 1968), several other investigators have investigated lethal temperatures using channel catfish of unspecified size and/or age (Hart, 1952: Cairns, 1956; Trembley, 1961)(Table PU-4). Despite using the slow temperature rise method (which results in a higher ULT) Trembley's (1961:VIII-7) use of low acclimation temperature (95 F, 7.2 C) resulted in lowest reported lethal temperature (91 F, 32.8 C). At higher acclimation temperatures (up to 30 C, 86 F) lethal temperatures for fish other than these tested by Allen and Strawn (1968) rose to 35 C (86 F) (Cairns, 1956).

Resistance times for temperatures above lethal limits as reported by Hart (1952) are given in Figure PU-2.

The results of studies by Cairns (1956) provide another example of the limitations of using short test durations for evaluating impact of high temperatures on fish populations. Fish sometimes survived weeks before death at high temperatures. While perhaps not the result of "immediate direct" effects (Fry, 1971:20; see also p.17-18) a slow attrition of fish result in a similar longterm population demise.

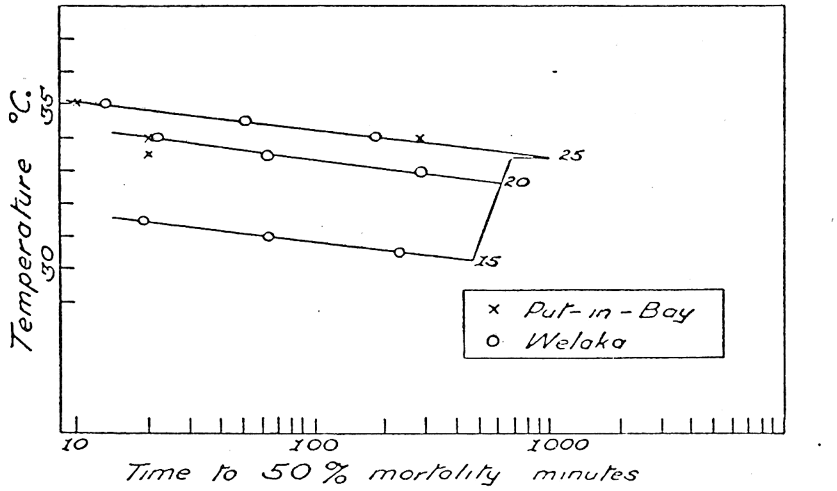

Figure PU-2. Upper lethal temperature relationships for channel catfish from Put-in-Bay, Ohio (acclimated to 20 C and 25 C) and Welaka, Florida (acclimated to 15 C, 20 C and 25 C). From Hart, 1952.

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MARGINED MADTOM

Distribution

The margined madtom is found from New York to Georgia, mostly on the eastern side of the Appalachians (Eddy, 1969). Several subspecies exist (Hubbs and Lagler, 1958).

General and Unspecified

Trembley (1960:IX-10) found only one madtom in a heated water discharge into the Delaware River. This was a recently killed specimen floating in 95 F (35 C) water.

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FLATHEAD CATFISH

Distribution

The flathead catfish is found from South Dakota and Lake Erie, throughout the Mississippi valley and south into eastern Mexico (Pflieger, 1971).

Spawning

In Texas spawning occurs in May (Henderson, 1965; cited in Carlander, 1969:562), while in Kansas spawning occurs from early June to late July (Minkley and Deacon, 1959; Deacon, 1961; both cited in Carlander, 1969:562).

Flathead catfish in a Texas hatchery were paired in pens and when water temperatures were between 76 and 80 F (24.4 C and 26.7 C), spawning was induced using hormones (White, undated). The NTAC (1968:33, 43) recommended 80 F (26.7 C) as the maximum temperature compatible with spawning in catfish.

Incubation

Hatching occurs in 6 to 7 days at water temperatures of 75 to 82 F (23.9 to 27.8 C) (Giudice, 1965; cited in Carlander, 1969:562).

Juveniles

The NTAC (1968:33, 43) recommended 93 F (33.9 C) as the maximum temperature compatible with growth in catfish.

General and Unspecified

In the Wabash River, Gammon (1973:44) found flathead catfish were more abundant in effluent and mixed water below a heated water discharge, preferring waters ranging from 31.5 to 33.5 C (88.7 to 92.3 C). Proffitt and Benda (1971:38) have captured flathead catfish in effluent water up to 92.5 F (33.6 C).

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ROCK BASS

Distribution

The rock bass is found from Saskatchewan to Vermont and south to the Gulf of Mexico (Eddy, 1969). Two subspecies occur, *A. r. ariommus* Viosca within the lower Mississippi valley and adjacent Gulf coast drainages, and *A. r. rupestris* (Rafinesque) occupying the rest of the range.

Spawning

Spawning occurs between April and June in New York (Wright and Allen, 1913; cited in Breder, 1936) between mid May and mid June in Indiana (Evermann and Clark, 1920; cited in Breder, 1936). In the New York Aquarium Breder (1936) noted spawning in mid July in water temperatures of 20.5 and 21 C (68.9-69.8 F).

Juveniles

In laboratory studies Neill and Magnuson (1974) report a mean temperature preference of 27.3 C (81.2 F) for fish 48-59 mmTL.

Adult

The mean body temperature of rock bass (98-182 mmTL) collected in a Wisconsin lake heated discharge was 27.5 C (81.5 F) (Neill and Magnuson, 1974). Gammon (1971) collected specimens only in mixed water below a Wabash River heated discharge at mean water temperature of 27.4 C (81.3 F).

General and Unspecified

In Wisconsin lakes during summer Hile and Juday (1941; cited in Ferguson, 1958) found fish distributed in water between 14.7 and 21.3 C

(58.5 and 70.3 F), while in southern Ontario, Hallam (cited in Ferguson, 1958) found rock bass to concentrate at 20.7 C (69.3 F).

Most specimens found by Trembley (1960:IX-13) around a heated discharge into the Delaware had body temperatures below 86 F (30 C), though they were collected at temperatures up to 90 F (32.2 C).

Bailey (1955) noted death of a rock bass and distress in others in a small Michigan pond which had reached temperatures of 38 C (100.4 F).

Lethal temperature determinations using a slow temperature rise (0.79-2.0F/hour) have been made on several occasions by Trembley (1961:VIII-6 to VIII-7). The highest LT_{50} was 99.5 F (37.5 C) from an acclimation temperature of 75 F (23.9 C).

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REDBREAST SUNFISH

Distribution

The redbreast sunfish is distributed from New Brunswick to Florida and along the Gulf coast to Texas (Eddy, 1969). It has not been reported in Kentucky (Clay, 1962), in the Great Lakes region (Hubbs and Lagler, 1958), in Missouri (Pflieger, 1971), or in Ohio (Trautman, 1957).

Spawning

Fowler (1923, cited in Breder, 1936) found spawning in Pennsylvania to occur in mid June, and Breder (1936) reports that in the vicinity of New York spawning nests have been found from early June to mid August at temperatures ranging from 68 to 82 F (20 to 27.8 C).

Adults

Definite school formation occurs in adults only below 5 C (41 F) and hibernating habit breaks up at 10 C (50 F) (Breder and Nigrelli (1935; cited in Breder and Rosen, 1966:413, 427).

General and Unspecified

Van Vliet (1957), in discussing early findings of Trembley (1960, 1961), relates that there were numerous cases in which individuals swam directly into water 40 F (22.2 C) above ambient and died without any coordinated effort to return to colder water.

Trembley (1960:VIII-4, 1961:VIII-6 to VIII-7) performed lethal temperature determinations using a slow temperature rise (1.0-3.5 F/hour). He found that even for specimens acclimated to 45 F (7.2 C), the LT_{50} was 89 F (31.7 C) and rose with acclimation temperature to 101 F (38.3 C) (70 F, 21.1 C acclimation temperature.)

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GREEN SUNFISH

Distribution

The green sunfish is distributed from Minnesota and the Great Lakes and west of the Alleghenies south to Mexico (Eddy, 1969).

Spawning

Spawning has been reported to occur between mid May (Hunter, 1963; cited in Scott and Crossman, 1973:712) and August (Hubbs and Cooper, 1935; cited in Breder and Rosen, 1966:413) at temperatures between 15.6 C (60.1 F) (Wojtalik, unpublished; cited in NAS, 1973) and 82.4 F (28 C) (Hunter, 1963; cited in Scott and Crossman, 1973:712) (Table CY-1).

During spring Nickum (1966) found increased sensitivity of green sunfish to rapid temperature elevations--perhaps related to (pre-) spawning period. During this time a rapid temperature rise of 8 F (4.4 C) from 62 F (16.7 C) resulted in delayed mortality.

A series of papers have indicated that a combination of long photoperiod and elevated water temperature is the effective stimulus to gonadal recrudescence and rapid gametogenesis in green sunfish (Kaya and Hasler, 1972; cited in Kaya, 1973a), and that the responsiveness of the gonads to stimulating hormones in a constant photoperiod environment is markedly modified by temperature (Kaya, 1973b). Rates of gonadal regression following spawning were greatly affected by temperature, but very little by photoperiod, suggesting that the rapid rate at which regression occurs in natural populations is related to the attendant elevated mid summer water temperatures (Kaya, 1973a).

Table CY-1. Green sunfish spawning times and temperatures at various locations.

Date	Temperature		Location	Comment	Author
	C	F			
Mid May - Early August	(20-28 C)	68-82.4	Wisconsin	Spawning	Hunter, 1963**
June and July				Nesting	Cahn, 1927*
Late June - August			Michigan	Spawning	Hubbs and Cooper, 1935*
Mid Summer			S. Dakota	Probable spawning time	Churchill and Over, 1933*
	15.6	(60.1)		Spawning	Wojtalik, unpublished***

*Cited in Breder and Rosen, 1966:413

**Cited in Scott and Crossman, 1973:712

***Cited in NAS, 1973

General and Unspecified

Roots and Prosser (1962) determined the relationship between temperature and maximum swimming speed in green sunfish acclimated to temperatures between 5 and 30 C (41 and 86 F). They found that swim speed for fish acclimated to temperatures between 10 and 30 C (50 and 86 F) increased with test temperature, except at the highest test temperature for each level of acclimation (Figure CY-1). The greatest swim speed was achieved by specimens acclimated to 30 C (86 F) and tested at 35 C (95 F).

Proffitt and Benda (1971:38) collected green sunfish in White River heated effluent water of up to 97 F (36.1 C).

Nickum (1966) reported delayed mortality during summer, fall, and winter, when sunfish were exposed to rapid temperature elevations, though in general survival following changes of 20 F (11.1 C) or less was as good, or better, than in control groups.

No effect of water hardness levels of between 30-400 mg/1 were noted by Whitford (1970) on upper incipient lethal temperatures for green sunfish. He found that for specimens acclimated to 20 and 30 C (68 and 86 F), incipient lethal temperatures were 35 and 40 C (95.0 and 104.0F) respectively.

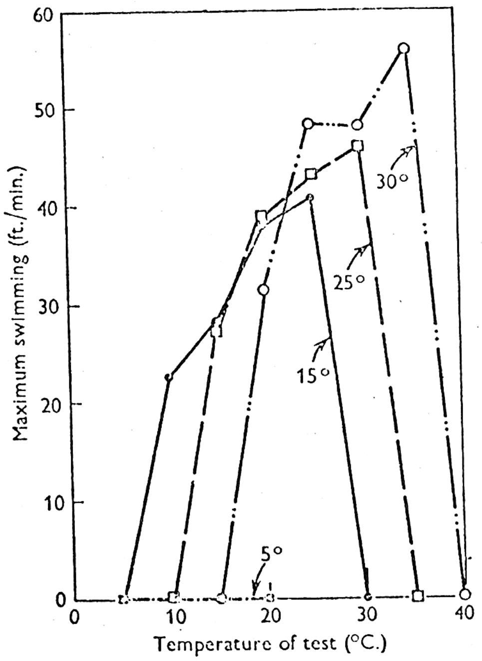

Figure CY-1. Relationship between temperature and maximum swimming speed in green sunfish acclimated to different temperatures. The acclimation temperature is shown beside each curve. From Roots and Prosser, 1962.

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PUMPKINSEED

Distribution

The pumpkinseed is distributed from southern Manitoba and New Brunswick, south through South Carolina, and west to Nebraska (Pflieger, 1971).

Roberts (1967) has extended the work of Hart (1952) and McCauley (1958) on possible geographical differences in temperature responses within a species of fish. Working with the green sunfish he found evidence of geographic separation in the rate-temperature curves for Massachusetts and North Carolina fish.

Spawning

Breder (1936) cites studies (Table GI-1) that show nesting to occur from May (e.g., Hankinson, 1908) to August (e.g., Bensley, 1915). In the vicinity of New York City nesting was seen in water ranging in temperature from 20 to 29 C (68 to 84.2 F) (Breder, 1936), and spawning observed at 28 C (82.4 F) in aquaria.

Smith (1970; cited in Coutant and Goodyear, 1972) observed male prespawning aggregations at 25 C (77 F) but not at 11 to 13 C (51.8 to 55.4 F). According to Breder and Rosen (1966:437) the beginning of spawning season can evidently be considerably advanced by maintenance of a continuous high temperature (24 C, 75.2 F).

Eggs

Hatching takes place in as little as 3 days when eggs are incubated at 82.4 F (28 C) (Scott and Crossman, 1973:716).

Table GI-1. Pumpkinseed spawning times at various locations*.

Date	Location	Comment	Author
May	New York (?)	Nesting	Abbott, 1884
May		Nesting	Gill, 1907
May	Michigan	Nesting	Hankinson, 1908
May		Nesting	Hankinson, 1909
May	Illinois	Nesting	Forbes and Richardson, 1908
May	New York	Nesting	Wright and Allen, 1913
Late May - August	New York City area	Nesting	Breder, 1936
June - July	Michigan	Spawning	Hankinson, 1908
June - July	New York (?)	Spawning	Embody, 1915
Up to August	Ontario	Nesting	Bensley, 1915
Up to August	Michigan	Nesting	Leathers, 1911

*Cited in Breder (1936)

Juveniles

In the laboratory, Anderson (1951; cited in Ferguson, 1958) found young pumpkinseeds to have a final preferendum of 31.5 C (88.7 F).

Several young (17-18 mm) pumpkinseeds were seined from a shallow Michigan pond following a week of water temperatures of up to 38 C (100.4 F) (Bailey, 1955).

Adults

Bailey (1955) also noted one adult undergoing heat stroke in the shallow pond when waters reached 38 C (100.4 F), but many other adult (?) green sunfish were active and apparently not affected.

General and Unspecified

Bardach and Bjorklund (1957) found pumpkinseeds (length 6-10 cm) able to perceive temperature changes of less than 0.10 C (0.18 F).

In studies around a power plant in Wisconsin, Neill and Magnuson (1974) found 100-161 mm TL pumpkinseeds had mean internal body temperatures of between 28 C (82.4 F) (night) and 30.5 C (86.9 F) (day). Around a power plant on the Delaware River, pumpkinseed body temperatures ranged up to 89 F (31.7 C) for specimens caught in the river, while seining in the discharge canal produced specimens with body temperatures as high as 96 F (35.6 C) (Trembley, 1960:IX-13). A single specimen was taken alive in 100 F (37.8 C) water, but it was sluggish and in poor condition. Pumpkinseeds were unusually abundant in the heated discharge (Trembley, 1960:IX-13), though temperatures much above 90 F (32.2 C) were generally avoided (Trembley, 1961:IX-17).

When acclimated to approximately 18 and 24 C (64.4 and 75.2 F), Black (1953) found 24 hour LT_{50}'s of 28 and 30.2 C (82.4 and 86.4 F), respectively, though Trembley (1961) (using a 1.8 F/hour temperature rise) found specimens acclimated to 70 F (21.1 C) had an LT_{50} of 102 F (38.9 C).

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LONGEAR SUNFISH

Distribution

The longear sunfish is found from Iowa to southern Quebec and south to South Carolina and into Mexico (Eddy, 1969). While several authors (Hubbs and Lagler, 1958; Trautman, 1957) recognize subspecies, more recent work (Eddy, 1969; Pflieger, 1971) does not seem to support this.

Spawning

Spawning has been reported between late May and late August (Hankinson, 1919) (Table ME-1) and has been reported at 23.3 C (74.0 F) (Wojtalik, unpublished; cited in NAS, 1973) and at probably between 74 and 77 F (23.4 and 25 C) (Scott and Crossman, 1973:726).

In the laboratory, prespawning aggregations of males have been seen at 25 C (77 F), but not at between 11 and 13 C (51.8 and 55.4 F) (Smith, 1970; cited in Coutant and Goodyear, 1972).

Juveniles

For specimens acclimated to 25, 30 and 35 C (77, 86 and 95 F) Neill et al. (1966) estimated the 14 hour upper incipient LT_{50} to be 35.5, 36.6 and 38.2 (95.9, 97.9 and 100.8 F), respectively. The upper incipient lethal temperature was elevated about 1.3 C (2.3 F) for each 5 C (9 F) rise in acclimation temperature, and in general larger young sunfish were more resistant to upper lethal temperatures than were their smaller siblings of similar age. Resistance times for the 25, 30 and 35 C (77, 86 and 95) acclimation temperatures are given in Figure ME-1 (Neill et al., 1966).

Table ME-1. Longear sunfish spawning times at various locations.

Date	Location	Comment	Author
Late May - Late August	Illinois		Hankinson, 1919
Mid June	Michigan		Hankinson, 1919
Late June - August	Michigan	Nests	Hubbs and Cooper, 1935*
July	New York	Nests	Adams and Hankinson, 1928*
July	Michigan	Nests	Hankinson, 1908*
Mid July	Northern Indiana	On spawning beds	Kirsch, 1895**

*Cited in Breder, 1936

**Cited in Hankinson, 1919

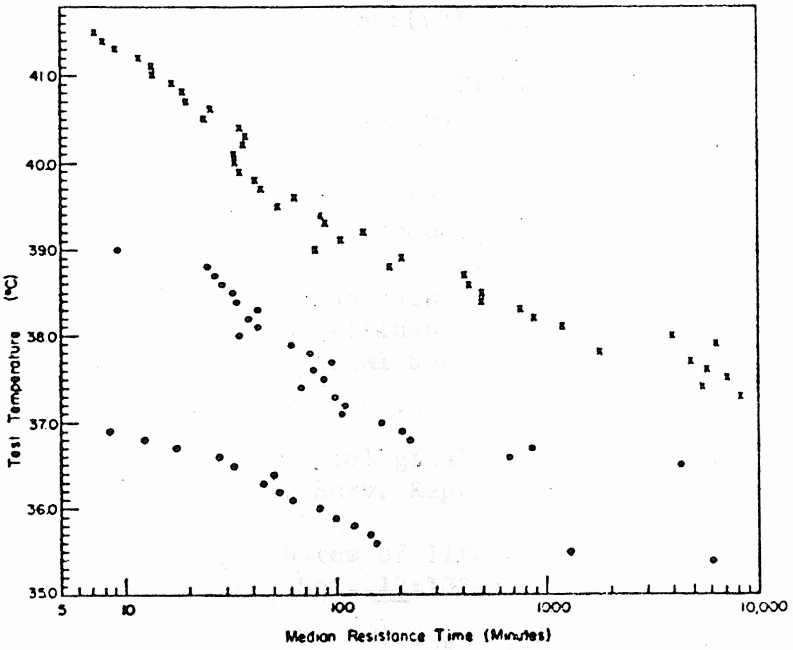

Figure ME-1. Median-resistance times for young longear sunfish acclimated to 25 C (●), 30 C (o), and 35 C (x). From Neill et al., 1966.

General and Unspecified

Gammon (1971) found longear sunfish only in mixed water below a heated water discharge on the Wabash River at water temperatures between 83.6 and 85.6 F, while Proffitt (1969) has sighted longears in water up to 93 F (33.9 C) in a White River heated effluent, and more recently (Proffitt and Benda, 1971:38), they have been collected in discharge water of 100 F (37.8 C).

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SMALLMOUTH BASS

Distribution

The smallmouth bass is distributed from Minnesota to Quebec and south to Arkansas and northern Alabama, and has been widely introduced elsewhere (Eddy, 1969).

Spawning

Spawning in smallmouth bass occurs from as early as March (Tracy, 1910; cited in Breder, 1936) to early August (Henderson and Foster, 1956), usually at temperatures between 59 to 65 F (Table DO-1), but may extend to perhaps 75 F (23.9 C) (Henderson and Foster, 1956).

Eggs

Wallace (1973) took newly fertilized eggs (16-cell stage) from 19 C (66.2 F) spring water and incubated them at temperatures between 17 and 29 C (62.6 and 84.2 F). Mortality was greatest at the extremes (17 and 29 C, 62.6 and 84.2 F) with lowest mortality occurring at 23 C (73.4 F).

Below 60 F several authors have noted fungal growth on eggs (Cleary, 1956; Henderson and Foster, 1956) and desertion of the nest, though Tester (1930; cited in Breder, 1936) observed eggs developing in water which had a morning temperature of 55.4 F (13 C) and made no mention of mortality. Tester (1930; cited in Hubbs and Bailey, 1938) found that if eggs were transferred from 61 to 73.5 F (16.1 to 23.1 C) just before hatching, the eggs did not survive. In other studies, (Webster, 1945) a rapid temperature change from 55 to 79 F (12.8 to 26.1 C) was not fatal to eggs about to hatch. Webster (1945) did not know whether his unsuccessful attempts to incubate eggs at 80 F (26.7 C) were

Table DO-1. Smallmouth bass spawning times and temperatures at various locations*.

	Temperature				
Date	C	F	Location	Comment	Author
Early as March			New York	Spawning	Tracy, 1910*
Early in spring		High 50's-mid 60's	Southern waters	Spawning	Lagler, 1956:50
Mid April-Mid May	(13.3)	56	New York	Spawning	Nesley, 1913
April-Early August	(12.8-23.9)	55-75**	Washington	Spawning	Henderson and Foster, 1956
Late April - Early July			Missouri	Spawning	Pflieger, 1966
		At much below 60		Temporary cessation of nest building	Hubbs and Bailey, 1938
At least as early as late April	(15-18.3)	59-65	Southern waters	Nest building and spawning	Hubbs and Bailey, 1938
May - Early June	(15-18.3)	59-65	Southern New York and Michigan	Nest building and spawning	Hubbs and Bailey, 1938
Continue throughout June	(15-18.3)	59-65	Northern New York, Ontario	Nest building and spawning	Hubbs and Bailey, 1938
May - July			Ontario	Spawning	Nash, 1908*
	(15.6)	Could be below 60		Nesting begins	Reighard, 1906*
	(16.7)	62	Michigan	Spawning	
		62		Spawning begins	Bennett, 1965

Table DO-1. (Continued)

	Temperature				
Date	C	F	Location	Comment	Author
	(16.7-17.8)	62-64		Most spawning	Wiebe, 1935*
Late May	(17.8)	64	Southern New York	Earliest spawning date	Breder, 1936
End of July		High 50's-mid 60's	Ontario	Spawning	Lagler, 1956:50

*Cited in Breder (1936)
**Report is unclear whether temperatures reported were for spawning or egg hatching.

due directly to temperature, or due to the rapid fouling of the water at that temperature. Hatching at 80 F (26.7 C) was accomplished by Langlois (1931; cited in Webster, 1945).

Several papers have discussed the length of egg incubation. Excluding abnormally extended periods reported by Beeman (1924; cited in Webster, 1945), incubation times generally range from 9 days at 55 F (12.8 C) to 2.2 days at 77 F (25 C) (Webster, 1945) (Table DO-2).

Larvae

Larimore and Duever (1968) studied effects of temperature on swimming ability of smallmouth bass fry acclimated to temperatures between 5 and 35 C (41 and 95 F). The maximum swimming speed for fish acclimated to a particular temperature increased with successively higher test temperatures, to a level above which swimming ability declined rapidly. Swimming speeds were progressively higher for each higher level of acclimation with the exception of those from 35 C (95 F). The best swimming performance was at a temperature above the acclimation temperature for all fry except those acclimated to 30 and 35 C (86 and 95 F), and those fry failed to swim above their acclimation temperatures. Larimore and Duever concluded that natural temperature changes in streams might not directly cause loss of fry, but might reduce their ability to swim, and thereby contribute to their displacement when exposed to turbid and turbulent floodwaters.

Tester (1930; cited in Hubbs and Bailey, 1938) stated that while eggs were killed when raised from 61 to 73 F (16.1 to 23.1 C), newly hatched young were not so affected.

Table DO-2. Incubation times for smallmouth bass eggs.*

Temperature C	Temperature F	Incubation Time (Days)	Author
(12.8)	55	~ 9.85	Webster, 1945
15	(59)	7	Wojtalik, unpublished***
(15)	59	7.0	Webster, 1945
(15-17.8)	59-64	21	Beeman, 1924**
(15)	60	6	Lydell, 1904**
(Min. of 15.6)	Min of 60	16	Langlois, 1931**
(17.2)	63 or somewhat higher	4 - 3	U. S. Comm. Fish, 1900**
(17.8-21.1)	64-70	14	Beeman, 1924**
(18.3)	65	4.1	Webster, 1945
(18.3-21.1)	65-70	4	Rawson, 1937**
(21.1+)	70+	7	Beeman, 1924*
(21.7)	71	2.9	Webster, 1945
(23.3)	74	4	Embody, unpublished**

Table DO-2 (Continued)

Temperature		Incubation Time	
C	F	(Days)	Author
(25.0)	77	2.2	Webster, 1945
(Max. of 26.7)	Max. of 80	7	Langlois, 1931**

*Cited in Breder, 1936.

**Cited in Webster, 1945.

***Cited in NAS, 1973.

Juveniles

According to Hubbs and Bailey (1938) a much faster rate of growth has been observed in warmer streams and lakes in the northern states, and the size of young fish has been demonstrated to influence their survival (Hokanson, 1969). In a laboratory experiment, overwinter mortality of young smallmouth bass was greater among small fish (MacLeod, 1967; cited in Hokanson, 1969).

Horning and Pearson (1973) also found juvenile smallmouth grew best in the 26 to 29 C (78.8 to 84.2 F) range, and Peek (1965: cited in Horning and Pearson, 1973) found that the maximum amount of energy available for growth was at 28 to 29 C (82.4 to 84.2 F) and that above 29 C (84.2 F), maintenance requirements increased faster than food intake, resulting in decreased growth. The NTAC (1968:33,43) recommended 84 F (28.9 C) as the maximum temperature compatible with smallmouth growth.

Peek (1965; cited in Horning and Pearson, 1973) also showed that laboratory-reared smallmouth bass fingerlings (9.65 mm) tended to choose temperatures (28 to 29 C, 82.4 to 84.2 F) at which their growth was maximum. Field observations indicated that wild smallmouth bass fingerlings react in the same manner. In an undated manuscript by F. E. J. Fry (cited in Ferguson, 1958), juvenile smallmouth bass had a final preferendum of 28 C (82.4 F).

Early studies by Wells (1914) showed small (4 in.) smallmouth bass to select warmer temperatures in a gradient ranging from 5 to 8 C (41 to 46.4 F). He also stated that "fishes [including smallmouth bass?]

tend to select an optimum temperature, 16 to 19 C (60.8 to 66.2 F) for they will turn back from warm water when it is above this temperature". While Wells addressed a number of subjects relevant to present day concerns, his discussion was insufficient to permit evaluation of why his preference results differed from those of other authors cited above.

General and Unspecified

Smallmouth bass became inactive in the middle Snake River when water temperatures fell below 6.7 C (44.1 F) and remained hidden within the rocky substrate until the water temperature rose to 7.8 C (46.1 F) (Munther, 1970; cited in Coutant, 1971). Keast (1968; cited in Scott and Crossman, 1973:732) found smallmouth bass began feeding in spring when the water temperature reached 47.3 F (8.5 C). Hubbs and Bailey (1938) state that a water temperature of about 50 F (10 C) marks the beginning and end of the period of nonactivity, and of reduced or suspended growth.

Field observations by Hallam (1958; cited in Ferguson, 1958), and Hile and Juday (1941; cited in Ferguson, 1958) found smallmouth bass to prefer water between 20.3 and 21.4 C (68.5 and 70.6 F).

Gammon (1971) noted that while smallmouth bass avoided a Wabash River heated water discharge during summer, they returned to areas below the plant when temperatures dropped below about 27 C (80.6 F) in the fall. Increasing populations in a heated water discharge into the Delaware River were also noted (Van Vliet, 1957) when temperatures dropped to around 80 F (26.7 C). Trembley (1960:IX-12) found smallmouth bass were nevertheless well represented. Body temperatures of fish taken angling in the open river below the discharge ranged up to 92 F (33.3 C); in the discharge lagoon, body temperatures ranged up to 94 F (34.4 C). Other observations of specimens in water of 90 F (32.2 C) or above were also made (Trembley, 1961:IX-16). Hokanson (1969) stated that specimens have been collected in 100 F (37.8 C) water around TVA power plant discharges.

Hoak (1961) stated that Trembley (1960) reported smallmouth bass striking at lures cast into 104 F water, though this mention in Trembley's report could not be located.

Trembley (1960:VIII-4) reported an upper LT_{50} of between 85 and 90 F (29.4 and 32.2 C) temperature when specimens acclimated to 55 F (12.8 C) were exposed to 3.5 F/hour temperature elevations.

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SPOTTED BASS

Distribution

The spotted bass ranges from southern Illinois, Missouri and Ohio southward to eastern Texas and the Gulf of Mexico (Eddy, 1969).

Spawning

According to Howland (1932; cited in Breder, 1936), the reproduction of this species is very like that of *M. dolomieui*.

The NTAC (1968:33,43) suggested 75 F (23.9 C) as the maximum temperature compatible with spawning in spotted bass.

Eggs

According to Wojtalik (unpublished; cited in NAS, 1973) eggs hatch in 4 to 5 days when incubated at 20.0 C (68.0 F).

Juveniles

The NTAC (1968:33,43) suggested 93 F (33.9 C) as the maximum temperature for growth in spotted bass.

General and Unspecified

Hubbs and Bailey (1938) placed the spotted bass intermediate between the smallmouth bass and the largemouth bass in terms of water temperature preference. Gammon (1973:44) indicated a range of optimum temperatures to be between 28 and 30 C (82.4 and 86 F). The maximum temperature in which spotted bass were captured in the White River was 97 F (36.1 C) (Proffitt and Benda, 1971:38).

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LARGEMOUTH BASS

Distribution

The largemouth bass is distributed from southern Canada, through the Great Lakes drainage and south into Mexico; and Virginia to Florida on the Atlantic coast (Eddy, 1969). Except for Florida where a southern subspecies, M. s. floridanus (Lesueur) occurs, the range is occupied by the northern largemouth bass, M. s. salmoides (Lacepede) (Hubbs and Lagler, 1958). Hart (1952) found large differences in lethal temperatures for these subspecies.

Spawning

Spawning of the northern subspecies occurs between April (Bean, 1903; Tracy, 1910; both cited in Breder, 1936) and July (Bean, 1903, cited in Breder, 1936), depending upon location (Table SL-1). The southern subspecies M. s. floridanus spawns in Florida between mid November and early May (Clugston, 1966).

In Minnesota first spawning occurred 2-5 days after the daily mean water temperature reached and remained above 60 F (15.6 C) (Kramer and Smith, 1960), though Wiebe (1935; cited in Breder, 1936) stated that "It is generally assumed that largemouth bass do not spawn at temperatures much below 64 F"(17.8 C). Breder (1936) reports spawning at 70 F (21.1 C) and the NTAC (1968:33,43) states 75 F (23.9 C) to be the maximum temperature compatible with largemouth bass spawning.

Nickum (1966) reports increased sensitivity to rapid temperature changes in largemouth bass during spring when gonads were developing. At this time a temperature change of 8 F (4.4 C) resulted in 40% mortality after one week.

Table SL-1. Largemouth bass spawning times and temperatures at various locations.*

Date	Temperature C	F	Location	Comment	Author
Mid November			Florida		Clugston, 1964**
Mid December - Early May	(15.6)	60	Florida	Begin	Clugston, 1966
	(21.1)	70	Florida	Peak	Clugston, 1966
	(23.9)	80	Florida	Maximum	Clugston, 1966
April - May			Rhode Island		Tracy (1910)*
April - July			New York		Bean (1903)*
Mid April - Early June	(>15.6)	>60	Minnesota		Kramer and Smith (1960)
Late April - Mid May			Illinois		Richardson (1913)*
May - June			Illinois		Forbes and Richardson (1908)*
Mid May			Michigan		Hankinson (1908)*
Mid to late May			Indiana		Evermann and Clark (1920)*
Late May	(21.1)	70	New York		Breder (1936)

Table SL-1. (Continued)

Date	Temperature C	F	Location	Comment	Author
Early June			Ontario		Bensley (1915)*
	(23.9)	75		Maximum	NTAC (1968)
	20-24	(68-75.2)	Alabama		Swingle, 1956***

*Cited in Breder (1936)

**Cited in Clugston, 1966

***Cited in Hokanson, 1969

NOTE: Observations by Clugston, 1964, 1966 are of Florida largemouth _M_. _s_. _floridanus_

Incubation

The incubation period varies inversely with water temperature, and times reported in the literature range from 96 hours at 60.1 F (15.6 C) (Kramer and Smith, 1960) to 64-47 hours at 73 to 79 F (22.8 to 26.1 C) (Carr, 1942; cited in Kramer and Smith, 1960) (Table SL-2).

Kelley (1968) compared hatching success of eggs acclimated at 0.5 F/hour to temperatures ranging from 50 to 85 F (10 to 29.4 C), and those transferred directly to these temperatures from nests ranging from 63 to 70 F (17.3 to 21.1 C). The percent hatch of eggs acclimated to 50, 80, and 85 F (10.0, 26.7 and 29.4 C), was generally much higher than the percent hatching from non-acclimated eggs. However, in most cases between 55 and 75 F (12.8 and 23.9 C) the acclimation process did not significantly alter survival rates. In field tests where eggs were prevented from receiving aerated water by fanning of the tail of an adult bass, high fungal mortalities were observed at normal temperatures, 66 to 70 F (18.9 to 21.1 C).

According to Badenhuizen (1969; cited in EPA, 1974) the optimum temperature for egg incubation and hatching is 20 C (68 F).

Wiebe (1935; cited in Breder, 1936) reported eggs and fry in nests when temperatures ranged from 65 to 73 F (18.3 to 22.8 C) in the morning and 69 to 82 F (20.6 to 27.8 C) in the late afternoon.

When eggs about to hatch were put directly into 90.5 F (32.5 C) water, none survived (Strawn, 1961).

Larvae

Kramer and Smith (1960) found a significant direct relationship between growth rate in sac fry and temperatures between 62.7 and 70.9 F (17.1 and 21.6 C) (the highest temperature encountered).

Table SL-2. Incubation times for largemouth bass eggs.

Temperature C	Temperature F	Incubation Time (Days)	Comment	Author
(15.6-19.6)	60.1-67.2	72-96 (3-4 days)	Range	Kramer and Smith (1960)
(17.7)	63.9	79.2 (3.3 days)	Average	Kramer and Smith (1960)
(≥17.2)	≥63	70		Page (1898)*
(22.8-26.1)	73-79	64-47		Carr (1942)*

*Cited in Kramer and Smith (1960)

At 15 C (59 F) Strawn (1961) found that although eggs hatched and fry rose from the nest, few fed and all eventually died. The minimum temperature at which fry fed appeared to be 15.9 C (60.7 F), and growth increased with temperature to a maximum at 27.5 and 30 C (81.5 and 86.0 F). At 32.5 C (90.5 F) growth occurred, but more slowly (Figure SL-1).

Juvenile

Hocutt (1973) collected juvenile (52-64 mm TL) largemouth bass from waters between 27 and 31 C (80.6 and 87.8 F), placed them overnight (14-20 hours) between 15 and 35 C (59 and 95 F) at 5 C (9 F) intervals, and the following day evaluated swimming performance at each temperature. Swimming performance increased with temperature over the entire test range, though at a decreasing rate.

Drew and Tilton (1970) state that extensive feeding programs in Texas hatcheries has shown maximum growth of largemouth bass occurs between June and October when water temperatures are 75 F (23.9 C). Johnson and Carlton (1960) determined the optimum for activity, cruising speed and food consumption in fingerlings to be between 71.8 and 84.2 F, with maximum at 77 F. Other studies have found higher optima than these reported by Drew and Tilton (1970) and Johnson and Carlton (1960).

Using subadult bass Coutant et al. (1974) found that when fish were fed *ad libitum* at instant temperatures between 75.2 F (24 C) and 95.9 F (35.5 C), fastest growth occurred between 78.8 F (26 C) and 82.4 F (28 C. Lee (1969; cited in EPA, 1974) reported optimum

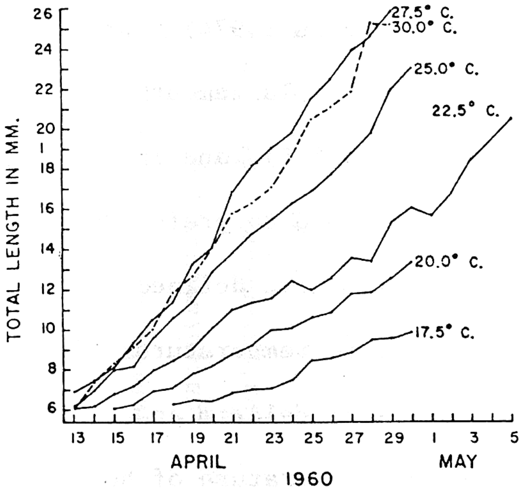

Figure SL-1. Growth rates of largemouth bass fry at various temperatures. From Strawn, 1961.

growth of juveniles at 30 C (86 F), with growth occurring in the range 23 to 31 C (73.4 to 87.8 F). The NTAC (1968:33,43) stated 90 F (32.2 C) to be the maximum temperature compatible with growth of largemouth bass.

According to Fry (1950?; cited in Ferguson, 1958) young largemouth bass have a final temperature preferendum of 30 to 32 C (86 to 89.6 F). Neill and Magnuson (1974) found a median body temperature in young (72-99 mm TL) largemouth around a thermal discharge to be about 29.7 C (85.5 F), and in the laboratory, young bass (65-75 mm TL) were found to prefer 29.1 C (84.4 F), the temperature preference being here defined as the midpoint between lower and upper avoidance temperatures (27.2 and 31 C, 81.0 and 87.8 F, respectively). Meldrim and Gift (1971:36) determined an upper avoidance temperature of between 87 and 91 F (30.6 and 32.8 C) for 57-90 mm TL bass acclimated to 77 F (25 C).

Several authors have determined lethal temperatures for juvenile largemouth bass (Hathaway, 1927; Hart, 1952; Black, 1953). The results of these studies are summarized in Table SL-3 along with results of studies by Trembley (1961 using fish of unspecified size and/or age. For young fish, lethal temperatures have been found to range from 31.8 C (89.3 F) when acclimated to 20 C (68 F) (Hart, 1952), to 38 C (100.4 F)

Table SL-3. Summary of results of lethal temperature studies using largemouth bass.

Acclimation Temperature C	Acclimation Temperature F	Upper LT_{50} C	Upper LT_{50} F	Test Duration Hours	Rate of Change	Location	Author
(7.2)	45	(30.6)	87	21	2.0 F/hour	Pennsylvania	Trembley, 1961: VIII-7
(11.1)	52	(35)	95	43	1.0 F/hour	Pennsylvania	Trembley, 1961: VIII-6
20	(68)	31.8	(89.3)		Instantaneous	Florida	Hart, 1952
20	(68)	32.5	(90.5)		Instantaneous	Ohio	Hart, 1952
20-21	(68-69.8)	28.9	(84.1)	24	Instantaneous	British Columbia	Black, 1953
22-23	(71.6-73.4)	32.2	(90.0)	24	Instantaneous	Wisconsin	Hathaway, 1927
22-23 and 1 day at 30	(71.6-73.4 and 1 day at 86)	36.0	(96.8)	24	Instantaneous	Wisconsin	Hathaway, 1927
22-23, 1 day at 30, then exposed to 36	(71.6-73.4, 1 day at 86, then exposed to 96.8)	38	(100.4)	24	Instantaneous	Wisconsin	Hathaway, 1927
(24.4)	76	(36.1)	97	11.45	1.8 F/hour	Pennsylvania	Trembley, 1961: VIII-6
(24.4)	76	(37.2)	99	11.75	1.9 F/hour	Pennsylvania	Trembley, 1961: VIII-6
30	(86)	33.7	(92.7)		Instantaneous	Florida	Hart, 1952
30	(86)	36.4	(97.6)		Instantaneous	Ohio	Hart, 1952

when acclimated to between 22 and 23 C (71.6 and 73.4 F), held one day at 30 C (86 F), exposed to 36 C, and then tested (Hathaway, 1927). Resistance diagrams prepared by Hart (1952) are given as Figure SL-2 and Figure SL-3. Figure SL-3 also includes some data from Hathaway (1927).

Neither Black (1953) nor Hathaway (1927) evaluated effects of age or size on lethal temperature, though Hart (1952) could find no difference in resistance times for the various size classes (of 9-11 month old fish) he tested. As already mentioned, Hart did find geographic differences in lethal temperatures (Table SL-3, Figure SL-2 and Figure SL-3).

Adults

In acoustic temperature telemetry studies using large bass in Tennessee, Coutant (1974) found specimens to prefer nearly the warmest water available to them, except when surface waters began to exceed 26 C (78.8 F), indicating a preferendum near 27.0 C (80.6 F). Clugston (1973; cited in Coutant, 1974) found large bass in Par Pond, South Carolina preferred 27 to 30 C (80.6 to 86 F) water with 30 C (86 F) also the upper avoidance temperature.

Beamish (1970; cited in Hocutt, 1973) found bass (150-270 mm TL) to show better performance with increasing temperatures between 10 and 30 C (50 and 86 F). Performance decreased at 30 to 35 C (86 to 95 F).

Nickum (1966) found that in winter largemouth bass could tolerate rapid temperature changes of 20 F (11.1 C) with no mortality after one week, but during the summer an 18 F (10 C) rise produced 20% mortality after a week.

General and Unspecified

In Tennessee, Dendy (1945; cited in Ferguson, 1958) found largemouth bass to prefer water between 26.6 and 27.7 C (79.9 and 81.9 F), and bass (100-408 mm TL) were found to have a median internal body temperature of about 29.5 C (85.1 F) around a thermal discharge in Wisconsin (Neill and Magnuson, 1974). However, around a thermal discharge into the Delaware River, Trembley (1961:IX-15) reported most bass were in the 90 F (32.2 C) zone when a thermal gradient ranged from 73 to 90 F (22.8 to 32.2 C). During several years of study Trembley (1960; IX-12) collected largemouth bass with body temperatures up to 96 F (35.6 C). In a South Carolina reservoir receiving heated effluent,Bennett (1971; cited in Morgan, 1973) found fish near the discharge had higher body temperatures (12 to 32 C, 53.6 to 89.6 F) than fish collected in control areas. In the same reservoir during winter, Gibbons et al. (1972) determined catch/effort to be significantly greater in the discharge area (mean surface temperature 27.0 C, 52.0 to 61.7 F), though the authors felt the difference could not be attributed to temperature alone. A 13 C (23.4 F) surface to bottom temperature variation further confounds results of the latter study.

Using the slow temperature rise method Trembley (1960, 1961) determined upper lethal temperatures of largemouth bass. The results of tests reported in 1961 are given in Table SL-3.

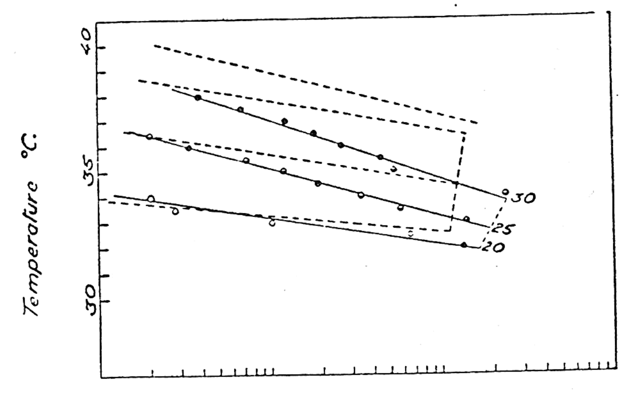

Figure SL-2. Upper lethal temperatures of largemouth bass from Welaka, Florida, at acclimation temperatures for Knoxville and Put-in-Bay samples. The various symbols represent different samples varying considerably in their average weight. From Hart, 1952.

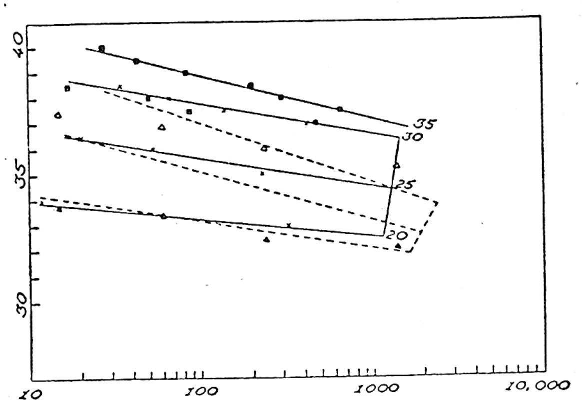

Figure SL-3. Upper lethal temperatures of largemouth bass from Put-in-Bay, Ohio (crosses) and Knoxville, Tennessee (squares). The dotted lines represent Welaka fish for comparison. Data for Lake Mendota fish (Hathaway, 1927) at 22 C and 30 C are included (closed and open triangles). From Hart, 1952.

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WHITE CRAPPIE

Distribution

The white crappie is distributed from Minnesota and the Great Lakes region south to Texas and west Florida (Eddy, 1969).

Spawning

Spawning has been observed between March (Morgan, 1951) and early July (Siefert, 1969) (Table AF-1). According to Siefert (1968; cited in EPA, 1974) spawning occurs at temperatures between 14 and 23 C (57.2 and 73.4 F), though the range 16 to 20 C (60.8 to 68 F) is optimum.

Eggs

At a water temperature of 57.9 F (14.4 C) eggs hatch in about 4 days (Scott and Crossman, 1973:742) and between 70 to 74 F (21.1 to 23.3 C) hatching occurs in from 24 to 27.5 hours (Morgan, 1954; cited in Breder and Rosen, 1966:424).

Juveniles

The optimum temperature for juvenile growth is reported to be 25 C (77 F)(Kleiner and Hokanson, 1973; cited in EPA, 1974), and the NTAC (1968:33,43) considered 90 F (32.2 C) as the maximum temperature compatible with crappie growth.

The ultimate upper incipient lethal temperature for juveniles is 33 C (91.4 F)(Kleiner and Hokanson, 1973; cited in EPA, 1974).

General and Unspecified

Walburg (1969) found a rather even distribution of white crappies in waters seasonally ranging in temperature from 0.6 to 26.1 C (33.1 to 79 F)(the highest temperature recorded), but Gammon (1973:44) found

Table AF-1. White crappie spawning times at various locations.

Date	Location	Author
March - July	Iowa	Morgan, 1951
April - Early July	Ohio	Morgan, 1954**
May	Illinois	Forbes and Richardson, 1908*
Late May	Washington Aquarium	Anonymous, 1919*
Late May - Early July	Nebraska - S. Dakota	Siefert, 1969

*Cited in Breder, 1936

**Cited in Breder and Rosen, 1966:424

the optimum temperature range to be between 27 and 31 C (80.6 and 87.8 F). Agersborg (1930) has found white crappies in 28 to 30 C (82.4 to 86 F) water, and Proffitt and Benda (1971:38) in waters up to 88 F (31.1 C).

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BLACK CRAPPIE

Distribution

The black crappie is distributed from the upper Mississippi valley and the Great Lakes, southward throughout Florida and into Texas (Eddy, 1969; Pflieger, 1971).

Spawning

Spawning has been reported to occur from March (Goodson, 1966; cited in EPA, 1974) to early July (Evermann and Clark, 1920; cited in Breder, 1936) at temperatures between 14 C (57.2 F)(Goodson,1966; cited in EPA, 1974) and 68 F (20 C) (Pearse, 1919; cited in Breder, 1936) (Table NG-1).

Juveniles

During day and night sampling over a two summer period, 50% catch/effort of small (< 76 mm TL) black crappies occurred at between 27 and 29 C (80.6 and 84.2 F) (Neill and Magnuson (1974).

Hokanson and Kleiner (1973; cited in EPA, 1974) determined optimum growth in juvenile black crappies to occur at between 22 and 25 C (71.6 and 77.0 F). Eleven and 30 C (51.8 and 86.0 F) were the limits of zero growth. The NTAC (1968:33,43) considered 90 F (32.2 C) to be the maximum temperature for crappie growth.

For juveniles acclimated to 29 C (84.2 F) Hokanson and Kleiner (1973; cited in EPA, 1974) determined an ultimate upper incipient lethal temperature of 33 C (91.5 F).

General and Unspecified

Neill and Magnuson (1974) reported a 28.3 C (83.0 F) laboratory preference for 75-88 mm TL fish, a temperature identical to mean body temperatures of 126-249 mm TL specimens around a power plant heated water

Table NG-1. Black crappie spawning times and temperatures at various locations.

	Temperature				
Date	C	F	Location	Comment	Author
March	14-18	(57.2-64.4)	California	Begins	Goodson, 1966***
March - June			Ohio		Morgan, 1951
Early May	(17.8)	64	Illinois		Richardson, 1913*
May			S. Dakota		Churchill and Over, 1933*
May into July			Wisconsin		Eddy and Surber, 1943**
Early July			Indiana		Evermann and Clark, 1920*
	(20)	68			Pearse, 1919*

*Cited in Breder (1936)

**Cited in Breder and Rosen, 1966:425

***Cited in EPA, 1974

discharge into Lake Monona, Wisconsin. Gammon (1971) and Trembley (1960:IX-12) collected black crappies only in heated water areas, in the latter study, mostly in May, June and July. Gammon (1971) found specimens at a mean temperature of 31.8 C (89.2 F) and Trembley (1960:IX-12) reports netting specimens with body temperatures of 93 F (33.9 C) and he observed schools remaining in 93 F (33.9 C) water.

In November, Trembley (1961:VIII-7) performed tests to determine the upper lethal temperature determinations of black crappies using a 2 F/hour temperature rise. At an acclimation temperature of 45 F (7.2 C), he found an LT_{50} of 84 F (28.9 C).

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GREENSIDE DARTER

Distribution

The greenside darter maintains two disjunct populations and ranges from Illinois to Pennsylvania and south to Alabama and Missouri (Eddy, 1969; Pflieger, 1971). Three subspecies occur, two in the western population, and *E. b. blennioides* Rafinesque in the eastern area.

Spawning

According to Fahy (1954; cited in Scott and Crossman, 1973:778) spawning season extends from mid April to mid June and was initiated in Salmon Creek, Lake Ontario drainage of New York when water temperatures reached 51 F (10.6 C). This temperature was critical, with spawning activity ceasing if temperatures cropped below this level. Trautman (1957) observed spawning chiefly in April in water usually below 65 F.

Eggs

Hatching occurs in 10 to 18 days when eggs are incubated at between 54.4 and 59 F (13 to 15 C) (Scott and Crossman, 1973:778).

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FANTAIL DARTER

Distribution

The fantail darter is distributed from Minnesota to Vermont and south to northern Georgia and Oklahoma (Eddy, 1969; Pflieger, 1971). From data in Pflieger (1971) and Trautman (1957) it appears that the range eastward of about the Illinois-Indiana border is occupied by *E. f. flabellare* Rafinesque.

Spawning

Lake (1936; cited in Scott and Crossman (1973:788) reported movement into spawning areas in northern New York commenced in late March and extended into April, and that egg laying (and incubation) extended from late April to late June. Temperatures during spawning in New York have been reported as between 66 and 76 F (18.9 and 24.4 C) (Greeley, 1927; cited in Breder and Rosen, 1966:451).

Eggs

According to studies cited in Scott and Crossman (1973:789), eggs incubated at about 70 F (21.1 C) hatch in about 21 days.

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Trautman, M. B. 1957. The Fishes of Ohio. Ohio State Univ. Press, 683 p.

GREENTHROAT DARTER

Distribution

The greenthroat darter occurs from Oklahoma south through central Texas (Eddy, 1969).

Spawning

Hubbs (1961a) reports spawning in central Texas from November through May.

Eggs and Larvae

Hubbs (1961b) incubated eggs of two Texas populations. Average hatching for the two populations occurred in about 36 and 40 days, at 9 C (48.2 F) to between 5 and 6 days at 26 C (78.8 F). Eggs of one population did not hatch at incubation temperatures of 27 and 28 C (80.6 and 82.4 F). In further studies, Hubbs (1961a) reported eggs and larvae could survive constant temperatures throughout an interval ranging between 11 and 27 C (51.8 and 80.6 F), though as noted above (Hubbs, 1961b) stocks from one locality appeared to tolerate temperatures 1 or 2 C (1.8 or 3.6 F) below this limit.

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Hubbs, C. 1961b. Differences in the incubation period of two populations of *Etheostoma lepidum*. Copeia 1961 (2):198-200.

FINESCALE SADDLED DARTER

Distribution

This darter has a distribution restricted to the upper Kanawha River drainage in Virginia and West Virginia (Eddy, 1969).

General and Unspecified

No temperature related life history data have been located on this species.

References Cited

Eddy, Samuel 1969. How to know the freshwater fishes, 2nd ed. William C. Brown Comp., Dubuque, Iowa, 286 p.

ORANGETHROAT DARTER

Distribution

The orangethroat darter occurs between eastern Colorado to Ohio and Tennessee (Eddy, 1969).

Spawning

Hubbs (1961a) and Hubbs and Armstrong (1961) report spawning in Texas from November through May. In northwestern Arkansas spawning occurs between March and May (Hubbs and Armstrong, 1962).

Eggs and Larvae

West (1966) found that fertilized eggs placed in 21 C (69.8 F) water began hatching in 6 days.

In laboratory studies using central Texas populations, Hubbs (1961) found best egg and larval survival when held at temperatures between 13 and 25 C (55.4 and 77.0 F). Survival of some specimens above and below this range were considered chance. More recently, Hubbs and Armstrong (1962) found optimum survival temperatures for Missouri - Arkansas and central Texas populations to occur at between about 17 and 22 C (62.6 and 71.6 F), though survival occurred up to 25 C (77.0 F) for the Texas population, and up to about 27 C (80.6 F) for the Missouri - Arkansas population.

West (1966) has studied growth rates in orangethroat darter larvae in temperatures from 13 to 27 C (55.4 to 80.6 F). Maximum growth occurred at 26 C (78.8 F)(Figure SP-1).

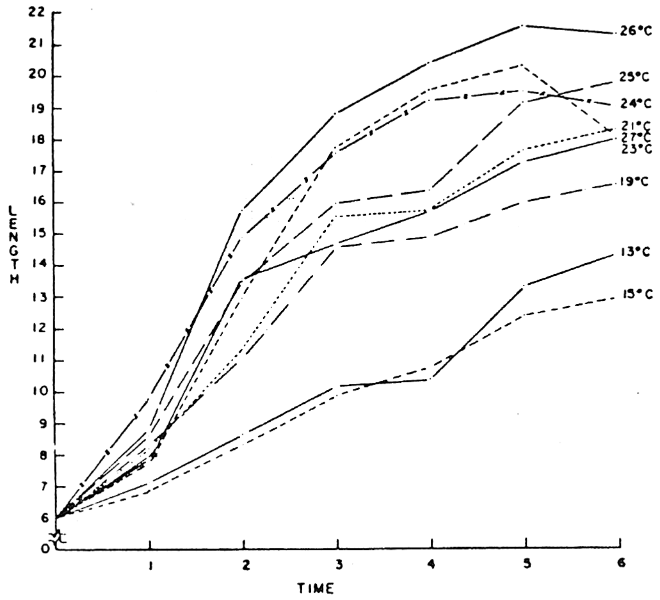

Figure SE-1 Growth curves for Etheostoma spectabile larvae. Time in weeks is plotted against length in millimeters. Points at 1-5 represent mean lengths of ten fish. Points at 6 represent mean lengths of all fish in the tank. From West, 1966.

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LOGPERCH

Distribution

The logperch is a wide-ranging species in North America occuring from St. Lawrence River tributaries of eastern Quebec southeast through Lake Champlain, the Great Lakes, west to Saskatchewan and south through the Mississippi River system to the Rio Grande River in Southern Texas. Three subspecies have been described. (Scott and Crossman, 1973:798).

Spawning

In Texas, Hubbs (1961) reports spawning from January through June. According to Scott and Crossman (1973:798) logperch spawn in late spring, usually beginning in June.

Eggs and Larvae

In laboratory studies using central Texas populations, Hubbs (1961) found best survival at temperatures between 22 and 25 C (71.6 and 77.0 F).

Additional experiments (mentioned but not described by Hubbs and Armstrong, 1962) showed Texas (?) populations to have lower egg and larval temperature tolerances than more northern stocks.

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Hubbs, C., and N. E. Armstrong 1962. Developmental temperature tolerance of Texas and Arkansas-Missouri *Etheostoma spectabile* (Percidae, Osteichthyes). Ecology *43* (4):742-744.

Scott, W. B., and E. J. Crossman 1973. Freshwater fishes of Canada. Fish. Res. Board Can., Bull. 184, 966 p.

YELLOW PERCH

Distribution

The yellow perch is widely distributed from northern Kansas to Ohio and South Carolina and northward into Canada (Eddy, 1969). An isolated population also occurs in Alabama.

Spawning

According to laboratory studies of Jones et al. (ms) and as cited in USFWS (1970:59), water temperatures must be below 4 C (39.2 F) for five months to ensure egg maturation within female yellow perch. Higher temperatures were reported to upset the natural temperature and photoperiod cycles and to significantly reduce both the number and viability of spawn. However, because of conflicting findings concerning egg maturation requirements in perciform fish (Hergenrader, 1969; deVlaming, 1972) these findings must be accepted with caution. Also based upon the wide distribution of yellow perch, and the wide range of reported spawning times and temperatures (Table FA-1), generalizing the results of Jones et al. (ms) to other perch populations appears questionable.

Field studies have observed spawning from the latter part of February (Muncy, 1962) to the beginning of July (Wells; cited in USFWS, 1970:62) at water temperatures ranging from 35.6 F (2 C) (Muncy, 1962) to 54 F (data cited in Breder and Rosen, 1966:441) (Table FA-1).

Citing unpublished laboratory studies, USFWS (1970:63) indicated that optimal spawning temperatures were between 46 and 54 F (7.8 and 12.2 C) while at 61 F (15.6 C) spawning was reduced, and at 62 F (16.7 C) eggs were aborted without being fertilized. In aquaria,

Table FA-1. Yellow perch spawning times and temperatures at various locations.

Date	Temperature C	F	Location	Comment	Author
Late February - Early March	(2-10.6) (3.3-8.9)	35.6-51 38-48	Severn River, Maryland	1st spawn, 17 yr. per. peak spawn, 17 yr. per.	Muncy, 1962
Late March	8.5-10	(47.3-50.0)	Patuxent River, Maryland	Peak spawn; surface temperature	Tsai and Gibson, 1971
Spring		44.0-54.0	New York	Range	Forbes & Richardson, 1908*; Titcomb, 1922*; Meehan, 1913*
	(7.8-12.2) (16.1) (>16.7)	46 - 54 61 >62	Duluth, Minn.	Lab. studies, optimum Lab studies, reduced Lab studies, aborted	EPA, unpublished**
April	14	(57.2)	Wisconsin	Aquarium	Hergenrader, 1969
Late April	8	(48.4)	Lake Poygon, Wisc.	Natural spawning	Hergenrader, 1969
May - Early June	(6.3-15.3)	43.4-59.6		Median spawning dates in lab; median temperatures for highest egg viability in lab	Jones, et al., ms
Mid May - Early July			Lake Michigan		Wells, unpublished observations**
Late May - Early June	14	(57.2)	Eastern Lake Michigan		Brazo, 1973***

*Cited in Breder and Rosen, 1966:441
**Cited in USFWS, 1970:62
***Personal communication from J. C. Ayers.

Hergenrader (1969) reports perch spawning at temperatures between 11 and 14 C (51.8 and 57.2 F).

Eggs

Data cited in Breder and Rosen (1966:441) indicate that hatching time for perch eggs is 27 days when held at 47 F (8.3 C).

Eggs have been observed incubating at 47 F in Oyster River, New Hampshire (Echo, 1954), at 48 F (8.9 C) in Thompson Lakes, Montana (Harrington, 1947; cited in Breder and Rosen, 1966:442), and apparently in median water temperatures of between 7 and 15 C (44.6 and 59 F) in Lake Monona, Wisconsin (Neill and Magnuson, 1974).

Hokanson and Kleiner (1973; cited in EPA, 1974) found the range of constant incubation temperatures for hatching of normal larvae to be between 7 and 10 C (44.6 and 68.0 F). Hokanson and Kleiner also determined that optimum hatch of normal larvae occurred when water temperatures of 10 C (59 F) rose 1 C/day to 20 C (68 F). NTAC (1968:33,43) considered this temperature (68 F, 20 C) to be the maximum compatible with egg development in yellow perch.

Larvae

In two Wisconsin lakes, Faber (1967) found larval perch in surface waters of the limnetic zone at night when water temperatures reached 13 to 18 C (55.4 to 64.4 F).

Hokanson and Kleiner (1973; cited in EPA, 1974) found that at swim-up larvae apparently died when acclimated to temperatures of both 10 C (50 F) and 19 C (66.2 F) though the data sheets probably reflect typographical errors. Mount (1969) showed 68 F (20 C) as safe for fry development, and 75 F (23.9 C) as the upper temperature tolerance.

Juveniles

Utilizing Lake Huron perch growth data, Coble (1966) extrapolated that growth began in spring at a mean water temperature of between 12.5 and 13 C (54.5 and 55.4 F).

The preferred summer temperature of small perch in one Wisconsin lake studied by Hile and Juday (1941; cited in Ferguson, 1958) was 12.2 C (54 F) (distributions in other lakes studies by Hile and Juday are given in the General and Unspecified section). Also in Wisconsin waters, but in normally warmer Lake Monona, Neill and Magnuson (1974) found that small perch were more abundant in ambient July and August water (ranging from mean temperatures of about 26 to 28.5 C, 78.8 to 83.3 F) rather than in waters heated by a power plant discharge. Fifty per cent of catch/effort in July and August of 1969 was made at temperatures of 27.5 C (81.5 F) and below, and 75 percent was made below 30.5 C (86.9 F) (Neill and Magnuson, 1974).

Several authors have studied preferred temperatures of young yellow perch in the laboratory, including Ferguson (1958), Meldrim and Gift (1971), Barans and Tubb (1973), McCauley and Read (1973), and Neill and Magnuson (1974). While discrepancies exist in the findings of these authors (see Barans and Tubb for discussion), stratifying the analyses by age (size), acclimation temperature, and season reduces some of this variability. The stratified data are presented in Table FA-2, but when available only data representative of summer and winter extremes and final preferenda are discussed. Barans and Tubb (1973) found that for underyearlings held in ambient temperature Lake Erie water (averaging 23 to 24 C, 73.4 to 75.2 F) during test period, the modal preferred temperature was 28 to 29 C (82.4 to 84.2 F) in August. In February

Table FA-2. Laboratory determinations of preferred temperatures of yellow perch; stratified by age/size, season, and acclimation temperature.

Season	Acclimation Temperature C	F	Fingerling	Yearling	Adult
Summer	5	(41)			
	10	(50)			
	15	(59)			
	20	(68)		23C (73.4F)[6]	
			28-29C (82.4-84.2F)[1]		
	25	(77)			
	30	(86)			
Fall	5	(41)			
	10	(50)			
	15	(59)			
	20	(68)			
				24C (73.4F)[3]	18C(64.4F)(Oct)[3], 20C(68F)(Nov)[3]
	25	(77)			
	30	(86)			
Winter			13C(55.4F)[1]		15(59F)[1]
	5	(41)			11C(51.8F)[4]
	10	(50)			17C(62.6F)[4]
	15	(59)			20C(68F)[4]
	20	(68)			20.5C(68.9F)[4]
	25	(77)			21.5C(70.7F)[4]
	30	(86)			27.5C(81.5F)[4]
Spring	5	(41)			
	10	(50)	20.6C(69.1F)[2]		
	15	(59)	24.5C(76.1F)[2]		
	20	(68)	21.5C(70.7F)[2]		
				24C(75.2F)[3] 22.2C(72F)[5]	24C(75.2F)[3]
	25	(77)	24C(75.2F)[2]		
	30	(86)	26.5C(79.7F)[2]		

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[1] Barans and Tubb, 1973; mode.

[2] Ferguson, 1958; mode.

[3] McCauley and Read, 1973; mode.

[4] McCracken and Starkman, 1948; cited in Ferguson, 1958; mode.

[5] Meldrim and Gift, 1971.

[6] Neill and Magnuson, 1974; midpoint between upper and lower avoidance temperatures.

they found that when ambient water averaged 1 C (33.8 F), underyearlings preferred 13 C (55.4 F). Ferguson (1958) determined the final preferendum for fingerlings to be 24.2 C (75.5 F) in spring.

For larger fish (82 to 118 mm TL), Neill and Magnuson (1974) found that the preferred temperature, by their definition the region bounded by the upper and lower median avoidance temperatures (26 and 20 C, 78.8 and 68 F, respectively), was 23 C (73.4 F) at some time between August and November for fish held previously at 20 to 22 C (68 to 71.6 F). [In July, Meldrim and Gift (1971:36) working with fish between 121 and 169 mm TL and acclimated to 77 F (25 C) determined upper avoidance temperatures to be between 92 and 93 F (33.3 and 34.4 C)]. During spring and fall fish acclimated to between 24 and 25 C (75.2 and 77 F) were found to prefer water of between 22.2 C and 24 C (72 and 75.2 F) (Meldrim and Gift, 1971:28; McCauley and Read, 1973).

Neill and Magnuson (1974) studied the possible modifying influence of food availability upon temperature preference of small perch. They found that fish avoided areas containing food 95% of the time when water temperatures were 33 C (91.4 F) and spent less than 5% of their time at temperatures above 31 C (87.8 F) water when food was not available. The upper temperature limiting aquisition of a maximum daily meal was about 30 C (86 F) (Neill and Magnuson, 1974).

In early studies of fish lethal temperatures, Hathaway (1927) determined that for young yellow perch acclimated to between 22 and 23 C (71.6 and 73.4 F), the 24 hour upper LT_{50} was 29.6 C (85.3 F). A temperature of 31.5 C (88.7 F) was resisted for 4 hours, 32 C (89.6 F) for 1 hour, and 34 C (83.2 F) for 15 minutes. At the higher probable acclimation temperature of between 25 and 26 C (77 and 78.8 F), Brett (1944) determined a 12 hour upper LT_{50} of 30.9 C (87.6 F).

Adults

Data on preferred temperatures of adult yellow perch are presented along with those of juvenile perch in Table FA-2. No data were available for summer, though in spring and fall for fish acclimated to 24 C (75.2 F), the preferred temperature ranged from 18 to 24 C (64.4 to 75.2 F) (McCauley and Read, 1973). In winter, McCracken and Starkman (1948; cited in Ferguson, 1958) tested fish (2 years and older) acclimated to temperatures between 5 and 30 C (41 and 86 F). The modal preferred temperature ranged from 11 to 27.5 C (51.8 to 81.5 F), with a final preferendum at 21 C (69.8 F).

General and Unspecified

During summer, perch in an Ontario lake preferred 19.7 C (67.5 F) water (Ferguson, 1958), while in those Wisconsin lakes where perch size and age were not differentiated (Ferguson, 1958; citing Hile and Juday, 1941) temperature preference was for water at temperatures between 20.2 and 21 C (68.3 and 69.8 F). Wells (1968) found that in southern Lake Michigan, perch were most abundant in summer waters of from 11 C (51.8 F) to at least 22 C (71.6 F) (the warmest water sampled).

Hergenrader and Hasler (1967) found that the rate of movement of perch increased from a low at between 32 and 41 F during winter to a maximum at between 70 and 77 F during summer.

In addition to those lethal temperature studies cited earlier (see Juvenile section), several other papers (Black, 1953; Hart, 1947,

1952) considered lethal temperatures of yellow perch. For different reasons precise age and/or size variations in lethal temperatures were not made in these studies. Black did not determine the influence of these variables upon lethal temperatures, and Hart (1947) could not distinguish any size/age related differences.

The data of Black (1953) conform to the pattern established in the more extensive studies by Hart (1947, 1952), as do those of Brett (1944) and Hathaway (1927), cited earlier. The temperature tolerance polygon of Hart (1947) is given in Figure FA-1, and resistance times for temperatures beyond these lethal limits are given in Figure FA-2. These data represent studies carried out by Hart in winter. When comparing summer and winter experiments, Hart (1952) noted seasonal differences, e.g., when acclimated to 25 C (77 F) in winter, the incipient lethal temperature was 29.7 C (85.5 F) (as given in the Figure FA-1 polygon), while at the same acclimation temperature during the summer specimens had an incipient lethal temperature of 32.3 C (91.2 F).

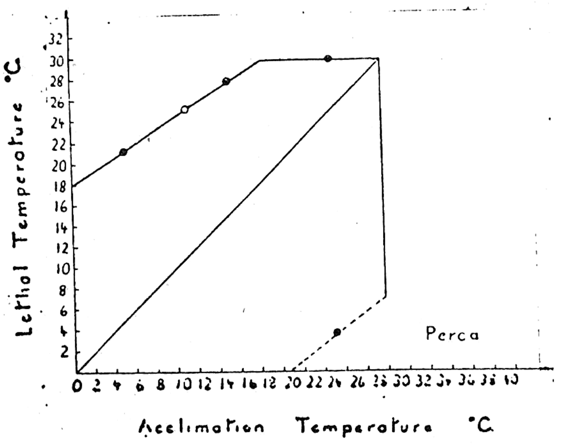

Figure FA-1. The relation between acclimation temperature and the upper and lower incipient lethal temperatures for yellow perch. From Hart, 1947.

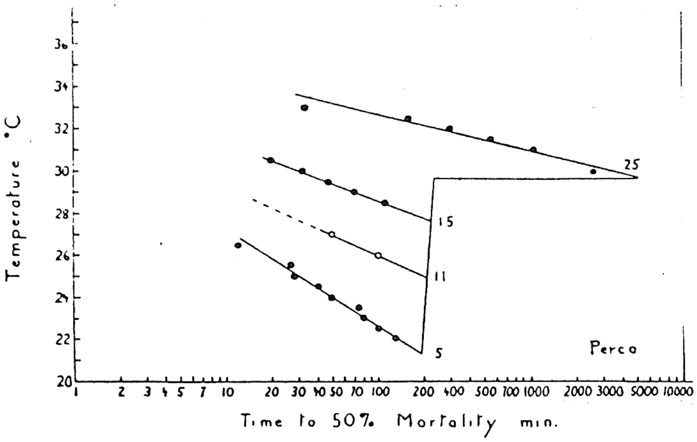

Figure FA-2. The relation between temperature and time to death (resistance time) at various acclimation temperatures for yellow perch. From Hart, 1947.

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BLACKSIDE DARTER

Distribution

The blackside darter occurs from the western part of the Lake Ontario drainage west (excluding the Lake Superior drainage) to North Dakota, Manitoba and Saskatchewan; southerward to the west of the Appalachian Mountains to the Ozark region, the Gulf coast in Alabama, and northeastern Texas (Scott and Crossman, 1973:803-804).

Spawning

Petravicz (1938) and Winn (1958) (both cited in Scott and Crossman, 1973:804) observed spawning in early May in southern Michigan at temperatures of about 62 F (16.5 C), Scott and Crossman (1973:804) felt spawning probably occurs in May or June in Canada. Cahn (1927; cited in Breder and Rosen, 1966:448) found spawning in Wisconsin to occur in June.

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PIEDMONT DARTER

Distribution

The piedmont darter is distributed from Virginia to South Carolina (Eddy, 1969).

General and Unspecified

No temperature related life history data have been located for this species.

References Cited

Eddy, Samuel 1969. How to know the freshwater fishes, 2nd ed. William C. Brown Comp., Dubuque, Iowa, 286 p.

SHARPNOSE DARTER

Distribution

This species is restricted to the Cheat and New Rivers in Virginia and West Virginia (Eddy, 1969).

General and Unspecified

No temperature related life history data have been located on this species.

References Cited

Eddy, Samuel 1969. How to know the freshwater fishes, 2nd ed. William C. Brown Comp., Dubuque, Iowa, 286 p.

DUSKY DARTER

Distribution

The dusky darter occurs from Indiana southward to the Gulf of Mexico and Texas (Eddy, 1969).

Spawning

In Texas, Hubbs (1961) reports spawning from February through June.

Eggs and Larvae

In laboratory studies, Hubbs (1961) found significant survival of eggs and larvae occurred at temperatures between 22 and 27 C (71.6 and 80.6 F).

References Cited

Eddy, Samuel 1969. How to know the freshwater fishes, 2nd ed. William C. Brown Comp., Dubuque, Iowa, 286 p.

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MOTTLED SCULPIN

Distribution

This species is widely distributed from around Hudson's Bay southward, on the west in western Minnesota, northern Illinois, and down the Appalachians into Alabama (Pflieger, 1971); and on the east in upper tributaries of the Atlantic coastal drainage rivers from New York to Virginia (Hubbs and Lagler, 1958; Pflieger, 1971). Disjunct populations occur in the Ozarks and in the Rocky Mountains from Montana to northern Nevada and New Mexico (Pflieger, 1971).

Spawning

Among the various subspecies spawning has been reported between late February (Simon and Brown, 1943; cited in Bailey, 1952) and June (Bailey, 1952)(Table BA-1), and temperatures during breeding season have been reported between 41 and 61 F (Hann, 1927; cited in Bailey, 1952).

Eggs

At water temperatures between 46 and 63 F (7.8 and 17.3 C), Bailey (1952) found eggs to incubate for 21 to 28 days.

General and Unspecified

The mottled sculpin prefers cool water (Pflieger, 1971; Robins, 1954) and according to Hallam (1958; cited in Ferguson, 1958) in southern Ontario 61.9 F is the preferred summer temperature. Robins (1954:162) observed *C. b. bairdi* in waters of 62 F (16.7 C), but not at temperatures above this.

Table BA-1. Mottled sculpin spawning times and temperatures at various locations.

Date			Location	Comment	Author
Late February - Late May				*S. b. semiscaber*	Simon and Brown, 1943*
Mid March	(6.1-7.2)	43-45	Maryland	Eggs observed at these temperatures	Savage, 1963
	(6.1-16.1)	43-61		Temperature during spawning season	
Late March - Early April			Rivers in several southeastern states	Breeding season of *C. b. fumorum*	Robins, 1954:141
April				Eggs observed	Gage, 1878*; Hann, 1927*
April - May				Eggs observed	Smith, 1922
Mid May			Ontario	Spawning	Ricker, 1934*
Most of June			Montana	*S. b. punctulatus*	Bailey, 1952
	(12.8)	55	Michigan	Spawning in aquarium	Hann, 1927*
	(5.0-16.1)	41-61		Temperature during breeding season	Hann, 1927*

*Cited in Bailey, 1952.

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BANDED SCULPIN

Distribution

Eddy (1969) states that the banded sculpin has a distribution restricted to the Ozarks and the upper Tennessee River drainage, though Robins (1954) reports it in the New River.

General and Unspecified

According to Robins (1954) and Pflieger (1971) the requirements of the banded sculpin are much like those of the mottled sculpin; however, the former tolerates warmer temperatures than does the latter. Robins (1954:162) collected this species in water temperatures of up to 82 F (27.8 C).

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SUPPLEMENTS

As time goes on additional species may be added to the Handbook. Rather than continually revising Table I-1, information on taxonomy and abbreviations for supplemental species is given here in the sequence the species are added. The completion date of each supplement is given on the last page of the species' References Cited section.

Classification	Common Name	Figure and Table Abbreviation
Family Centrarchidae		
Lepomis macrochirus Rafinesque	Bluegill	MC
Family Salmonidae		
Salvelinus fontinalis Mitchill	Brook trout	FO

BLUEGILL

Distribution

Bluegill is widespread from Minnesota to Lake Champlain and south to Florida and Texas, and has been widely introduced elsewhere (Eddy, 1969).

Spawning

Natural spawning has been observed from late February (Clugston, 1966) through August (Morgan, 1951) (Table MC-1). In the laboratory spawning has been induced in late December by hormone injection and by manipulation of temperature and photoperiod (Banner and VanArman, 1973).

Temperatures during spawning range from about 17 C (62.6 F) (Stevenson et al., 1969; cited in Kitchell et al., 1974) to 90 F (32.2 C) (Clugston, 1966) (Table MC-1). According to Trembley (1961:IX-17) this 90 F (32.2 C) temperature is also the highest at which bluegills will guard a nest.

Kitchell et al. (1974) cite data indicating that while spawning continued intermittently throughout summer, it appeared to be stimulated by a drop in temperature to below 26 C (78.8 F) followed by an increase. Banner and VanArman (1973) also found that a sharp temperature rise did not in itself trigger spawning, but that cycled temperatures might be conducive to spawning.

Eggs

For eggs spawned at 26 C (78.8 F) in the laboratory, the constant incubation yielding optimal hatch (44 and 58%) occurred at 22.2 and 23.9 C (72.0 and 75.1 F) respectively (Banner and VanArman, 1973), while 50% of optimal normal hatch occurred at 33.8 C (92.9 F).

Table MC-1. Bluegill spawning times and temperatures at various locations.

Date	Temperature C	F	Location	Comment	Author
	17	(62.6)			Stevenson et al., 1969**
	(~19.4)	~67	Wisconsin	Spawning begins	Snow et al., 1970
Late May - Early August				Range	
June				Peak	
Late February - Early March	(21.1 - 32.2)	70 - 90	Florida	Range	Clugston, 1966
	(23.9 - 26.7)	75 - 80		Nests most abundant	
April - Late August			California		Emig, 1966**
April - October			Alabama	Spawning at intervals	Swingle & Smith, 1943*
May			Illinois		Richardson, 1913*
May			S. Dakota		Churchill & Over, 1933*
May - June			New York		Wright & Allen, 1913*

Table MC-1. (Continued)

Date	Temperature		Location	Comment	Author
	C	F			
May - August			Ohio		Morgan, 1951
June			Indiana		Evermann & Clark, 1920*
Mid - Late July	(24.4)	76	New Jersey	On nests	Breder, 1936

*Cited in Breder and Rosen, 1966 : 413-414
**Cited in Kitchell et al., 1974

Larvae

The period when bluegill fry begin to feed and when they starve is only two days at 23 C (73.4 F) (Toetz, 1966; cited in Hokanson, 1969), and this period is shortened at high temperatures (Hokanson, 1969; citing unpublished National Water Quality Laboratory data).

Juveniles

The NTAC (1968; 33,43) provisionally considered 90 F (32.2 C) as the maximum temperature compatible with bluegill growth and, according to Fry and Pearson (1952; cited in Ferguson, 1958), the final temperature preferendum for young bluegills is 32.3 C (90.2 F). Neill and Magnuson considered 30.3 C (86.6 F) to be the preferred temperature of young (53-83 mm TL) bluegills because it was the midpoint of the temperature range (28.5 and 33.5 C, 83.3 and 92.3 F) in which the bluegills behaviorally thermoregulated in the laboratory. For 93-93 mm TL bluegills, Neill and Magnuson found that preferred temperatures were shifted 3 C (5.4 F) downward and 2 C (3.6 F) upward by the availability of food in that environment when no food was available at the preferred temperature. Bluegills did not obtain a maximum daily meal at temperatures below 24 C (75.2 F) or above 34 C (93.2 F).

When competing with young (12.9 g, 9.6 cm) rainbow trout for limited rations, young (5.7 g, 9.8 cm) bluegills increased their per centage of food capture when tested at increasing acclimation temperatures between 15 and 24 C (59.0 and 75.2 F) (Bowen and Coutant, 1973). Along with tests designed to develop a series of temperature-specific competition profiles using unlimited rations, results indicated to the authors that sublethal temperatures could affect the success of a species in feeding competition, an effect expected to influence both species composition and population sizes of fish communities.

By comparing resistance times to exposure at 36.5 C (97.7 F) for age-0 bluegills acclimated to various temperatures in the laboratory and those collected in the vicinity of a thermal discharge, Neill and Magnuson (1974) determined the field fish were acclimated to temperatures between 29.4 and 31.1 C (85.0 and 88.4 F). Because of the effects of summation of exposure to high temperatures (eg. see Brett, 1944), the authors considered that field acclimation levels represented temperatures near the upper avoidance temperature. This belief was corroborated by their findings that maximum internal body temperature of bluegills around the thermal discharge was 31.8 C (89.3 F), and was within 2.4 C (4.3 F) of their laboratory avoidance findings cited earlier.

Nickum (1966) exposed young (0.75-1.5 in) bluegills to rapid temperature elevations of up to 36 F (20 C) above ambient (with a 80.0 F, 26.7 C maximum temperature) and determined mortalities for periods up to 7 days. While rapid mortality occurred at the larger temperature changes (30, 32, and 36 F; 16.7, 17.8, and 20.0 C), in most cases greater than 50% survival was observed for seven day exposures to temperatures up to 26 F (14.4 C) above ambient. During summer however, a 12 F (6.7 C) resulted in 85% mortality within two days. Because of the small size of the fish, Nickum did not believe thermal sensitivity associated with gonad maturation to be a contributing factor.

Using fish mostly between 1 and 2 years old, Hathaway (1927) found the 24-hour ULT_{50} to be 34.0 C (93.2 F) for fish acclimated to 22 and 23 C (71.6 and 73.4 F). If held for one or four days at 30 C (86.0 F) after acclimation at 22 to 23 C (71.6 to 73.4 F), the 24-hour ULT_{50} was raised to 34.3 C (93.8 F) or 35.6 C (96.1 F) respectively.

Hickman and Dewey (1973) found that slow heating increased temperature tolerance in small (mean length 37 mm) bluegill. In their studies with fish acclimated to 21.5 C (70.7 F), those exposed to a rapid temperature rise had an (interpolated) upper lethal temperature of approximately 31.0 C (87.8 F), while for those fish heated slowly (2 C/day), the upper lethal temperature was 35.5 C (95.9 F).

More extensive studies by Speakman and Krenkel (1972) further determined that in 2-4 bluegills the rate and magnitude of temperature change influenced the upper (and lower) lethal temperature. Slower rates and smaller magnitudes of change increased tolerance to a certain extent, but did not affect the ultimate upper incipient lethal temperature of approximately 36 C (96.8 F) (Figure MC-1).

Adults

Anderson (1959; cited in EPA, 1974) found optimum growth of adult bluegill at temperatures between 24 and 27 C (75.2 and 80.6 F), though the range for growth in adults is said to be between 16 C (60.8 F) (Emig, 1966; cited in EPA, 1974) and 30 C (86.0 F) (Mahoney, 1949; cited in EPA, 1974).

Nickum (1966) exposed adult (3-7 in) bluegills to rapid temperature changes of up to 36 F (20 C) above ambient (80 F, 26.7 C maximum temperature). Fish exposed to the maximum temperature change all died within 4 hours, though except for fish tested in summer, temperature changes of up to 26 F (14.4 C) were not lethal to more than 10% of the fish within the 7 day test period. During summer Nickum found increased sensitivity to temperature changes, with a 12 F (6.7 C) change

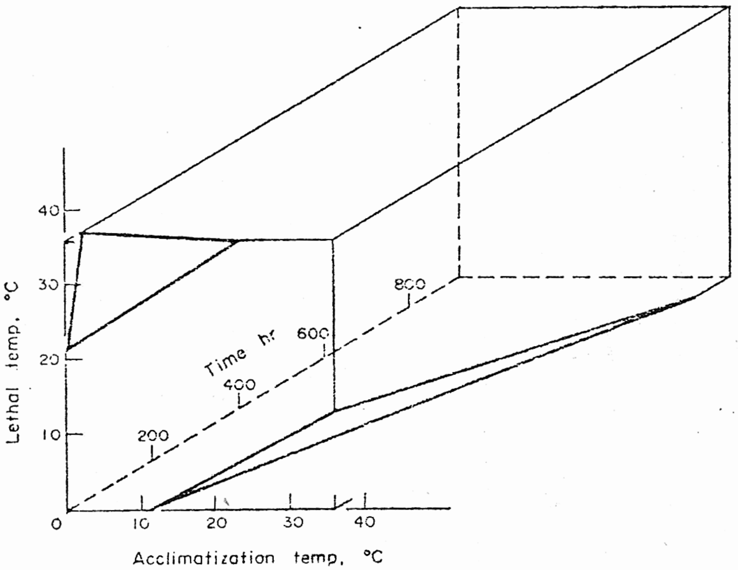

Figure MC-1. Three dimensional representation of temperature tolerance for 2.4 in. bluegill. From Speakman and Krenkel (1972).

resulting in 50% mortality in 6 days.

General and Unspecified

Citing unpublished data, Fry (1967) stated that for bluegills acclimated to test temperatures, cruising speeds rose with temperature at between 12 and 25 C (53.6 and 77.0 F), and remained constant to about 31 C (87.8 F).

Pierce and Wissing (1974) found that while greatest feeding intensity of bluegills (weight range 20.2-148.6 g, mean 68.1) tested at 15, 20, and 25 C (59.0, 68.0, and 77.0 F) occurred at the highest temperature, gross growth efficiency was inversely related to test temperature, but was directly related to the decrease in routine metabolism at lower temperatures. While the increased metabolic requirements at higher temperatures are to be expected, the overall decrease in growth efficiency for bluegill at the temperatures used is not and the results should be accepted with caution (see eg. Brett et al., 1969; Warren, 1971: 135-167).

In winter when heated discharge from a corn products manufacturing plant reached 35 C (95.0 F), Agersborg (1930) collected bluegills at temperatures up to 30 C (86 F). During summer in Alabama, Byrd (1951) found bluegills in greatest numbers in the shallows where surface temperatures ranged from 76.5 to 97 F, and Proffitt and Benda (1971:38) collected them around a thermal discharge into the White River in Indiana at temperatures up to 92.5 F (33.6 C). Around a heated discharge into the Delaware River, Trembley (1960:IX-13) found bluegills schooling in 86 F (30 C) water when the lagoon temperature gradient was between 86 and 94 F (30.0 and 34.4 C), though on another occasion, a group was observed swimming in 95 F (35.0 C) water with no ill effect.

A number of bluegills with body temperatures above 90 F (32.2 C) were collected with 98 F (36.7 C) being the highest body temperature recorded.

Holland et al. (1974) determined that for several South Carolina bluegill populations not accustomed to thermal discharges, acclimation at 35 C (95.0 F) commonly resulted in internal body hemorrhaging and loss of weight, though those bluegills living in a heated pond showed no evidence of stress. Holland et al. also found that for fish (not from the most thermally affected area) held for different periods at 25 C (77.0 F) prior to exposure to temperature increases of 1 C/min, the lethal temperature stabilized at about 38.3 C (100.9 F) in 60 hours. Fish from the most thermally affected pond were found to have a higher mean upper lethal temperature and critical thermal maximum (CTM, the temperature at which fish become disorganized and lose equilibrium; see also p. for further discussion of CTM) than did fish from other ponds (Holland et al., 1974). In the most tolerant group the ULT for fish exposed to a 1 C/min temperature rise was 42.8 C (109.0 F), and the CTM was 41.4 C (106.5 F). These results led Holland et al. to state that fish from the heated pond seemed to have evolved behavioral and physiological adaptations (relatively higher CTM) as well as a higher physiological limit to temperature stress (lethal temperatures).

Hart (1952) found that when acclimated to 30 C (86.0 F) fish (5.8-14.2 g, range of mean weight classes) had a ULT_{50} of 33.8 C (92.9 F), but that for one Knoxville sample (15.6-33.7 g weight range), resistance times were longer; they could be held at 36.5 C (97.7 F) without mortality for 4 hours, and when raised to 38 C (100.4 F) in 20 minutes, 50% mortality occurred in 48 minutes. Bluegills were the only species Hart tested which showed a significant tendency for larger fish to be more resistant. Also, when interpreting his own data and those gathered by Hathaway (1927), Hart indicated that bluegills might vary geographically in their lethal temperature.

Exposing bluegills from Texas and Pennsylvania populations to 2 C/day temperature rises, Cairns (1956) reports no significant differences in tolerance limits. Cairns' data showed that once the final temperature was reached, 39.2 C (102.6 F) was resisted for at least one, but not three days, by 50% of the test fish. Lower temperatures were resisted for longer periods, eg. 35.8 C (96.5 F) for 11 days, and 32.3 C (90.2 F) for 27 days.

Trembley (1961: VII:6) tested bluegills acclimated to several temperatures. At the highest acclimation temperature (76 F, 24.4 C), he found that when exposed to a 0.98 F/hour temperature rise, the ULT_{50} was 100 F (37.8 C).

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March, 1975

BROOK TROUT

Brook trout distribution in relation to environmental variables in nature was reviewed by Creaser in 1930. Somewhat later Fry (1951) summarized both field and laboratory studies concerned with environmental relations, and Bridges and Mullan (1958) prepared a compendium of brook trout life history. Recent studies at the EPA National Water Quality Laboratory in Duluth, Minnesota (Hokanson et al., 1973; McCormick et al., 1972), have related many of these earlier findings to their own test results during their efforts to develop thermal criteria for this species. All these reviews have proved useful, though when possible original sources have been examined.

Distribution

The brook trout was natively distributed in North America from eastern Manitoba to the Atlantic and south to Wisconsin, Michigan, and New Jersey with an extension in the Appalachian Mountains into northern Georgia (MacCrimmon and Campbell, 1969). Extinctions have somewhat modified native distributions in the east, but the major distribution alteration has been the extensive introductions which have occurred in western north America (MacCrimmon and Campbell, 1969).

Spawning

Laboratory test results suggest that spermatozoa are eliminated rapidly at 21 C (69.8 F) if fish are functionally mature (Hokanson et al., 1973).

Brook trout spawning has been observed between late August (eg. Vladykov, 1956) and January (White, 1934) with one instance (White, 1934) when spawning continued into February (Table FO-1).

Table FO-1. Brook trout spawning times and temperatures at various locations.

Date	Temperature C	F	Location	Comment	Author
Late August			Canada North	May begin as early as this.	Scott and Crossman, 1973:210
Late Aug. or Sept.				Northern most part of range (60°N)	Henderson, 1963
Late Aug. - Late Oct.			Quebec		Vladykov, 1956
Aug. - Nov.				Summary of literature	Katz, 1954*
Sept. - Dec.			Maine		Havey, 1958*
Sept. - Dec.			California		McAfee, 1966*
Sept. - Dec.			N.H.		Newell, 1960*
Late Sept.			Kowkash	Begin as early as this	Ricker, 1932
Late Sept. - Mid Nov.	10.7	(51.4)	Minnesota	Laboratory studies	Hokanson et al., 1973
Late Sept. - Nov.			Central and W. Pennsylvania		Wydoski & Cooper, 1966
Late Sept. - Nov.			S and E Canada	Usual spawning	Scott & Crossman, 1973:210

Table FO-1 (Continued)

Date	Temperature		Location	Comment	Author
	C	F			
October			Ontario		Patrick & Graf, 1962*
October			California	Daily mean wtr. temp.	Needham, 1961
Early Oct. - Nov.					Mount, 1969
Early Oct. - Nov.			Lake Nipigon		Ricker, 1932
Mid Oct.			Toronto area		Henderson, 1963
Mid Oct.				Begin spawning N. part of range	Brasch et al., 1973
Mid Oct. - Mid Dec.			S. Ontario		Ricker, 1932
Late Oct.			Mad River, Ontario	Well underway	Ricker, 1932
Late Oct. - Nov.			Wisconsin		O'Donnell & Churchill, 1954*
Late Oct. - Nov.			Vermont	Hatchery	Davis, 1931
Late Oct. - Early Dec.			Michigan		Greeley, 1932

Table FO-1 (Continued)

Date	Temperature C	F	Location	Comment	Author
Late Oct. into Jan.			Prince Edward Isl.	Usual	White, 1934
November			Southern most part of range (35°N)		Henderson, 1963
Early Nov.	(9.4)	49	Michigan		Hazzard, 1932
Mid Nov.			Mad River, S. Ontario	Spawning in full swing	Ricker, 1932
Mid Nov.			Wisconsin	Peak spawn	Brasch et al., 1973
Late Nov.	(4.7) (2.2)	40.4 36.0	Prince Edward Isl.	Temp. in gravel of spawning area Running bottom water over area	White, 1930
Mid Dec.				Occurs this late, S. part of range	Brasch et al., 1973

*Cited in Carlander, 1969:264

Brook trout functional maturity can be induced several months before the normal time or delayed several weeks by adjustment of photoperiod (see discussion in Henderson, 1963; and more recent reviews by Schwassmann, 1971; and deVlaming, 1972).

Spawning has been observed at a maximum water temperature of 49 F (9.4 C) (Hazzard, 1932) (Table FO-1). White (1930) reports microhabitat differences in temperatures around a spawning area. Temperatures recorded in running water 10 ft. above the spawning area were 32.5 F (0.3 C), 35.4 F (1.9 C) three inches in gravel 10 ft. above spawning area, and 40.4 F (4.7 C) three inches in the gravel in spawning area where spawning actually occurred.

In laboratory studies Hokanson et al. (1973) found ovulation and spawning occurred at 16 C (60.8 F), though 11.7 C (53.1 F) was the upper mean effective temperature (an estimate of the median sublethal response derived by plotting the number of viable eggs spawned per female, expressed as a percentage of the highest response, against temperature).

Incubation

Three egg incubation studies have been undertaken (Embody, 1934; Garside, 1966; and Hokanson et al., 1973). The first two emphasized rate of development and their findings are consistent, ranging from 14.5 days at 1.5 C (34.7 F) to 28 days at 14.8 C (58.7 F) (Table FO-2). Garside further found that reductions in dissolved oxygen below saturation prolonged incubation times.

Hokanson et al. (1973) found percent of normal hatch varied with temperature, success decreasing with increasing incubation temperature. No hatch occurred at 18 C (64.4 F) and maximum incidence of abnormalities occurred at 15 C (59 F). A maximal mean normal hatch occurred at

Table FO-2. Incubation times of brook trout eggs held at various temperatures.

Temperature		Days	
C	F	Garside**	Embody
1.6	34.9		142.5
2.5	36.5	130	
3.9	39.1		105.0
5.0	41.0	Lost	
7.5	45.5	60	64.7
10.0	50.0	50	48.8
13.0	55.4		34.0
14.8	58.7		28.0

*From Embody (1934) and Garside (1966).

**Data are for eggs incubated at oxygen levels near saturation. Reductions in oxygen prolonged incubation times.

6 C (42.8 F). Markus (1962) stated that observations indicate brook trout eggs will develop normally at a water temperature of roughly 55 F (12.8 C), and Embody (1934) reported neither abnormalities nor mortalities when he incubated eggs to 14.8 C (58.6 F).

The upper LT_{50} for normal hatch was reported as 12.7 C (54.9 F) (Hokanson et al., 1973). The authors also found that for eggs initially incubated at 7.0 C (44.6 F), and transferred directly or tempered (3 C/hour) to various temperatures between 9 and 15 C (48.2 and 59.0 F) at different stages of development, age of embryo was more important than tempering method in determining the response.

Larvae

Fisher and Elson (1950) found that for fry raised at 4 C (39.2 F), the selected temperature in a gradient ranging in temperature from 0 to 30 C (32.0 to 86.0 F) was 10 C (50 F).

Fry (1947) reports maximum scope for rate of heart beat in brook trout alevins at about 12 C (53.6 F); a response representative of the sort of circumstance which might make it possible for the fish to perform maximum work.

Instantaneous growth, net biomass gain and mortality were determined by McCormick et al. (1972) for alevin through juvenile brook trout. When fed ad libitum (on demand) best growth occurred at 15.4 C (59.8 F), though the range of 9.8 to 17.9 C (49.7 to 64.3 F) was said to provide suitable conditions for growth (Figure FO-1). (According to Shelbourn et al., 1973, such feeding may not have provided fish with a maximum ration. This fact, combined with the findings of Brett et al., 1969, that the optimum temperature for growth is directly related to ration size in another salmonid, suggests McCormick et al. may therefore have

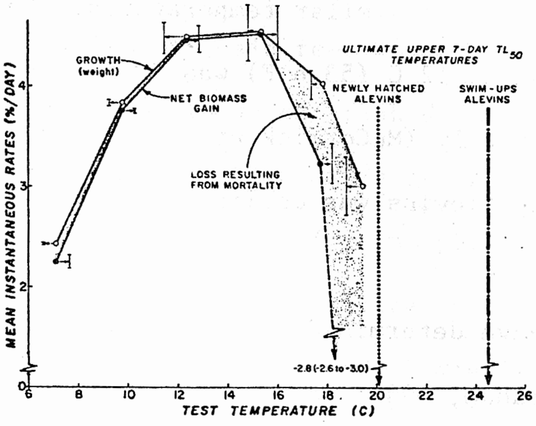

Figure FO-1. Effects of temperature on mean instantaneous rates of growth, mortality, net biomass gain, and ultimate 7-day median temperature tolerance limits of brook trout during their first 8 weeks after hatching. Vertical bars indicate the range of the replicate means. Dashed lines indicate data obtained from only the first 4 weeks of temperature exposure. From McCormick et al., 1972.

underestimated temperatures for optimal growth at maximum ration. However satiation probably does not occur in nature). McCormick et al. found maximum instantaneous net biomass gain (derived by subtracting weight lost through mortalities within the lot from weight gained by the members of a test lot) occurred at 12.4 and 15.4 C (54.4 and 59.8 F).

Newly hatched alevins were more sensitive to high temperatures than swim-up alevins acclimated to similar temperatures, the 7-day ULT_{50} for these stages acclimated to 12 C (53.6 F) was 20.4 C (68.8 F) and 24.3 C (75.8 F) respectively (McCormick et al., 1972). The ultimate 7-day ULT_{50} for swim-up alevins was estimated to be 24.5 C (76.1 F).

Juveniles

Several studies have determined scope for activity in brook trout of various weights (Graham, 1949; Job, 1955, cited in Fry, 1957; Basu, 1959; and Beamish, 1964a). For Graham, Basu, and Beamish the greatest scope was found to occur at about 15 or 16 C (59.0 or 60.8 F). Working with the widest range of weights Job demonstrated effect of weight on the relation of scope for activity to temperature. As cited by Fry (1957), Job found smaller fish showed increasing scope from 5 to 20 C (41.0 to 68.0 F). Comparing data of Job with those of Graham (1949) and her own for a standard weight fish (164 gm.), Basu felt fish tested by Job were not stimulated to maximum effort and therefore Job failed to recognize a real drop in active metabolism at 20 C (68.0 F) as found by Graham and herself.

Two studies (Elson, 1942; Fisher and Elson, 1950) determined that for young fish acclimated to 4 C (39.2 F, Fisher and Elson) or 5 to 10 C (41.0 to 50.0 F, Elson) greatest movement in response to an electrical stimulus occurred at about 10 C (50.0 F).

For young (2 to 3 in.) fish acclimated to one (unstated) temperature and tested after equilibration at various temperatures, Fisher and Sullivan (1958: see also Fisher, 1958) found spontaneous movement was low at low temperatures, rose with temperature to a peak at about 9 C (48.2 F) (Figure FO-2) (Fisher, 1958, interpreted this peak to occur in the order of 9 to 15 C, 48.2 to 59.0 F), and then fell as the temperature went higher to a minimum at 18 to 20 C (64.4 to 68.0 F). After this temperature spontaneous movement again rose sharply to a second "pre-lethal peak and then fell abruptly as the fish died.

Sullivan (1954) also reported that cruising speed, measured using (probably young) fish acclimated to one (again unstated) temperature and tested after equilibration at other temperatures, showed a pattern very similar to that for activity (Figure FO-3; compare with Figure FO-2).

Additional information on cruising speeds in young fish has been reported by Graham (1949) for fish acclimated to test temperatures. His data show peak swimming speed to occur at 20 C (68.0 F). Graham also cites Rogers (1938) as finding peak cruising speed for acclimated fish at about 16 C (60.8 F), though Fry (1951) did not consider the fish tested by Rogers to be fully acclimated to test temperatures.

Sullivan and Fisher (1958) found temperatures selected by young (2 to 3 in.) brook trout were always about the same as those at which the first peak in frequency of movement occurred (see Figure FO-2). Graham (1948; cited in Fry, 1951) and Cherry et al. (1975) have provided more detailed information on temperatures selected by young trout at various acclimation temperatures. These data are given in Table FO-3 and show the final temperature preferendum to lie at between 14 and 16 C (57.2 and 60.8 F). Slight discrepencies in the findings of these two studies may be due to one or a combination of other variables. Among such

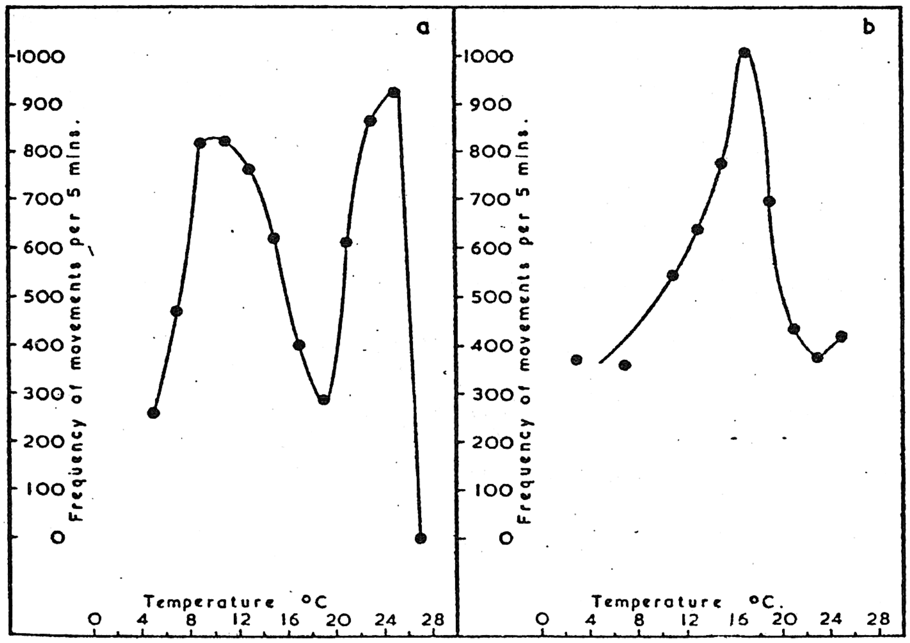

Figure FO-2. Frequency of movement of normal brook trout at various equilibration temperatures.

(a) Averaged data of five experiments in which various temperatures used occurred in order from low to high

(b) Averaged data of four experiments in which the various temperatures used occurred in random order

(Both from Fisher and Sullivan, 1958)

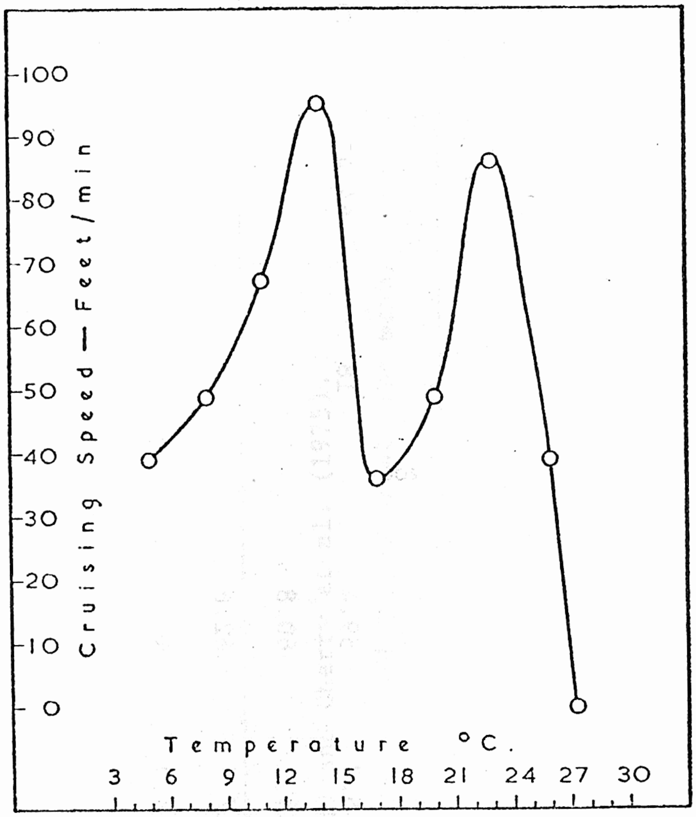

Figure FO-3. Maximum cruising speed of brook trout at various equilibration temperatures. (From Sullivan, 1954).

Table FO-3. Temperatures selected and avoided by young brook trout at various acclimation temperatures

Acclimation Temperature		Preferred Temperature**		Upper Avoidance Temperature		Source
C	(F)	C	(F)	C	(F)	
6	42.8	11.2	52.2	14	57.2	Cherry et al.
7	44.6	13	55.4			Graham
9	48.2	11.3	52.4	15	59.0	Cherry et al.
10.5	50.9	13	55.4			Graham
12	53.6	13.7	56.7	16	60.8	Cherry et al.
14	57.2	14	57.2			Graham
15	59.0	15.2	59.4	18	64.4	Cherry et al.
16	60.8	16	60.8			Graham
17.5	63.5	17	62.6			Graham
18	64.4	18.0	64.4	20	68.0	Cherry et al.
19	66.2	18.5	65.3			Graham
21	69.8	18.3	65.0	23	73.4	Cherry et al.
22	71.6	19	66.2			Graham

Table FO-3. (Continued)

Acclimation Temperature		Preferred Temperature**		Upper Avoidance Temperature		Source
C	(F)	C	(F)	C	(F)	
24	75.2	19.0	66.2	25	77.0	Cherry et al.
		21.5	70.7			Graham

*From Graham (1948; cited in Fry, 1951) and Cherry et al. (1975).

**Graham reported modal selected temperature, and Cherry et al. the mean.

selection influences investigated using young brook trout are effects of season (Sullivan and Fisher, 1953), light (Sullivan and Fisher, 1954), nutritional state (Javaid and Anderson, 1967), and chlorinated hydrocarbons (Peterson, 1973). Briefly, Sullivan and Fisher (1953) found there was a seasonal change of selected temperature which was distinct from changes in selected temperature brought about by changes of acclimation temperature, Sullivan and Fisher (1954) found light intensity influenced precision of the selected temperature interval but not the actual temperature selected, Javaid and Anderson found starvation lowered the selected temperature, and Peterson found fish previously exposed to chlorinated hydrocarbons selected higher temperatures than controls (previously exposed to only a hydrocarbon carrier).

Hokanson et al. (1973) determined growth rates for yearling brook trout from mid July until December (following spawning). Constant temperature test tanks ranged from 10 to 21 C (50.0 to 69.8 F), and one additional tank followed seasonal temperature regime of Lake Superior surface water (ranging from 15.0 to 5.0 C, 59.0 to 41.0 F). Mean body weight (total weight minus gonad weight) and mean total length increased with temperature to a maximum at 16 C (60.8 F). Growth decreased progressively at higher temperatures. Hokanson et al. concluded 10 to 19 C (50.0 to 66.2 F) to be the optimal range for relative condition, gain in body weight, and total length.

Less comprehensive growth evaluations in juvenile (and weight unspecified) brook trout concur with the findings of Hokanson et al. Results of all studies are summarized in Table FO-4.

Cherry et al. (1975) determined upper (and lower) avoidance temperature for fish acclimated to various temperatures. These data,

Table FO-4. Summary of results of growth studies using brook trout.

Temperatures C	F	Comment	Author
(4.4-10.0 to 10.0-15.6)	40-50 to 50-60	Change accompanied by a tremendous increase in growth and condition	Cooper, 1953; cited in Bridges and Mullan, 1958
~8-11	(~46.4-51.8)	Progressively better at each higher temperature	Haskell et al., 1956; cited in McCormick et al., 1972
10-19	(50.0-66.2)	Optimal Range	Hokanson et al., 1973
16	(60.8)	Optimum	
(10.6 ave.)	51 ave.	Overall growth better than at average of 48 F (8.9 C)	Titcolm, 1920; cited in M'Gonigle, 1932
(11.8-18.9)	55-66	Best condition and greatest volume of food in stomach	Benson, 1953
13	(55.4)	Better growth than at 9, 17, or 21 C (48.2, 62.6, or 69.8 F)	Baldwin, 1956
13-16	(50.0-60.8)	Opt. for growth	Davis, 1956; cited in McCormick et al., 1972
14	(57.2)	Opt. growth	Baldwin, 1951; cited in Fry, 1951
(27.5)	81.5	Grew in pond which ranged up to this temperature	Embody, 1921

included in Table FO-3, indicate that within the acclimation limits employed avoidance temperature ranged from 14 to 25 C (57.2 to 77.0 F).

Lethal temperature relations in young brook trout have been evaluated in various detail by M'Gonigle (1932), Brett (1940, 1944a, 1944b; the latter cited in Fry et al., 1946), Elson (1942), Huntsman (1946), and most extensively by Fry et al. (1946). Because findings of earlier studies in general conform with those of Fry et al. (Table FO-5), only the latter are treated in detail.

The paper by Fry et al. (1946) is important not only because of the comprehensive results obtained, but also because it presented concise definitions (see p. 15-16) and helped standardize test procedures. Among their innovations, Fry et al. did not terminate testing after a specified time, instead tests were generally continued until all fish were dead or sufficient time had elapsed for death to have occurred as determined by extrapolation from results at higher temperatures. By not restricting test duration Fry et al. avoided a common limitation of other studies; their data more thoroughly representing temperature as the primary lethal factor and thereby presenting a more complete picture of the species response to temperature.

The $UUILT_{50}$ determined using these methods was found to be 25.3 C (77.6 F). The temperature polygon reflecting upper (and lower) lethal temperatures at various levels of acclimation is given in Figure FO-4. Temperatures survived for shorter periods at the various acclimation levels can be derived from resistance data plotted in Figure FO-5. NAS (1973) has tabulated equations used in the development of resistance lines plotted by Fry et al. for brook trout and for a number of

Table FO-5. Some observations on lethal temperature in young brook trout.

Acclimation Temperatures		Lethal Temperature		Comment	Author
C	F	C	F		
8	(46.4)	22.0	(71.6)		Brett, 1944b, cited in Fry et al., 1946
~11	(~51.8)	23.6	(74.5)		
13.0	(55.4)	24.0	(75.2)	14-hour ULT	Brett, 1940
16.0	(60.8)	24.9	(76.9)		
19.0	(66.2)	25.8	(78.5)		
				1 C/5 min. change	M'Gonigle, 1932
		22-29	(71.6-84.2)	Range in which death occurred in unhealthy fish	
		29	(84.2)	Healthy died	
		25.3	(77.6)	Ultimate upper lethal temperature. See text for further discussion	Fry et al., 1946
		26.1	(79.1)	Stream at maximum summer temperatures; 12 hour-ULT	Brett, 1944a
		26.5-28.0	(79.7-82.4)	Dead in northern Nova Scotia rivers	Huntsman, 1946

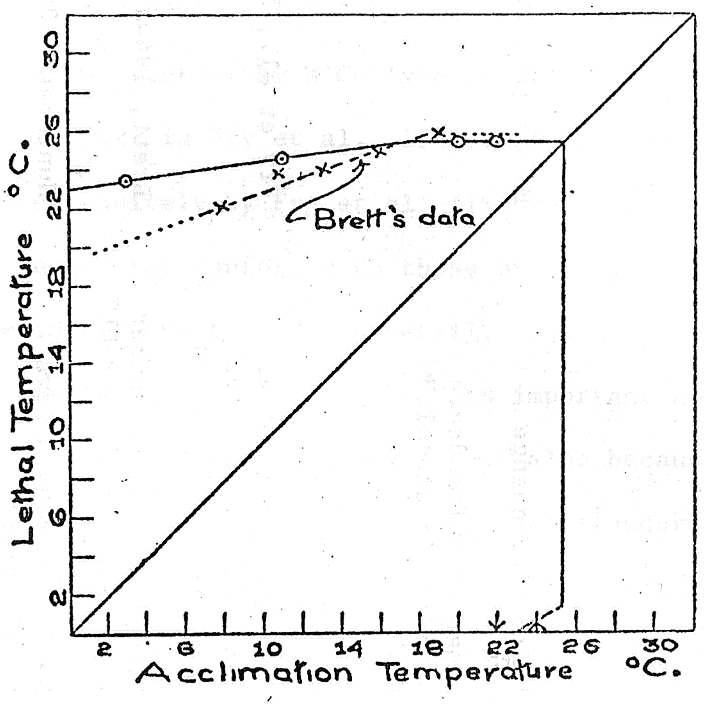

Figure FO-4. Thermal tolerance of a sample of yearling brook trout measured in May and June in Toronto tap water. The dotted line indicates the trend of Brett's (1940) data for another population of slightly older yearlings measured in Opeongo Lake water, and for further data (Brett, 1944b) he subsequently gathered on yearlings from the same source as those used here but not necessarily of the same stock. From Fry et al., 1946.

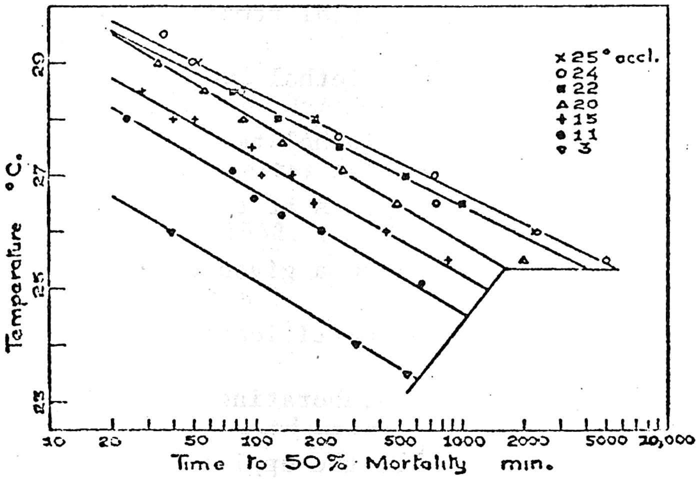

Figure FO-5. Resistance times for brook trout at various temperatures in the lethal range plotted for various levels of thermal acclimation. From Fry et al., 1946.

studies on various other species treated in the Handbook.

Fry et al. also proposed a method for evaluating time to death for fish exposed to changing temperatures within the zone of resistance. Such a method was considered significant because it was felt to more accurately reflect thermal death in nature. The method was based on the observation that death in changing lethal temperatures appeared to be the sum of thermal experience at each lethal level. What was termed the _minute rate of mortification_ at any lethal temperature is the reciprocal of the resistance time in minutes at that temperature, and the degree of mortification resulting from a given exposure to that temperature would be the minute rate of mortification multiplied by the exposure time in minutes. Rather than elaborating here the reader is referred to Coutant (1970) who discussed the applicability of the method in terms of recent efforts to develop techniques for accurately evaluating impact of thermal discharges. Its use has since been adopted with modification (to assure no mortality) in the NAS (1973) Water Quality Criteria 1972.

Adults

The studies by Job (1955; cited in Fry, 1957) included examination of metabolic scope of large fish (eg. 405 gm. and 1,000 gm.). As cited earlier (see Juvenile section) small fish showed increasing scope with temperature though the effect decreased with size. In large fish, scope decreased with temperature an effect which, according to Fry (1957), was brought about by a relatively greater reduction in the active metabolic rate in larger fish as the temperature increased.

Beamish (1964b) found a seasonal cycle for standard oxygen consumption in mature male and female brook trout. Maximum standard rates coincided approximately with spawning season. Unfortunately standard oxygen consumption tests were carried out at a single temperature (10.0 C, 50.0 F) and active consumption rates were not determined so that it is not possible to assess how this seasonal change might influence scope for activity.

Legal size trout stocked in Michigan waters at temperatures less than 50 F (10.0 C) exhibited immediate downstream movements, but when water temperatures were greater than 50 F (10.0 C) fish showed very little movement (Cooper, 1952; cited in Newell, 1957). Newell (1957) reported a similar reaction.

General and Unspecified

McCauley (1958) evaluated effects of water temperature on cruising speed for two geographic races (Pennsylvania and Ontario) of brook trout. McCauley found no difference between size and cruising speed, though the sizes tested were not reported. Nor was there a difference between cruising speed and temperature for the two races. For fish acclimated to 10 C (50.0 F), highest cruising speed when tested at various temperatures occurred at about 20 C (68.0 F). McCauley also found evidence for a second "prelethal" peak at 23 C (73.4 F), a finding similar to that reported for presumably young trout by Sullivan (1954) (see Juvenile section). When tested at various acclimation temperatures, peak swimming speed occurred at about 15 to 17 C (59.0 to 62.6 F).

From field observations Kendall (1924; cited in Creaser, 1930) considered 60 F (15.6 C) to represent the optimum temperature. The average water temperature at which Hallam (1959) collected brook trout in Ontario streams was 60.3 F (15.7 C). Creaser and Brown (1927; cited in Creaser, 1930) considered them to probably prefer water less than 18 C (64.4 F) in Michigan, and Embody (1927; cited in Creaser, 1930) stated brook trout preference did not exceed 20 C (68.0 F). According to two studies cited in Graham (1949), brook trout have been found to frequent waters varying in mean summer temperature from 10.5 C (50.9 F) (Dymond, 1926) to 21 C (69.8 F) (Cooper, 1939). Three other papers have reported brook trout to be distributed over a range of temperatures; 7 to 21 C (44.6 to 69.8 F) in two Nova Scotia lakes (Hayes, 1946; cited in Henderson, 1963); 14.2 to 20.3 C (57.6 to 68.6 F) in Moosehead Lake, Maine, (Cooper and Fuller, 1945; cited in Ferguson, 1958), and 12.0 to 20.0 C (53.6 to 68.0 F) in Redrock Lake, Ontario (Baldwin, 1948; cited in Ferguson, 1958). Field studies by Smith and Saunders (1958; cited in Coutant, 1974) indicate 20 C (68.0 F) as the upper avoidance temperature.

Comments have been made by a number of authors on temperatures limiting distribution of brook trout. These are summarized in Table FO-6. It can be seen that reports of limiting temperatures vary considerably and extend up to 80 F (26.7 C); undoubtedly at least in part due to differences in duration of exposure experienced. Usefulness of such data is therefore limited unless the context of the statement is known.

In laboratory studies using two geographic races of unspecified size, McCauley (1958) obtained resistance data in agreement with those of Fry et al. (1946) cited earlier (see Juvenile section).

Table FO-6. Summary of observations on limiting high temperatures for brook trout.

Location	Temperature		Comment	Author
	C	F		
Michigan streams	17	(62.6)	Brook trout waters not above this temperature during summer	Creaser, 1930
Smoky Mountains	19	(66.2)	Sharply limited to temperatures below this	Powers, 1929*
Western Virginia	19	(66.2)	Corresponds almost exactly with downstream limit	Burton and Odum, 1945
Mad River, Ontario	19	(66.2)	On many occasions	Ricker, 1934
	21 or 22	(69.8 or 71.6)	Many good Ontario trout streams	
	24	(75.2)	Near limit of frequent occurrence	
Pigeon River, Michigan	(20.0)	68	Maximum temperature	Benson, 1953
	(20.0)	68	Streams stocked should not rise above this temperature	Bean, 1909*
Alleghany Park	(20.0)	68	With one exception nowhere was temperature as high as this	Kendall and Dence, 1927
	(21.1-26.7)	70-80	Live in apparent comfort, though prefer cooler	Belding, 1928

Table FO-6. (Continued)

Location	Temperature C	F	Comment	Author
Pigeon River, Michigan	up to 23	up to 73.4	Reported	Creaser and Brown, 1927
Alleghany Park	(23.9)	75	Limit of temporary existence	Kendall, 1924*
Thompson Co., N.Y. streams	(23.9)	75	Except where this temperature is exceeded, brook trout commonly occur and apparently thrive	Embody, 1921
	(27.2)	81	Highest stream temperatures where brook trout found in numbers	
	24	(75.2)	Tolerance in very rapid streams	Embody, 1927*
Ashe Co., N.C. streams	(26.7)	80	Common in streams with temperatures at least as high	Breder, 1927
Moser River, Nova Scotia	29.5	(85.1)	Dead after previous days high temperature	Huntsman, 1942

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*Cited in Creaser, 1930
**Cited in Burton and Odum, 1945

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