THERMAL EFFECTS LITERATURE REVIEW
FOR HUDSON RIVER
REPRESENTATIVE IMPORTANT SPECIES

Prepared for:

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March 1978

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CHAPTER 1: INTRODUCTION

This report provides a review of the existing thermal effects literature for selected fish and invertebrates designated by the United States Environmental Protection Agency (U.S. EPA) as representative important species (RIS) for the Hudson River that should be addressed by studies to determine the effects of power plant thermal discharges on biological communities (Table 1-1). Specific thermal effects information is presented for each RIS, based on general categories set forth in the U.S. EPA's 316(a) Technical Guidance Manual (draft issued 1 May 1977). It is intended that this report serve as a source document for evaluating the effects of power plant thermal discharges on Hudson River RIS that will be addressed in demonstrations pursuant to 316(a) of the Federal Water Pollution Control Act Amendments (PL 92-500).

Although the amount and emphasis of thermal research varies considerably on a species-by-species basis, the extant literature has been summarized for each Hudson River RIS, to the extent possible, under the following categories:

1. Life history summary, including normal dates and temperatures for spawning, and special temperature requirements for reproduction.
2. Temperature requirements for early development.
3. Upper thermal tolerance limits for eggs, larvae, juveniles, and adults.
4. Temperature as a factor determining behavior, i.e., preference and avoidance responses.
5. Optimum temperatures for physiological functions, including growth.
6. Lower thermal tolerance limits for juveniles and adults, i.e., cold shock.

TABLE 1-1 REPRESENTATIVE IMPORTANT SPECIES FOR FOUR POWER PLANTS LOCATED ON THE HUDSON RIVER

Power Plant	Common Name	Scientific Name
Danskammer Point Generating Station Roseton Generating Station	White perch	*Morone americana*
	White catfish	*Ictalurus catus*
	Alewife	*Alosa pseudoharengus*
	Atlantic tomcod	*Microgadus tomcod*
	Striped bass	*Morone saxatilis*
	Spottail shiner	*Notropis hudsonius*
	Atlantic sturgeon	*Acipenser oxyrhynchus*
	Shortnose sturgeon	*Acipenser brevirostrum*
	Phantom midge-fly	*Chaoborus* spp.
	Scud	*Gammarus* spp.
Bowline Point Generating Station Indian Point Nuclear Generating Station	White perch	*Morone americana*
	White catfish	*Ictalurus catus*
	Alewife	*Alosa pseudoharengus*
	Atlantic tomcod	*Microgadus tomcod*
	Striped bass	*Morone saxatilis*
	Spottail shiner	*Notropis hudsonius*
	Atlantic sturgeon	*Acipenser oxyrhynchus*
	Shortnose sturgeon	*Acipenser brevirostrum*
	Weakfish	*Cynoscion regalis*
	Bay anchovy	*Anchoa mitchilli*
	Scud	*Gammarus* spp.
	Oppossum shrimp	*Neomysis americana*
	Sand shrimp	*Crangon septemspinosa*

Thermal effects information based on research conducted on Hudson River species by New York University Medical Center from 1971 to 1975 and Texas Instruments from 1972 to 1974 is presented (as it applies to specific RIS), in addition to the results of thermal effects studies conducted on these same RIS originating from other systems and geographical areas. Recent thermal effects laboratory studies performed on Hudson River fish and macroinvertebrates by Ecological Analysts, Inc., are not included in this review, but are addressed extensively in "Hudson River Thermal Effects Studies for Representative Species, Final Report" (February 1978), prepared for Central Hudson Gas & Electric Corporation, Consolidated Edison Company of New York, Inc., and Orange and Rockland Utilities, Inc.

CHAPTER 2: TERMINOLOGY

2.1 INTRODUCTION

The terminology used in this review is defined in the following sections according to the appropriate thermal effects category. A brief definition of each category is included, as well as a limited discussion of the application of information in each category to thermal impact assessment. It is beyond the scope of this review to summarize the various methodologies used by researchers or to discuss general thermal biology concepts in depth. Excellent reviews of these subjects can be found in Fry (1947, 1958, 1964, 1971), Brett (1956, 1969, 1971), Coutant (1970, 1972), Fry and Hochachka (1970), Cairns (1971), Brown (1974), Battelle Pacific Northwest Laboratories (1975), and Richards et al. (1977). Terminology defined in the following categories is referenced to papers that address the concepts and limitations in greater detail.

2.2 THERMAL EFFECTS CATEGORIES

2.2.1 Life History Summary

The life history of each representative important species is briefly summarized in this category, including geographical range, habitat requirements, spawning temperatures and dates, life cycles, and movements and distribution patterns. These life-history elements are important for use in predicting the vulnerability of each life stage to potential power plant impact.

2.2.2 Temperature Requirements for Early Development

This category identifies the maximum temperature that early life stages of aquatic species can tolerate throughout development. Life stages addressed in this category are limited to those from egg to postlarval metamorphosis. This information is necessary for determining whether any areas of thermal plumes exist that are unsuitable for successful spawning and early development, owing to elevated temperatures (exclusion areas). Studies investigating the long-term effects of temperature on developing eggs or larvae are reviewed in this category. The terminology used within this category is from Hokanson et al. (1973), and includes:

Normal Hatch: All live larvae with no obvious deformities or abnormalities.

Total Hatch: All larvae hatched regardless of their condition.

Hatching Temperature Range: The range of incubation temperatures producing hatch (total or normal hatch specified).

Optimum Temperature: The temperature that produces the highest response (i.e., normal hatch, growth, or survival).

Optimum Temperature Range: The range of optimum temperatures over which the response was not significantly different.

2.2.3 Upper Thermal Tolerance Limits

This category defines (1) the upper limit of the temperature range permitting survival of juveniles and adults during all seasons, and (2) the tolerance of aquatic organisms to short-term elevated temperature exposures. Information addressing the first point is necessary to identify zones of a thermal plume that are not habitable by the organism because of excessive temperature (exclusion area); mortality would not be expected to occur in these zones since most organisms actively avoid temperatures resulting in stress. Information addressing the second point is applicable to identifying the maximum temperature elevation and exposure time that planktonic life stages (i.e., some fish eggs and larvae) or species (i.e., zooplankton, etc.) can tolerate during entrainment with the cooling water through a power plant or entrainment through the thermal plume as a result of passive drift. Terminology that applies to upper thermal tolerance tests is defined as follows:

Acclimation Temperature: The process of bringing the animal to a given steady state by setting the temperature conditions to which it is exposed for an appropriate time before a test; the temperature conditions may be fixed or cycled (Fry 1971). Where acclimation is used prior to testing, the definition of the acclimation process requires description.

Acclimatization Temperature: The "acclimation state" where physiological adjustments reflect acclimation to natural conditions of the environment; acclimatization provides for anticipatory and reactive adjustments (Fry 1971). Acclimatization temperature refers to the collection temperature, or holding temperature, where organisms are maintained under naturally fluctuating temperature regimes and tested soon after capture.

Lethal Temperature: The temperature that destroys the integrity of the organism (Fry 1967), resulting in death. Bioassay results using aquatic organisms are expressed in terms of tolerance limits (TL), followed by the percentage of survival and preceeded by the time of exposure, e.g., "24-hour TL95" (Standard Methods for the Examination of Water and Wastewater, 13th Edition). The expressions "lethal dose" (LD) and "lethal concentration" (LC) have also been used frequently (although incorrectly--see Standard Methods, 13th Edition, page 562). Unlike the term "tolerance limit," these expressions are followed by the percentage of mortality.

Median Tolerance Limit: The lethal temperature that results in 50 percent survival (mortality) expressed as TLm, TL50, LD50, or LC50 for a specified duration of exposure.

Upper (Lower) Incipient Lethal Temperature: The temperature that, when an organism is brought rapidly to it from a different temperature, will kill a stated fraction of the population with an indefinitely prolonged exposure (Coutant 1970). Unless otherwise stated, incipient lethal temperatures represent the median tolerance limit. Incipient lethal temperatures are usually estimated from tests conducted for 96 hours or longer and are a function of acclimation temperature. Fry (1971) suggests that 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.

Ultimate Upper (Lower) Incipient Lethal Temperature: The temperature that is lethal to the species, regardless of prior acclimation (Fry et al. 1946). The ultimate upper incipient lethal temperature is often determined as the temperature at which further increases in acclimation temperature fail to produce higher incipient lethal temperatures. The ultimate lower incipient lethal temperature is determined similarly, but is often equivalent to the freezing point of water (or blood).

Zone of Thermal Tolerance: The range of temperatures at which an organism can survive for an indefinite period of time (Fry et al. 1946; Fry 1971), delimited by the upper and lower incipient lethal temperatures (see Figure 2-1).

Zone of Thermal Resistance: The range of temperatures at which an organism can survive for a definite period of time (Fry et al. 1946), delimited by the incipient lethal and instantaneous death limits (see Figure 2-1).

Resistance Time: The length of time that an organism can resist the effects of a level of an environmental factor (temperature) which is beyond its zone of tolerance (Fry et al. 1946); resistance times decrease as the temperature rises above the incipient lethal level (see Coutant 1970). The resistance time defines the limits for survival within the zone of resistance.

Critical Thermal Maxima (CTM): The point at which the locomotor activity of an organism becomes disorganized and it loses the ability to escape from conditions, soon causing death. This point is reached as a result of slow heating or cooling to the temperature causing disorganization (Coutant 1970). The CTM is a temperature determination that involves two variables, time and temperature. Some researchers depart from this standard definition and report the temperature resulting in a stated fraction of mortality, i.e., LD1, LD50, or LD100. Lethal temperatures derived in this fashion reflect lethality due to a defined rate of temperature increase, and are not directly comparable to incipient lethal temperatures, although they are expressed in similar terms.

2.2.4 Temperature as a Factor Determining Behavior

This category provides information regarding the organism's attraction to or avoidance of thermal discharge areas. Laboratory determinations of preference and avoidance temperatures are useful for predicting the zones within thermal plumes that may attract and concentrate organisms, or the zones that are potentially avoided by organisms (areas of exclusion). However, the actual presence or absence of organisms in thermal plumes is determined by a combination of habitat type, plume velocities, and elevated temperatures (see Coutant 1970, 1975; Reynolds 1977). Terminology that applies to temperature preference and avoidance studies includes:

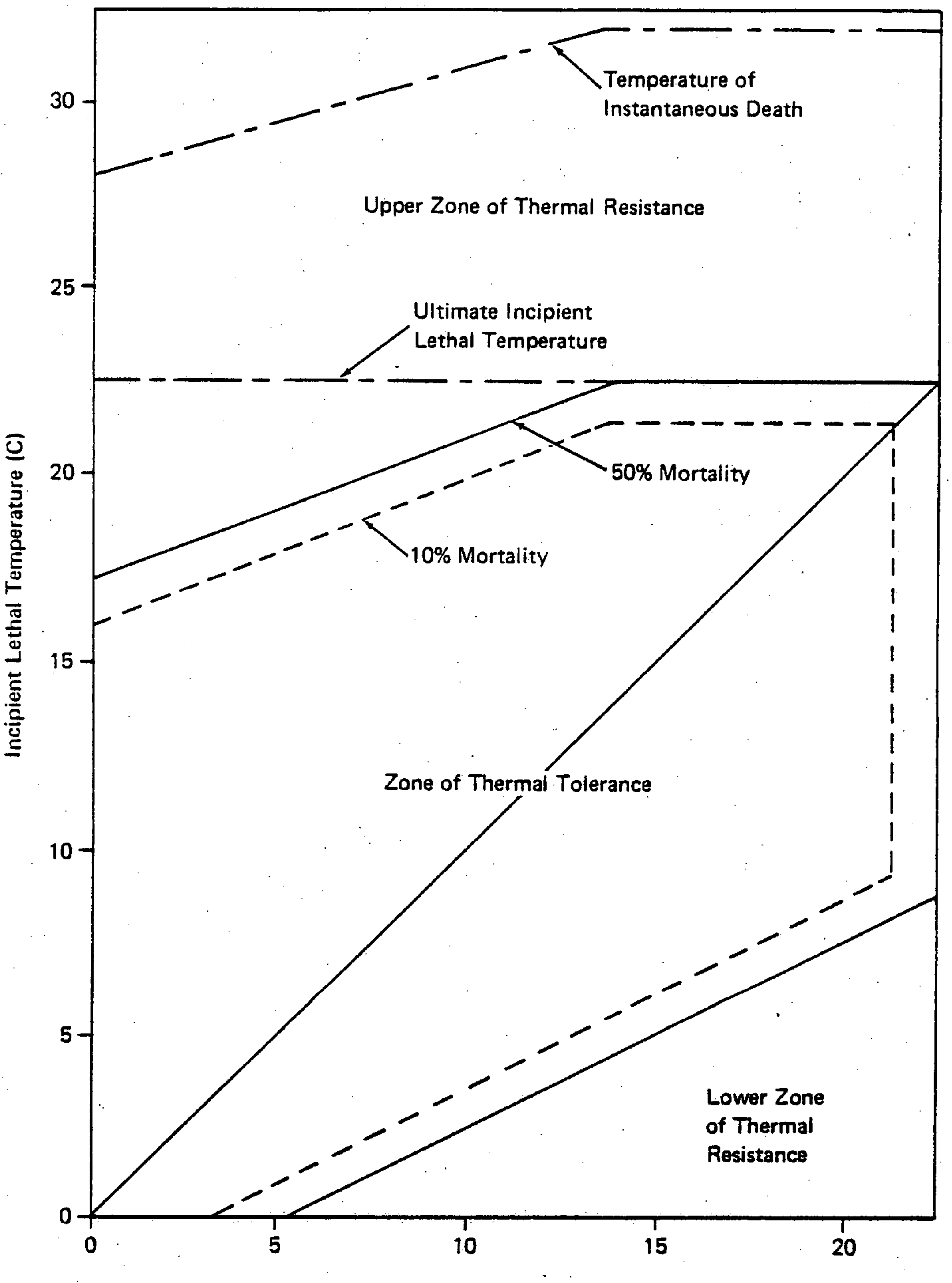

Figure 2-1. Thermal tolerance of a hypothetical fish in relation to thermal acclimation (from Coutant 1970).

Preferred Temperature: The range of temperatures in which animals congregate or spend the most time in a gradient or free-choice situation (Fry 1964; Reynolds 1977). Preferred temperatures determined upon initial contact by organisms to a thermal gradient are partially dependent upon acclimation state.

Final Preferendum: The temperature toward which a fish will finally gravitate regardless of its previous thermal history (acclimation) and where preferred and acclimation temperatures are equal (Fry 1947: Reyonlds 1977). If a fish is left in a thermal gradient for a sufficient length of time, it will eventually gravitate and become acclimated to its final preferendum.

Avoidance Temperature: The negative aspect of thermal behavior, characterized by escape or aversive reactions elicited by non-preferred temperature extremes, often called upper and lower "turnaround" or avoidance temperatures (Reynolds 1977); also defined as the temperature at which the organism detects a thermal stress sufficient to elicit an avoidance response (Gift and Westman 1971). Avoidance temperatures are partially dependent upon acclimation state.

Low Thermal Responsiveness: The inability of an organism to avoid areas in a thermal gradient which produce stress (Meldrim and Gift 1971), sometimes resulting in loss of equilibrium, or death. This response has been observed in laboratory studies and may be due to artificial conditions created in the experimental apparatus.

2.2.5 Optimum Temperature for Physiological Functions

This category identifies the temperatures producing an optimum level of performance for activities such as growth, food conversion, digestion rate, and metabolic activity. The natural occurrence of most organisms is limited within the thermal tolerance zone to temperatures somewhat below the ultimate upper lethal threshold, reflecting the results of poor physiological performance at near-lethal levels (Coutant 1972; Brett 1960, 1971). The upper temperature limit of the optimum temperature range for physiological activities can be used as an estimator of the maximum temperatures within thermal discharge zones that will permit optimum performance. Terminology used within this category is from Hokanson et al. (1973), as defined below:

Optimum Temperature for Growth: The temperature producing the highest growth rate.

Optimum Range for Growth: The range of optimum temperatures over which growth is not significantly different.

Growth Range: The range of temperatures over which growth occurs.

2.2.6 Lower Thermal Tolerance Limits

This category identifies the lower thermal tolerance limits, which are necessary to identify "cold shock" potential for organisms residing in thermal plumes. Plume resident organisms become metabolically acclimated to the higher discharge temperatures, and may die upon returning to ambient temperatures in the event that the artificial heating should suddenly cease (see Coutant 1972). Terminology used within this category is similar to that used for upper thermal tolerance limits, and is included in Subsection 2.2.3.

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CHAPTER 3: STRIPED BASS

3.1 LIFE HISTORY SUMMARY

The striped bass (Morone saxatilis) is an anadromous, coastal species distributed along the Atlantic coast of North America from the St. Lawrence River, Canada, to the St. Johns River in northern Florida, and in the Gulf of Mexico from western Florida to Louisiana (Scott and Crossman 1973). On the Pacific coast, striped bass inhabit coastal waters from the Columbia River to the United States - Mexican border (Radovich 1961). Striped bass are seldom found at sea more than a few miles from the coast. Bigelow and Schroeder (1953) stated that smaller striped bass inhabit enclosed bays, small marsh estuaries, and river mouths as well as coastal waters, but larger individuals generally frequent the open coast except during the spawning period or in winter. Most striped bass spend the winter in deeper waters of bays, estuaries, or coastal rivers (Talbot 1966).

In the spring, mature striped bass move upstream in rivers and estuaries to spawn in freshwater, usually from April to July depending on the specific location (Raney et al. 1952). An important requirement for successful spawning appears to be a current sufficient to keep the semibuoyant eggs from settling to the bottom where they might become silted over and smother (Bigelow and Schroeder 1953). In laboratory experiments, Albrecht (1964) demonstrated that eggs not kept suspended were unlikely to survive. In the Hudson River, spawning occurs primarily between river miles 40 and 100 (Rathjen and Miller 1957; Carlson and McCann 1969; Texas Instruments 1976a). The spawning season, based on the occurrence of ripe or near-ripe adults collected in the Cornwall region during 1973, extends from early May to early June at salinities not exceeding 0.1 ppt (Texas Instruments 1976a). During 1973 ichthyoplankton surveys, most eggs were collected near the bottom at water temperatures ranging from 11.2 to 18.4 C, while peak densities occurred at 13.8 C (Texas Instruments 1976a). McFadden (1977) summarized egg collections for striped bass in the Hudson River and reported that peak spawning occurred at 14-18 C during 1974 and 16-20 C during 1975. Spawning temperatures reported by other investigators are summarized in Table 3-1.

Striped bass larvae generally remain near the bottom water strata (Mansueti 1958; Texas Instruments 1976a; McFadden 1977). In the Hudson River, larvae (4-14 mm) were concentrated in the same general river mile locations as were eggs (Texas Instruments 1976a). Early juveniles move shoreward and downstream into shallow, low salinity nursery areas of the estuary through fall, and overwinter in the lower estuary (Texas Instruments 1976a). Subadult striped bass migrate upstream from the overwintering areas during the spring and remain in the shallow water zones until late fall (Texas Instruments 1976a). Talbot (1966) reported that, along the Atlantic coast, larger striped bass (usually those over 6 lb) leave the estuaries to make regular coastal migrations, apparently moving northward during spring and summer and southward during fall. He further stated that, although only a small percentage of striped bass leave the estuaries, the majority of those that do leave are predominately larger individuals.

Life history aspects are more thoroughly discussed in McFadden (1977), with emphasis on the vulnerability of Hudson River striped bass to Hudson River power plant effects.

TABLE 3-1 SUMMARY OF SPAWNING TEMPERATURES REPORTED FOR STRIPED BASS

Source	Location	Spawning Temperature Range (C)
Texas Instruments (1976a)	Hudson River	11.2-18.4 (13.8 peak)
McFadden (1977)	Hudson River	14-20 (11-23 = extremes)
Rathjen and Miller (1957)	Hudson River	15-20
Carlson and McCann (1969)	Hudson River	15-17.2 (10-24 = extremes)
Shannon (1969)	Roanoke River (N. Carolina)	16.7-19.4 (12.8-21.7 = extremes)
Bason (1971)	Delaware River	13-14
Murawski (1969)	Delaware River	15.4-18.3
Dovel (1971)	Chesapeake Bay	11-24
Barkuloo (1967)	Apalachicola River (Florida)	18.3-23.9
Tresselt (1952)	Virginia	12.2-21.1
Pearson (1938)	Lower Susquehanna River (Maryland)	15.5-21.1

3.2 TEMPERATURE REQUIREMENTS FOR EARLY DEVELOPMENT

3.2.1 Eggs

Because of the widespread artificial propagation and rearing programs for striped bass at hatcheries throughout the country, much information has been gathered regarding the early development of striped bass. The effect of temperature on the incubation time of striped bass eggs has been reported by a number of workers, as summarized in Figure 3-1. These data indicate that the rate of embryonic development steadily increases with increasing incubation temperature, with a marked increase in the rate of development between 12 and 15 C. In contrast, results reported by Morgan and Rasin (1973) showed no significant effect of temperatures on the developmental rate of striped bass eggs between 16 and 27 C, although a marked increase in developmental rate was observed between 13.5 and 16 C.

The upper limit for successful development of striped bass eggs appears to be 23-24 C. The University of Rhode Island (1976) observed successful hatching at 24 C; Albrecht (1964) determined that eggs survived both constant and fluctuating water temperatures ranging up to 24 C; and Morgan and Rasin (1973) considered 23 C to be the upper end of the survival optimum. In a Florida hatchery, Barkuloo (1967) found that striped bass eggs survived water temperatures up to 22.5 C, with less than 1 percent surviving at temperatures above 23.8 C; he further reported that striped bass females were observed to resorb their eggs when held at 25 C. To determine the effects of temperature changes on the survival of striped bass eggs, Shannon (1969) incubated eggs at 18.5 C and directly transferred the eggs to elevated temperatures at various stages of development (0, 16, and 44 hours) for the remainder of the incubation period. He observed no significant difference in hatching success among the

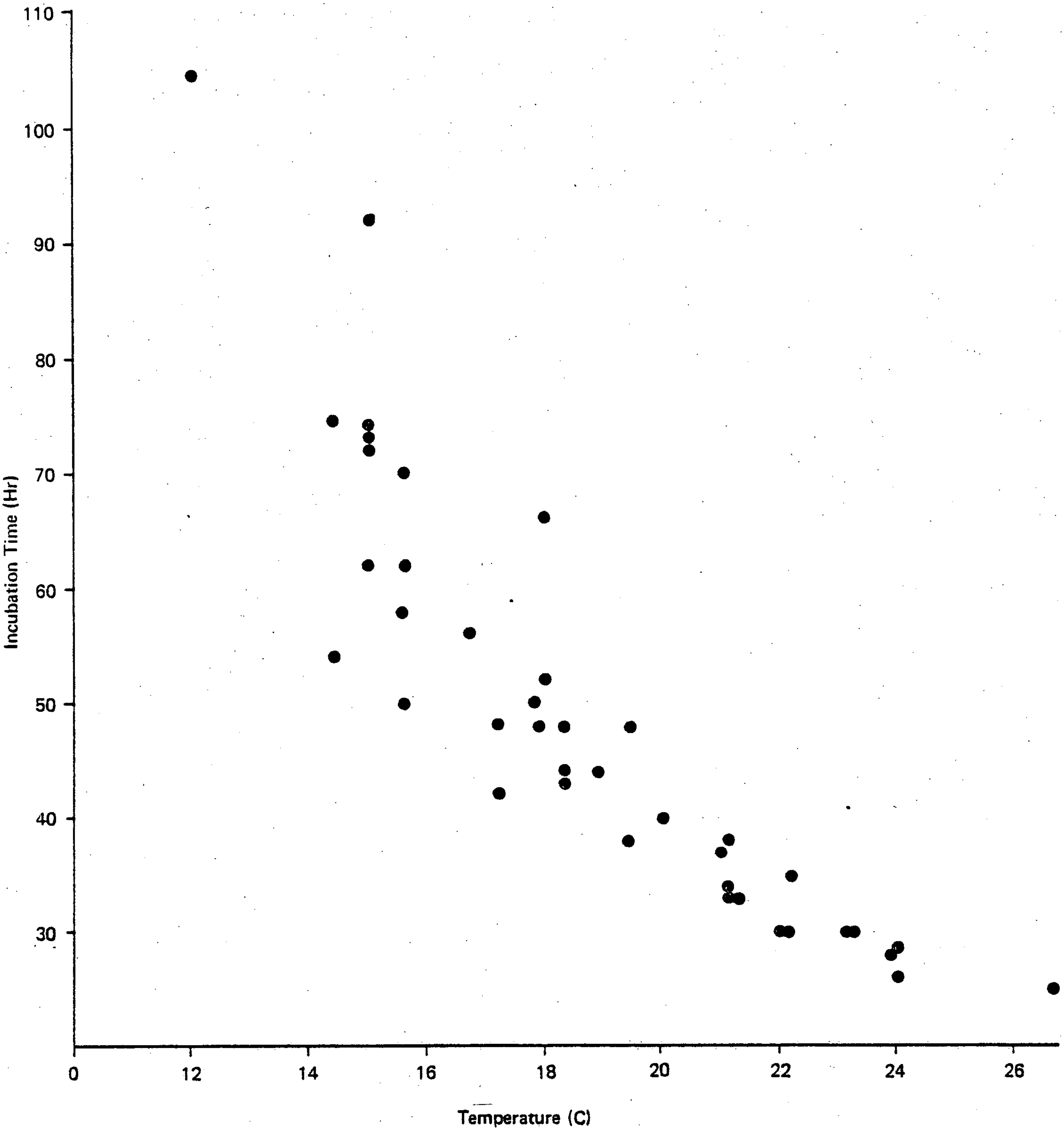

Figure 3-1. The effect of temperature on the incubation period of striped bass, based on observations by Pearson (1938), Merriman (1941), Bigelow and Schroeder (1953), Mansueti (1958), Stevens (1965), Regan et al. (1968), Shannon (1969), Bayless (1972), and University of Rhode Island (1976).

various stages of development or among test temperatures from 15.6 to 23.8 C. However, eggs transferred to elevated temperatures when 16 hours and older successfully hatched at temperatures as high as 29.4 C (range 34.6-69.3 percent hatch), indicating that striped bass eggs become more tolerant to thermal stress as development proceeds.

Time required for eggs to hatch at temperatures below 12 C tends to become infinite (Figure 3-1). In laboratory studies, Morgan and Rasin (1973) noted no successful hatching at 10.5 and 11 C; Barkuloo (1967) reported that all eggs died at temperatures less than 12.5 C; and Albrecht (1964) observed less than 4 percent hatch at 11.1 C. The University of Rhode Island (1976) reported that striped bass eggs incubated at 12 C experienced a steady mortality throughout the incubation period, which in most cases depleted the treatment population before hatching had occurred. Although striped bass eggs have been taken in the Hudson River at temperatures as low as 10 C (Carlson and McCann 1969), it is doubtful that successful development occurs at temperatures of 12 C or less.

3.2.2 Larvae and Early Juveniles

Research on the growth and survival of striped bass larvae and early juveniles has been conducted primarily to define conditions for rearing (Bayless 1972; Rhodes and Merriner 1973), or for stocking (Davies 1973a; Otwell and Merriner 1975), and does not identify the upper limit of the temperature range for growth and early development. The University of Rhode Island (1976), in an investigation of life stage durations of striped bass, observed the highest growth response of striped bass reared from yolk-sac larvae to juveniles at a constant temperature of 24 C. Otwell and Merriner (1975) similarly reported that the highest growth rates for striped bass larvae and early juveniles

(6-35 days old) occurred at 24 C (7-day experiment). In both studies, however, 24 C was the highest experimental temperature used. Loeber (1951, cited in Dorfman and Westman 1970) reported that striped bass fingerlings (average weight 1.75 g) increased their weight 119 percent when exposed to a temperature range of 25.6-29.4 C for 8 days; their weight increased an additional 2 percent after exposure to 31.1-35 C for 3 days.

3.3 UPPER THERMAL TOLERANCE LIMITS

3.3.1 Incipient Lethal Temperatures

3.3.1.1 Larvae and Early Juveniles

Kelly and Chadwick (1971) exposed post-yolk-sac larvae and early juveniles (8-31 mm length) to constant temperatures for 48 hours following a gradual increase in temperature at the rate of 5.6 C per hour until the desired test temperature was obtained (30-180 minutes equilibration time). Their experiments showed that the 48-hour TL50 for striped bass larvae and young up to several weeks old typically occurred at temperatures between 29.4 and 33.3 C. They reported no relationship between TL50s and acclimation temperature over the 15.5-24 C range tested, and variation associated with length was not observed.

3.3.1.2 Juveniles

Texas Instruments (1976b) conducted thermal tolerance experiments with juvenile striped bass acclimatized to temperatures ranging from 7.2 to 26.0 C and at salinities ranging from 0 to 8 ppt. Incipient lethal temperatures (96-hour TL50) ranged from 25.5 to 34.8 C, depending on acclimatization temperature, and are displayed along with upper avoidance temperatures in Figure 3-2. Tol-

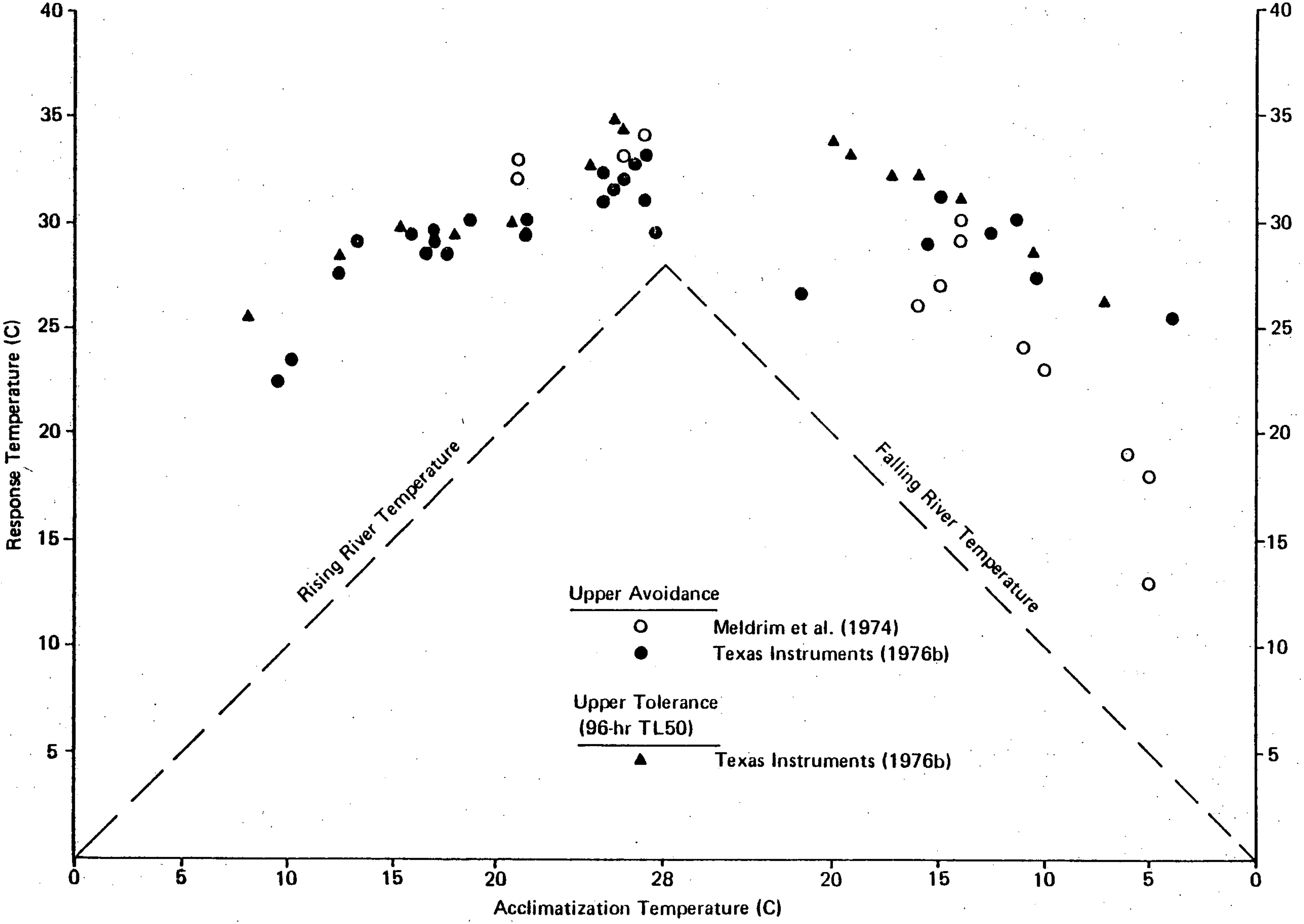

Figure 3-2. Relationship between upper avoidance temperature and upper tolerance limits of striped bass juveniles for both rising and falling acclimatization temperatures.

erance limits were significantly higher (P = 0.05) during falling river temperatures than during rising temperatures, but the difference was a maximum of only 2-3 C. The highest 96-hour TL50 observed was 34.8 C at an acclimatization temperature of 25.7 C.

Loeber (1951, cited in Talbott 1966) found that the maximum temperature tolerated by striped bass fingerlings (young of the year) in saltwater was 35 C; at an average temperature of 34.7 C, 7 out of 13 fish survived for 11 days. Dorfman and Westman (1970) gradually acclimated striped bass juveniles (previously acclimated to 21.1 C) to higher temperatures at a rate of 0.6-6.7 C per day, employing the slower heating rate at higher temperatures. They observed the first mortalities as the temperature exceeded 32.2 C. Two of the five fish tested survived and fed in water temperatures of 34.4-35 C for up to 24 hours. Upon increasing the temperature above 35 C, the remaining fish died. Davies (1973b) similarly found that striped bass fingerlings could not be acclimated to temperatures greater than 35 C. Fish acclimated to 32.2 C for 10 days and then subjected to a temperature increase of approximately 1 C per hour died as the temperature exceeded 35 C. These results indicate that the ultimate upper incipient lethal temperature for striped bass juveniles is just below 35 C.

3.3.1.3 Adults

Thermal tolerance of striped bass to long-term temperature exposures has been investigated primarily for juveniles; however, some thermal tolerance information exists for adults. Tagatz (1961) abruptly transferred 10 small adult striped bass (305-610 mm fork length) acclimated to 7.0 C into 26.5 C water and observed no mortalities after 10 days. Salinity in both the holding and test tanks averaged above 35 ppt.

3.3.2 Thermal Tolerance to Short-Term Exposure

Several investigators have studied the thermal tolerance of striped bass juveniles within the zone of thermal resistance (temperatures between incipient lethal and instantaneous death limits). Meldrim and Gift (1971) exposed juvenile striped bass to temperatures 5.6 and 8.3 C above river ambient temperatures ranging from 15 to 26 C for 15 minutes, and then returned the fish to ambient temperature for observation. They found that, at summer ambient temperatures up to 26 C, juveniles could tolerate sudden exposures for 15 minutes to temperatures at least as high as 34.3 C without loss of equilibrium. Dorfman and Westman (1970) acclimated four juvenile striped bass to 31.7 C for 4 days and increased the temperature to 38 C over an 18-40 minute equilibration period (exact experimental conditions were not defined). They reported that this temperature was endured for approximately 90 seconds before the fish lost equilibrium. Upon transfer to cooler water, all four fish recovered equilibrium and survived. Kerr (1953) exposed small yearling bass (47-83 mm) for 10 minutes to temperatures elevated at a constant velocity of 0.5 fps. He reported 85 percent survival of these fish at the end of a 5-day observation period following exposure to a 11.1 C temperature increase (33.3 C) above an ambient of 22.2 C. Exposures to temperatures over 34.4 C (12.2 C delta-T) resulted in greater than 50 percent mortality.

Lanza et al. (1974) exposed juvenile striped bass (63 mm mean standard length) for 1 hour to maximum discharge temperatures from the Indian Point Generating Station effluent. The fish were acclimated to river temperatures of 24 C prior to the test, and were subjected to temperatures 6.8 C above ambient (30.8 C). Immediate mortalities reached 50 percent in three replicate groups and 60 percent in the fourth group. These thermal tolerance results are in marked contrast to the higher incipient lethal temperatures (96-hour TL50s) reported by Texas Instruments (1976b) for similar size fish at similar acclimatization temperatures.

3.3.3 Thermal Tolerance to Entrainment Exposures--Laboratory Studies

Striped bass eggs and larvae have been extensively investigated with respect to thermally induced stress resulting from power plant entrainment. Schubel et al. (1977) exposed striped bass yolk-sac larvae (1-5 days old), acclimated to river temperatures of 19.3-21.2 C, to various time-excess-temperature histories of 7-20 C above ambient for 4-60 minute exposures followed by a 60-300 minute period of cooling to within 1 C of the base temperature. They reported that exposure to a maximum excess temperature of 10 C over ambient (29.3-31.1 C) did not significantly increase mortality in comparison to controls. Exposure to a delta-T of 15 C for 5 minutes with a 120-minute cooling period significantly increased mortality; however, a similar test conducted with a 10-minute exposure and a somewhat longer cooling period did not result in mortality greater than that observed for controls. All exposures to a delta-T of 20 C resulted in 100 percent mortality. In similar experiments, Schubel (1974), Schubel and Auld (1974), and Schubel and Koo (1975) found that striped bass eggs (late gastrula to late embryo stage) could tolerate the thermal stress induced by power plant entrainment at temperatures up to 15 C above a 14.5-19.6 C ambient, while hatching success of eggs exposed to a 20 C delta-T was reduced to 0-32 percent hatch, depending on the exposure time.

Kelly and Chadwick (1971) abruptly exposed larvae (7-8 mm mean length) and early juveniles (25-31 mm mean length) acclimated to ambient temperatures of 15.6-22.2 C to elevated temperatures for 0-6 minutes, followed by a gradual cooling period (unspecified duration) to simulate thermal exposure during plant entrainment. Mortality was assessed 48 hours after the exposure. Little mortality was observed until the experimental temperature exceeded 32.2 C; above which mortality increased sharply. Coutant and Kedl (1975) reported similar results based on thermal tolerances of younger larvae (4-6 mm). Kelly and Chadwick (1971) further suggested that mortality increased as the length of exposure to maximum temperature increased. Kerr (1953) exposed young striped bass (21-46 mm) to conditions simulating condenser tube entrainment and observed a survival rate of 94 percent at the end of a 5-day observation period following exposure to a temperature elevation of 8.9 C above the ambient river temperature (unspecified).

Lauer et al. (1974) indicated that maximum safe temperatures (those combinations of temperature rise and exposure time that caused no apparent increase in mortality compared to controls) varied according to life stage. Eggs in the blastula stage and 1-day-old yolk-sac larvae were reported to be the developmental stages most sensitive to short-term thermal stress (Figure 3-3). Results presented in Figure 3-4 indicate that the thermally induced mortality of eggs in the blastula stage became apparent as temperatures exceeded 26.1 C (6.1 C delta-T) for a 15-minute exposure, and 22.5 C (2.5 C delta-T) for a 120-minute exposure. The temperature tolerance of larvae (1-12 days old) exposed to elevated temperatures for 60 minutes ranged from 22.8 to 27.2 C (2.8-7.2 C delta-T), whereas fish 32 days old tolerated temperatures up to 31.1 C for 60 minutes (11.1 C delta-T).

Lauer et al. (1974) further reported that thermal tolerance also decreased with increased exposure time, as shown in Figure 3-4. The maximum safe temperatures for striped bass eggs subjected to 120-minute exposures compare favorably with the upper temperature limits reported by Shannon (1969) for

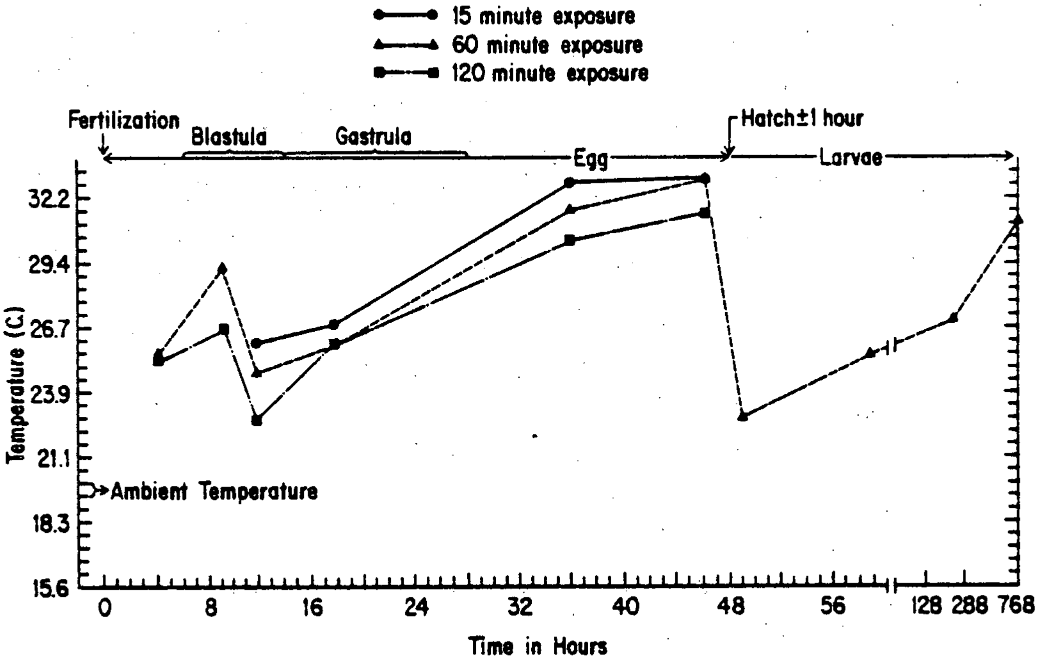

Figure 3-3. Maximum safe temperature for striped bass eggs and larvae from a Monck's Corner, S.C., hatchery stock (from Lauer et al. 1974).

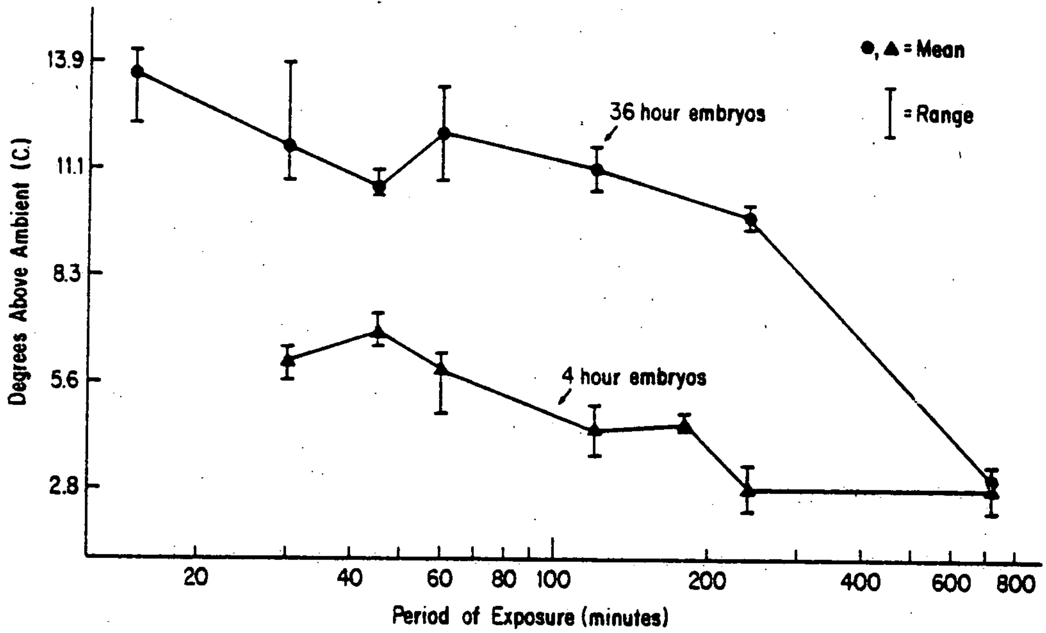

Figure 3-4. Upper safe temperature limits relative to exposure time for 4- and 36-hour striped bass embryos (ambient temperature = 18.9 C) (from Lauer et al. 1974).

eggs at various stages of development that were subjected to continuous exposure following an abrupt temperature change. However, the thermal tolerance levels of striped bass eggs reported by Lauer et al. (1974) for exposures greater than 120 minutes (Figure 3-4) are lower than satisfactory incubation temperatures reported by Shannon (1969) and others (see Section 3.2).

3.3.4 Thermal Tolerance to Entrainment Exposures--Field Studies

Finlayson and Stevens (1977) estimated the entrainment mortality for young striped bass (8-31 mm) at the Pittsburg and Contra Costa power plants in California based on field collections of live and dead larvae in the discharge canals, near the plant intakes, and at other near-field stations. They reported that mortality estimates increased linearly from 0 to 100 percent with increased discharge temperatures from about 28 to 35 C when river ambients ranged from 16 to 22 C (7-15 C delta-T). The transit time through the plant was estimated to be 5.5 minutes. Based on these field observations, they estimated a TL50 of 31 C, generally agreeing with the thermal tolerance limits identified in the laboratory by Kerr (1953), Kelly and Chadwick (1971), and Coutant and Kedl (1975). Finlayson and Stevens (1977) further concluded that heat, rather than mechanical stress, appeared to be the major factor causing mortality of entrained bass, a conclusion supported in condenser entrainment studies by Kerr (1953) and Kedl and Coutant (1975).

Ecological Analysts extensively studied the mortality of striped bass larvae and small juveniles entrained at the Bowline Point, Roseton, Lovett, and Danskammer Point power plants on the lower Hudson River estuary (Ecological Analysts 1976a, 1976b, 1976c, 1977a, 1977b, 1977c). Organisms were collected at the intake and discharge with pumps that delivered the sample to "larval table" collection flumes. The collection process exposed the fish to elevated discharge temperatures for 25-40 minutes as compared to normal entrainment exposures of 2-5 minutes at these plants. Mortality of striped bass was generally low (0-25 percent) at discharge temperatures less than 30 C (ambient 16-24 C), but increased rapidly to about 75 to 100 percent mortality at temperatures of 33-37 C. Entrainment mortality observed at discharge temperatures less than 26 C for larvae and 30 C for small juveniles was considered a result of mechanical stresses, and the thermal effect of entrainment was examined independently by adjusting for the estimated mechanical mortality. The combined results for all plants indicated a TL50 of 32-33 C for post-yolk-sac larvae, and a TL50 approximately 1-2 C higher for early juveniles (Ecological Analysts 1977d). The apparent increase in thermal tolerance observed for early juvenile striped bass may have been a result of higher acclimatization temperatures rather than an actual difference in thermal tolerance.

3.4 TEMPERATURE AS A FACTOR DETERMINING BEHAVIOR

3.4.1 Temperature Avoidance--Laboratory Studies

Texas Instruments (1976b) and Meldrim et al. (1974) investigated the avoidance responses of striped bass juveniles (34-210 mm) acclimated to river ambient temperatures. Salinities ranged from 0 to 8 ppt during both studies. The results of these studies are displayed in Figure 3-2 along with 96-hour TL50s (Texas Instruments 1976b) determined on similar sized striped bass. Both investigations found that acclimatization temperature was the most important factor determining the upper avoidance temperature.

Texas Instruments (1976b) reported a significant difference between avoidance responses during rising versus falling river temperatures; avoidance temperatures were higher during falling than during rising river temperatures for a given acclimatization temperature. Avoidance temperatures ranged from 2.5 to 7.2 C above ambient in summer (acclimatization temperatures ≥25 C), with fish consistently avoiding temperatures above 33 C. Avoidance temperatures ranged from 9 to 16 C above ambient during spring and fall. Striped bass tested during early winter avoided temperatures 21.5 C above a 4 C river temperature. In three tests performed during late winter (acclimatization temperatures less than 9 C), striped bass failed to avoid lethal temperatures in the gradient and lost equilibrium or died. Similar thermal nonresponsiveness was noted infrequently during other tests conducted at acclimatization temperatures less than 18 C. However, it is somewhat questionable that this would occur under natural conditions where the movements of fish are not restricted by the design constraints of an experimental system (i.e., artificially steep temperature gradients and size limitations of the experimental system). Meldrim et al. (1974) observed similar upper avoidance temperatures during summer, but slightly lower avoidance temperatures during late fall (Figure 3-2). They further reported that avoidance temperatures were slightly higher at lower light intensities, and reductions in dissolved oxygen in conjunction with increased temperature generally reduced the avoidance temperature.

3.4.2 Temperature Preference--Laboratory Studies

Temperature preference tests were conducted by Meldrim and Gift (1971) and Texas Instruments (1976b) on striped bass juveniles acclimated to river temperatures ranging from 5 to 25 C and salinities from 0 to 8 ppt, though different methods were employed. The principal difference between the two methodologies was the time allowed for fish to acclimate to higher temperatures. Meldrim and Gift (1971) terminated observations when fish failed to gravitate to higher temperatures after 20 minutes (1-4 hour tests, James J. Gift, personal communication), whereas Texas Instruments (1976b) continued observations for 27.5 hours. Figure 3-5 illustrates that temperature preference steadily increased with increasing acclimatization temperatures in both studies, with preferred temperatures typically ranging from 4 to 11 C above ambient. Differences in temperature preference between rising and falling river temperatures were not observed. The phenomenon of low thermal responsiveness (i.e., inability of a fish to avoid temperatures producing stress) was occasionally observed in both investigations.

3.4.3 Temperature Avoidance and Preference--Field Studies

Observations of fish aggregations near thermal discharges generally support the preference and avoidance temperatures determined for striped bass in the laboratory. Striped bass was the sixth most abundant species caught by anglers fishing in the discharge canal of the Connecticut Yankee Atomic Power Plant (Marcy and Galvin 1973; Marcy 1976). They reported that the catch was highest during the months of May and June when discharge temperatures ranged from 16 to 30 C. The majority of striped bass (85 percent) caught were under the legal size limit (406 mm) but one of the four larger fish weighed 4.6 kg (10 lb). Striped bass were not caught in the discharge canal by anglers during winter months, and extensive trawling in the canal during summer at temperatures above 32 C did not catch fish of any species. Moore and Frisbie (1972) reported that striped bass was a dominant species of a winter sport fishery in the 1-mi discharge canal of the Potomac Electric Power Company located on the Patuxent River, Maryland. Canal temperatures ranged from 8 to 10 C during January and February. Angler catches were greatly reduced during March and April.

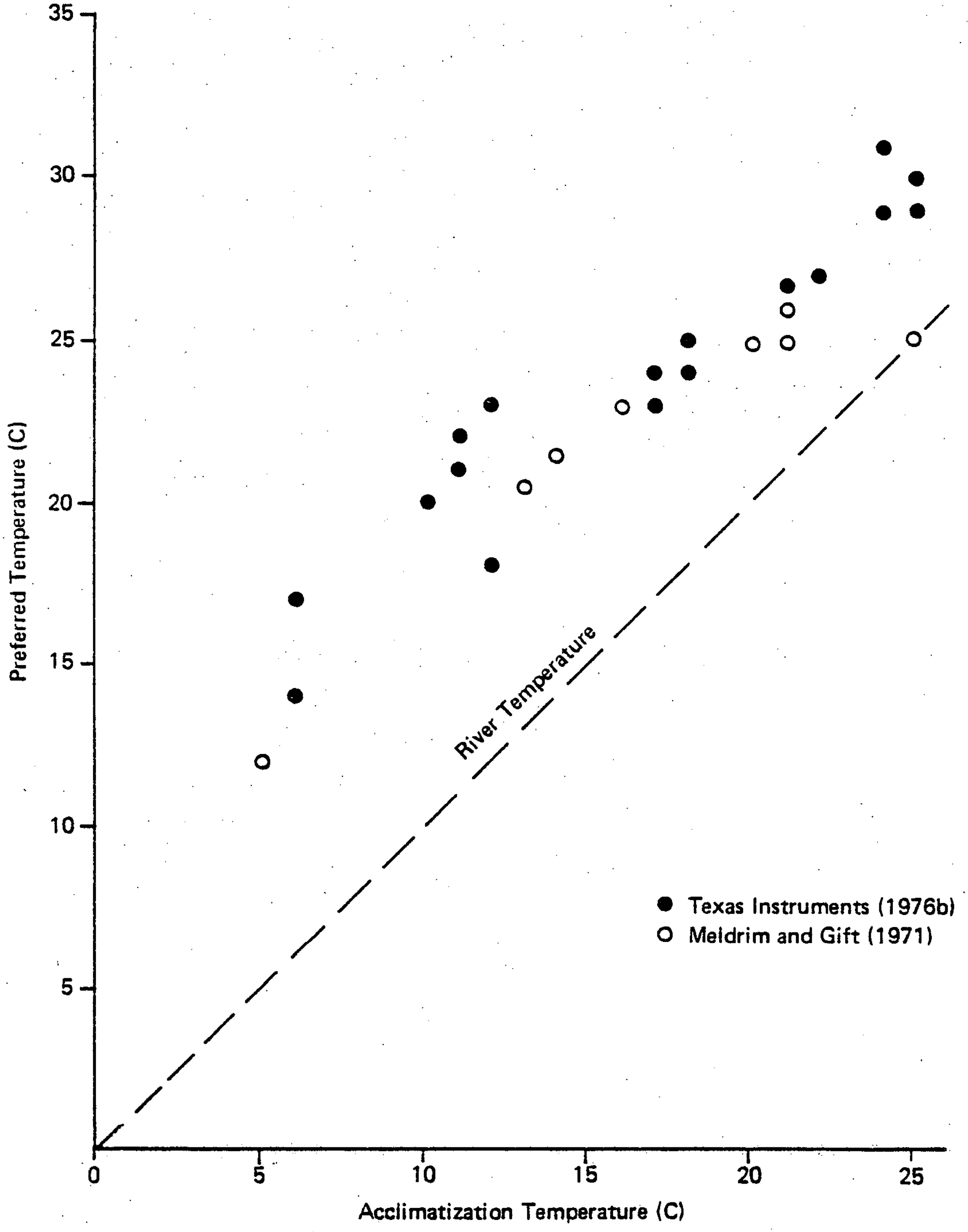

Figure 3-5. Temperature preference data for juvenile striped bass.

3.5 LOWER THERMAL TOLERANCE LIMITS

Texas Instruments (1976b) performed limited tests on striped bass juveniles to assess the potential mortality of fish residing in a thermal plume during the winter in the event of a plant shutdown. Striped bass acclimated to 10, 15, and 20 C were cold shocked by reducing the temperature 50 percent of the full decrease during the first 10-15 minutes of exposure, and continuing to decrease temperatures to 2 C over the next 3 hours. Results indicate that no mortality would be expected due to a drop of at least 8 C below plume temperatures to a lower temperature of 2 C. However, a drop of 13 C to 2 C resulted in 100 percent mortality.

Acclimation Temperature (C)	Test Temperature (C)	Mortality After 96 Hours (percent)
10	2	0
15	2	100

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CHAPTER 4: WHITE PERCH

4.1 LIFE HISTORY SUMMARY

The white perch (Morone americana) is a euryhaline fish found in saltwater, but usually restricted to brackish and freshwater (Mansueti 1964). It ranges along the Atlantic coast from the Gulf of St. Lawrence and Nova Scotia to South Carolina (Bigelow and Schroeder 1953). It is common in freshwater ponds in New England and is found as far west as the Great Lakes (Sheri and Power 1968; Miller 1963). In the Hudson River, white perch are common below Albany (Texas Instruments 1976a) and occur in many lakes in the lower Hudson River drainage (Scott and Crossman 1973). Mansueti (1961) described estuarine white perch as semianadromous; remaining within the estuary as a discrete self-contained population, generally inhabiting the brackish mid to lower portion of the estuary during most of the year, but regularly undertaking upstream migrations into tidal fresh and slightly brackish water to spawn in the spring. Mansueti (1964) stated that, while white perch occur in a wide range of salinities, the largest concentrations usually occur in brackish waters from 5 to 18 ppt salinity.

In the Hudson River, initial upstream and shoreward spawning migrations by adult white perch were observed as temperatures increased above 10 C in spring, as indicated by data presented by Texas Instruments (1976b). Spawning appeared to be concentrated in or near major tributaries of the estuary and occurred primarily during May and June between river miles 80 and 120 (Texas Instruments 1976a). White perch eggs were collected from late April through mid-June at water temperatures ranging from 10.0 to 22.6 C; more than 99 percent were collected above the salt/freshwater interface. Spawning temperatures reported for white perch in other areas are summarized in Table 4-1.

TABLE 4-1 SUMMARY OF SPAWNING TEMPERATURES REPORTED FOR WHITE PERCH

Source	Location	Spawning Temp. Range (C)
Texas Instruments (1976a)	Hudson River	10-22.6
Conover (1958)	Albemarle Sound, N.C.	12.2-16.7
Mansueti (1961)	Patuxent River, Md.	9.4-21.7 (16.1 = peak)
Miller (1963)	Delaware River	19.5-20.0
Smith (1971)	Tributary to Delaware River	11.0-19.0
Thoits (1958)	Massachusetts	14.4-15.5
Auclair (1956)	Maine	18.3-20.1
Dovel (1971)	Chesapeake Bay	8.0-16.0 (5.0-24.0 = extremes)
Sheri and Power (1968)	Lake Ontario	11.0-15.0

White perch eggs are demersal and adhesive, and are deposited in shallow waters near shore or in tributary streams (Auclair 1956; Mansueti 1961; Mansueti 1964). After spawning, adult white perch return to the lower estuaries (Texas Instruments 1976a).

After hatching, white perch larvae move toward brackish water (Dovel 1971). In ichthyoplankton surveys conducted in the Hudson River estuary during 1973, white perch post-yolk-sac larvae were concentrated predominately between river miles 62 and 106 during early June, and between river miles 24 and 85 during late June and early July (Texas Instruments 1976a). Juvenile white perch move downstream and shoreward into principal nursery areas during summer where they remain throughout fall (Mansueti 1964; Texas Instruments 1976a). As the water temperatures cool in fall to below 10 C (Texas Instruments 1976b), both adults and juveniles move from the shoals to deeper waters in the lower estuary, where they remain throughout the winter (Mansueti 1961; Texas Instruments 1976a).

Life history aspects are more thoroughly discussed in McFadden (1977), with emphasis on the vulnerability of Hudson River white perch to Hudson River power plant effects.

4.2 TEMPERATURE REQUIREMENTS FOR EARLY DEVELOPMENT

Limited information is available on the effects of increased temperature on the survival and normal development of early life stages of white perch. Foster (1918) reported that there is little development of white perch eggs at water temperatures as low as 7.5 C. He further stated that an increase in temperature to 14.5 C produced a hatch within 4-4.5 days, and at a temperature of 20.0 C the eggs hatched in about 30 hours. Mansueti (1964) indicated that hatching occurs in approximately 48 hours at 17 C. In an investigation of the effects of temperature on the development of white perch eggs, Morgan and Rasin (1973) reported that the optimum developmental rate occurred from 11 to 16 C, and that development at these temperatures was more than three times greater than at 20, 25, and 26 C. The expected result of high incubation temperatures is a continual increase in developmental rate as temperatures increase until they become lethal (see striped bass Subsection 3.2.1). The lower rate of development of white perch eggs at higher temperatures reported by Morgan and Rasin (1973) is in direct contrast to this expected result. Methods used by Morgan and Rasin are vague, particularly with respect to the pretest temperature history of the spawned adults, spawning temperature, and origin of the eggs incubated at each temperature. Hatching success and time-to-hatch information was not reported.

4.3 UPPER THERMAL TOLERANCE LIMITS

4.3.1 Incipient Lethal Temperatures

Texas Instruments (1976c) conducted thermal tolerance experiments on white perch acclimatized to temperatures ranging from 1.0 to 26.0 C. Incipient lethal temperatures (96-hour TL50) for both juveniles and adults ranged from 19.5 to 35.0 C, depending on acclimatization temperature. The upper tolerance limits for white perch adults (greater than 100 mm) are presented in Figure 4-1 along with upper avoidance temperatures. Significant variation due to size was not evident, although the highest lethal temperature (35.0 C) was reported for juvenile white perch acclimatized to 26.0 C. Tolerance limits were significantly higher during falling river temperatures than during rising temperatures, but the difference was a maximum of only 2-3 C.

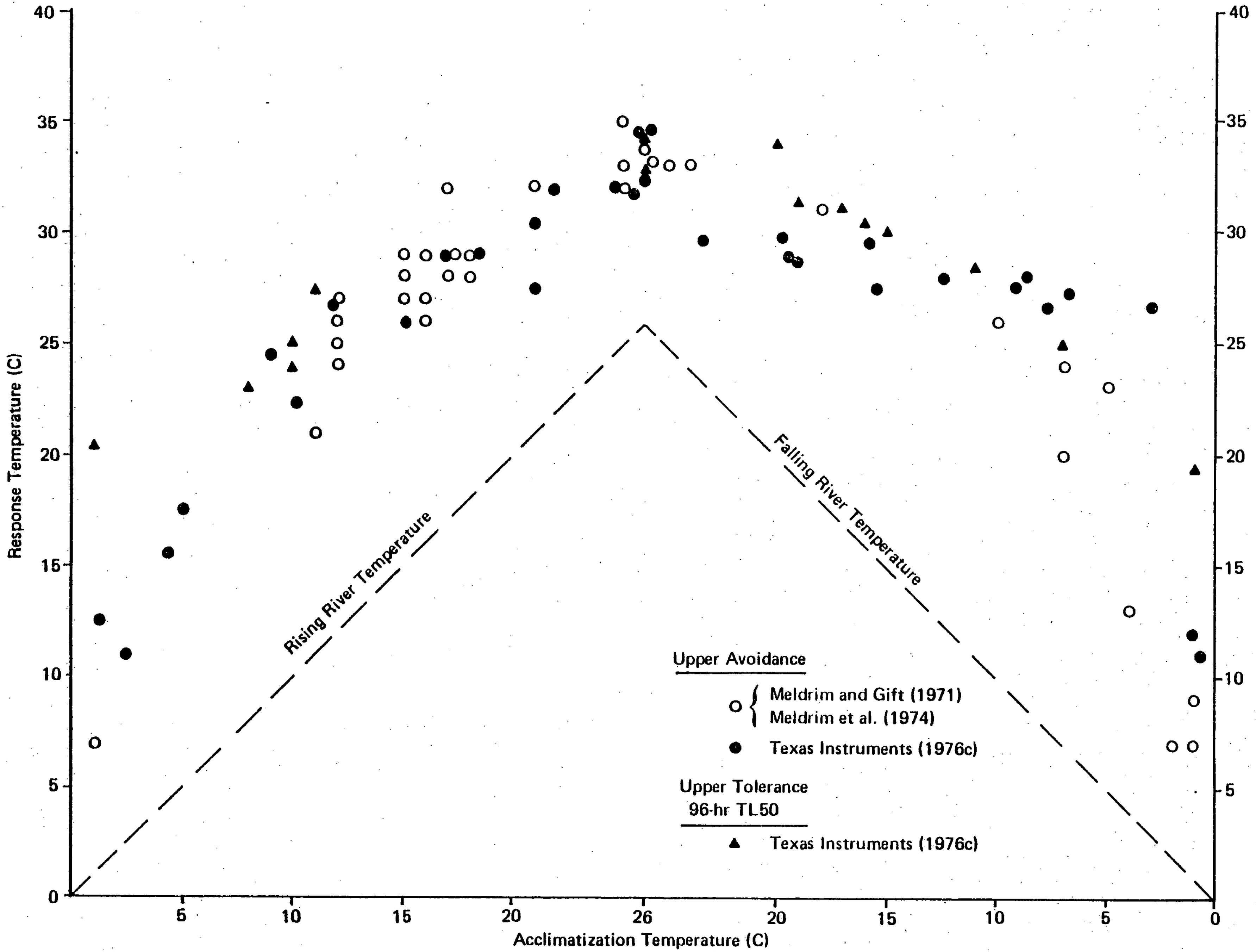

Figure 4-1. Relationship between upper avoidance temperature and upper tolerance limits of white perch adults (> 100 mm) for both rising and falling acclimatization temperatures.

McErlean and Brinkley (1971) conducted 24-hour TL50s on white perch to study the effects of thyroid activity on the temperature tolerance of white perch. Fish were acclimated to temperatures usually higher than the collection temperature prior to testing. The results indicated that tolerance levels were generally directly related to acclimation temperatures as shown in Table 4-2 (results presented are for nontreated white perch).

White perch thermal tolerance limits increase slightly when subjected to a gradual increase in temperature, rather than a sudden "shock." Trembley (1960) exposed white perch acclimated to 4.5 C to a temperature increase at a rate of 1.9 C per hour. The TL50 determined under these test conditions was 28.0 C.

4.3.2 Temperature Tolerance to Short-Term Exposure

Limited investigations of white perch thermal tolerance limits within the zone of thermal resistance have been reported. Meldrim and Gift (1971) exposed juvenile white perch to elevated temperatures for 15 minutes. They concluded that white perch could survive this short-term exposure to temperatures 8.5 C above river ambient temperatures not exceeding 26.5 C, although some stress was noted. White perch acclimated to 30.5 C survived a 15-minute exposure to 36.0 C, but did not survive an exposure to 39.0 C. Dorfman and Westman (1970) acclimated a group of four white perch to 18.9 C and a second group to 26.7 C and then increased the temperature until the fish lost equilibrium (18-40 minutes of heating; exact experimental conditions were not defined). White perch acclimated to 18.9 C lost equilibrium at 33.5 C, and fish acclimated to 26.7 C lost equilibrium at 36.3 C. Upon transfer to cooler water, six of the eight fish recovered equilibrium and survived.

TABLE 4-2 THERMAL TOLERANCE TESTS PERFORMED ON WHITE PERCH BY McERLEAN AND BRINKLEY (1971)

Month, Year		Collection Temp. (C)	Acclimation Temp. (C)	24-Hour[a] TL50 (C)
March	1968	2.9	10.0	26.2
November	1969	12.0	10.0	26.0
December	1968	3.8	10.4	27.2
December	1969	6.5	10.0	23.6
November	1967	6.5	17.5	27.7
June	1968	23.4	20.3	29.2
October	1967	22.7	27.8	32.7
September	1968	24.5	28.5	33.2

(a) Tests performed at 5 ppt salinity.

4.3.3 Temperature Tolerance to Entrainment Exposures--Laboratory Studies

To simulate power plant entrainment of fish eggs, Schubel (1974) exposed white perch eggs in the early gastrula stage (24 hours old) and early embryo stage (47 hours old) to various time-temperature histories of 6-10 C above ambient for 10-60 minutes, followed by a decrease in temperature to within 1 C of ambient during 60- to 300-minute cooling periods. The hatching success of experimental eggs was not significantly different from that of the controls. These findings indicated that temperature shocks up to 10 C above an ambient temperature of 13.4-14.5 C during plant or plume entrainment would not result in mortality of white perch eggs due to temperature.

4.4 TEMPERATURE AS A FACTOR DETERMINING BEHAVIOR

4.4.1 Temperature Avoidance--Laboratory Studies

Texas Instruments (1976c), Meldrim and Gift (1971), and Meldrim et al. (1974) investigated the avoidance responses of white perch acclimated to ambient river temperatures ranging from 1 to 26 C. Salinities ranged from 0 to 9 ppt during both studies. The avoidance results for adults (greater than 100 mm) are shown in Figure 4-1, along with 96-hour TL50s (Texas Instruments 1976c) determined on similar sized white perch. Both studies indicated that acclimatization temperature was the most important factor determining the upper avoidance temperature.

Texas Instruments (1976c) reported that size was significant (P = 0.05), with adults avoiding temperatures 6-8 C higher than juveniles during the winter; however, by summer these size specific differences were reduced to within 2 C. Both juvenile and adult avoidance temperatures were 1-5 C higher during falling ambient river temperatures than during rising temperatures. At maximum summer river temperatures (26-27 C), white perch consistently avoided temperatures 5-8 C above ambient (upper avoidance temperatures ranged from 31 to 35 C). No relationship was found between white perch avoidance and salinity. Similar size and season effects were reported by Meldrim and Gift (1971), except that smaller fish avoided slightly higher temperatures than did adults during falling river temperatures. Light levels and salinity were statistically significant variables, with avoidance temperature varying inversely with salinity. Further studies (Meldrim et al. 1974) showed that low dissolved oxygen saturation levels, when associated with warmer temperatures, reduced the avoidance response temperature.

4.4.2 Temperature Preference--Laboratory Studies

Temperature preference tests were conducted by both Meldrim and Gift (1971) and Texas Instruments (1976c) on white perch acclimated to river temperatures ranging from 3 to 29 C and salinities from 0 to 9 ppt, though different methods were employed. The principal difference between the methodologies was the time allowed for fish to acclimate to higher temperatures. Meldrim and Gift (1971) terminated observations when fish failed to gravitate to higher temperatures after 20 minutes (1-4 hour tests; James J. Gift, personal communication), while Texas Instruments (1976c) continued observations for 27.5 hours. Figure 4-2 compares the preference responses of white perch as determined by the two methods. Initial preferred temperatures were closely related to acclimatization temperature (Meldrim and Gift 1971), whereas fish tested for longer periods gravitated to much higher temperatures (Texas Instruments 1976c), resulting in an apparent curvilinear relationship with acclimation temperature. The curve depicted in Figure 4-2 for preferred temperatures determined by Texas Instruments (1976c) was fit by inspection for both juveniles

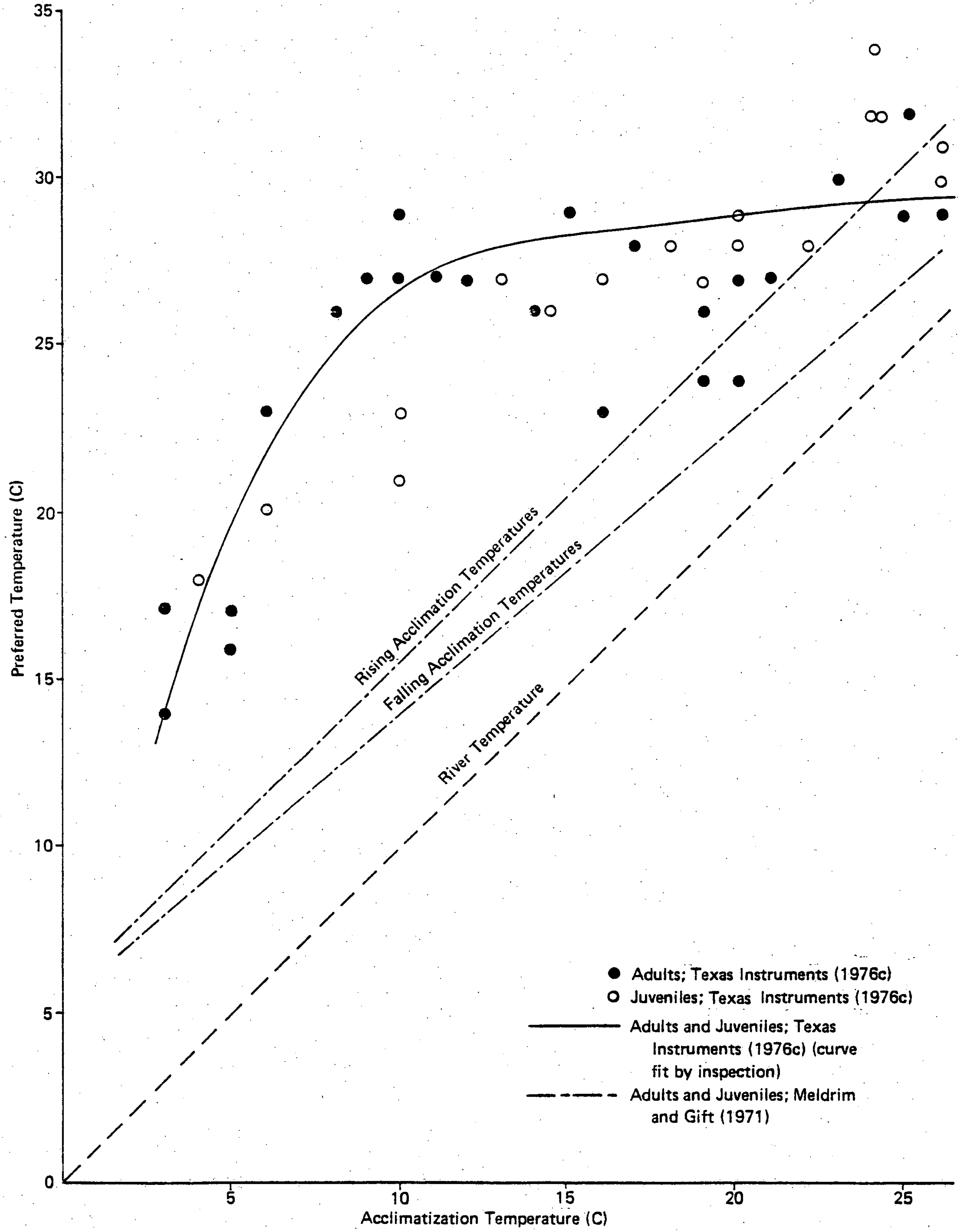

Figure 4-2. Temperature preference for white perch.

and adults. The higher values were judged to be more representative of gravitation towards a final preferendum, and therefore, were given more weight in fitting the curve.

Meldrim and Gift (1971) reported significantly higher preferred temperatures during rising river temperatures than during falling temperatures; however, this relationship was not significant in the longer tests performed by Texas Instruments (1976c). Size was not a significant factor determining temperature preference in either study, although Texas Instruments (1976c) found that juveniles preferred temperatures 1-3 C higher than adults when acclimated to high river temperatures in the summer. Salinity was also a significant variable in the Meldrim and Gift (1971) study, with preference varying inversely with salinity (i.e., higher salinities resulted in lower preferred temperatures).

Although the majority of laboratory information indicates that white perch avoid lethal temperatures, both Meldrim and Gift (1971) and Texas Instruments (1976c) observed that white perch entered lethal portions of the gradient and lost equilibrium or died. These observations were generally made during tests where the acclimatization temperature was less than 15.5-17 C. However, the occurrence of these incidences was low, and it is questionable that this would occur under natural conditions where the fish do not encounter the artificially steep gradients such as those in laboratory and experimental systems.

4.4.3 Temperature Avoidance and Preference--Field Studies

Consistent with laboratory avoidance and preference information, white perch are commonly attracted to heated discharges (Moore and Frisbie 1972; Marcy and Galvin 1973; Moore et al. 1973; Marcy 1976). Young white perch were found in the Connecticut Yankee Atomic Plant discharge canal (Connecticut River) in temperatures up to 40 C, and all sizes were available in the canal during all months except January and February (Marcy 1976). Marcy (1976) further reported that white perch apparently did not overwinter in the canal. Most fish left the canal when temperatures exceeded 35 C. White perch returned to the canal in large numbers during late summer. Moore and Frisbie (1972) reported a winter sport fishery in the discharge canal of a steam electric generating station on the Patuxent River, Maryland, where white perch was the most frequently caught fish from January through April.

4.5 LOWER THERMAL TOLERANCE LIMITS

Texas Instruments (1976c) performed limited tests on white perch adults to assess the potential for mortality of plume resident fish due to a plant shutdown during the winter. White perch acclimated to 10, 15, and 20 C were cold shocked by decreasing the temperature 50 percent of the full decrease during the first 10-15 minutes of exposure, and continuing to decrease temperatures to 2 C over the next 3 hours. Results indicate that no mortality would be expected due to a drop of up to 13 C below ambient, to a temperature of 2 C, as shown below. However, an 18 C drop to 2 C resulted in 50 percent mortality after 96 hours.

Acclimation Temperature (C)	Test Temperature (C)	Mortality After 96 Hours (%)
10	2	0
15	2	0
20	2	50

Meldrim et al. (1971) subjected four white perch adults (144-150 mm) to an instantaneous cold shock from 6.7 to 1.1 C. No mortalities occurred during the 72-hour exposure although all the test specimens lost equilibrium. Equilibrium was regained by two fish within 3 hours, but the remaining two fish failed to regain equilibrium after 72 hours of exposure to the depressed temperature. In other tests, fish were cold shocked for 15 minutes from 6.7 C to temperatures as low as 0.0 C. All fish lost equilibrium, but recovered after return to the acclimation temperature. These results suggest that the ultimate lower incipient lethal temperature for white perch may be slightly higher than 0 C.

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CHAPTER 5: ATLANTIC TOMCOD

5.1 LIFE HISTORY SUMMARY

The Atlantic tomcod (*Microgadus tomcod*) is distributed principally along the Atlantic coast of North America from southern Labrador to the Hudson River, and occurs incidently as far south as Virginia. Atlantic tomcod are also landlocked in Lake St. John, Quebec, and Deer Lake, Newfoundland (Scott and Crossman 1973). Tomcod are normally endemic to estuaries, embayments, and harbors; they are especially abundant at the terminus of stream and river drainage (Bigelow and Schroeder 1953) but sometimes ascend streams or rivers, well above the tidal influence, into freshwater (Scott and Crossman 1959, 1964). In the Maritime Provinces and the Gulf of Maine, tomcod remain close inshore year-round (Bigelow and Schroeder 1953; Leim and Scott 1966); south of Cape Cod, adult fish have been reported to move offshore into slightly deeper water as the inshore waters warm (Nichols and Breder 1926).

Tomcod are predominantly anadromous, migrating from lower estuaries and coastal waters during late fall and winter into brackish and freshwaters of rivers and estuaries to spawn (McKenzie 1959; Howe 1971; Texas Instruments 1976a), although spawning in saltwater has also been reported (Bigelow and Schroeder 1953). Spawning occurs from mid-November to about the end of February at water temperatures ranging from 0 to 3.9 C, with peak spawning occurring in January (Bigelow and Schroeder 1953; Scott and Crossman 1973). During winter fishery surveys on the Hudson River in 1973, the largest catches of spawning adults occurred during January at water temperatures of approximately 1 C and maximum salinity of 1 ppt (Texas Instruments 1976a). Booth (1967) collected running ripe males and females from the Mystic River, Connecticut, at a surface temperature of 0.0 C and a salinity of 15.7 ppt.

Spawning appears to be limited to salinities from 0 to 20 ppt, based on sperm motility observations by Booth (1967). Booth suggested that low salinity during the few seconds of the spawning act is more significant to spawning success than subsequent salinities during incubation. He hypothesized that in high salinity waters (>20 ppt), tomcod spawn in the lower salinities derived from freshwater influents or from melting snow and ice along the water's edge. Tomcod eggs are demersal and slightly adhesive, and sink to the bottom to become attached to the substrate (Booth 1967; Scott and Crossman 1973). Incubation time has been reported to be 30 and 24 days at temperatures of 4.4 and 6.1 C, respectively (Bigelow and Schroeder 1953), and nearly double this period at a temperature of 0 C (Leim and Scott 1966).

After hatching, the larvae drift downstream into the lower portions of the estuaries where they inhabit predominately bottom waters (Howe 1971). During Hudson River fishery surveys conducted in 1973, juvenile Atlantic tomcod first began to appear in bottom trawl catches in May, and most individuals were captured in more brackish, downstream areas (Texas Instruments 1976a). Howe (1971) reported that young tomcod were restricted to areas within the Wewantic River, Massachusetts, where the salinity was greater than 10 ppt and the temperature was less than 26 C. Texas Instruments further reported that tomcod were seldom collected in shore zones; the majority were collected in the 20- to 40-ft depth strata, with some occurring at depths exceeding 100 ft. Gonad maturation of young-of-the-year tomcod in the lower Hudson River was reported to begin in October, followed by a return to upriver areas in the winter to spawn (Texas Instruments 1976b).

Howe (1971) reported that 3-year-old tomcod were rare in the Wewantic River, and that tomcod older than 3 years were not taken. The spawning population of tomcod in the Hudson River is composed almost entirely of 11- to 13-month-old fish (Texas Instruments 1976b). The fate of postspawners in the Hudson River is generally not known. Texas Instruments (1976a) reported catching large numbers of postspawners (yearlings) from channel areas in the lower estuary until the end of May. During late May and late June, relatively large numbers were uncharacteristically collected in beach seines in the Yonkers region of the lower estuary, the southernmost collection stations during the survey (Texas Instruments 1976a). Although some adults older than 1 year accompany the yearlings during the spawning migration in the Hudson River, their numbers are very low, and they do not represent a significant element of the reproductive stock. Atlantic tomcod appear to be dependent on the estuarine environment for nearly all phases of their life history, and their abundance may be subject to the success or failure of individual year classes.

Life history aspects are more thoroughly discussed in McFadden (1977), with emphasis on the vulnerability of Hudson River Atlantic tomcod to Hudson River power plant effects.

5.2 UPPER THERMAL TOLERANCE LIMITS

Texas Instruments (1976c) conducted a single upper thermal tolerance test on Atlantic tomcod at an acclimatization temperature of 1.0 C and produced a 96-hour TL50 of 16.3 C. All specimens exposed to 20 C showed activity indicative of stress or equilibrium loss within 30 minutes; 60 percent died within 4.5 hours, and the remainder died within 20 hours.

Huntsman and Sparks (1924) exposed Atlantic tomcod acclimatized to 10.2-15.0 C to increasing temperature (0.1-0.4 C per minute) and identified the temperatures resulting in death. A single specimen was used in each test. Their results are shown below:

Size (mm)	Temperature Resulting in Death (C)	Number of Tests
20	19.0-20.9	4
20	27.2	1
140	26.1	1
150	23.5	1
220-290	25.8-30.3	8

Huntsman and Sparks (1924) suggested that the thermal tolerance limits observed for four smaller specimens may have been too low because of injury during collection. Excluding these tests, thermal tolerance limits obtained under these test conditions ranged from 23.5 to 30.3 C.

Short-term exposures of tomcod larvae to elevated temperatures were conducted by Lauer et al. (1974). They determined safe temperature exposures (those combinations of exposure time and temperature that caused no apparent increase in mortality or abnormal behavior compared with controls) for larvae 1-42 days old after exposure to elevated temperatures for 30, 60, and 720 minutes. The 26-hour-old tomcod larvae tolerated an 8.9 C delta-T above an ambient of 1.1 C for 30 minutes. Tomcod larvae 44 hours and older were able to tolerate temperature increases of at least 14.4 C above an ambient of 1.1 C for 30 minutes. Older larvae tested were also able to tolerate a 14.4 C delta-T for 60 minutes. Safe temperature increases for 720-minute exposures, however, were much lower, ranging from 3.3 to 4.9 C above ambient, or 4.4-6.0 C. These tolerance limits appear to be low, particularly since Booth (1967) successfully reared Atlantic tomcod eggs and larvae at 5.0 C in the laboratory for use in preparing egg and larval descriptions.

5.3 TEMPERATURE AS A FACTOR DETERMINING BEHAVIOR

Texas Instruments (1976c) conducted several avoidance experiments on yearling tomcod at acclimatization temperatures ranging from 0.5 to 8.9 C. Avoidance temperatures ranged from 9.6 to 20.0 C, increasing with increasing acclimatization temperatures, as summarized below:

Acclimatization Temperature (C)	Upper Avoidance Temperature (C)	Number of Tests
0.5-1.0	9.6-13.3	20
1.3-2.1	11.7-15.8	5
2.8-3.0	15.1-19.0	2
4.0	17.5	1
5.8	13.8	1
8.9	20.0	1

5.4 OPTIMUM TEMPERATURE FOR PHYSIOLOGICAL FUNCTIONS

In the summer, temperature appears to be a limiting factor for Atlantic tomcod in New England waters and southward (Nichols and Breder 1926; Howe 1971; Targett and McCleave 1974; Texas Instruments 1976a). Whereas most fish exhibit maximum growth during the summer, Howe (1971) reported the greatest feeding activity and growth for tomcod in the Wewantic River from January-March to July. Texas Instruments (1976b) reported a growth slowdown for tomcod in the Hudson River during midsummer, when temperatures were reported to be greater than 25 C (Texas Instruments 1976d), which resulted in marks (annuli) on scales and otoliths indicating the end of the growing season. Growth rates were observed to increase again during the fall as temperatures decreased below approximately 20 C. In addition, gonad maturation was reported by Texas Instruments (1976b) to begin as temperatures began to decrease in the fall. These observations indicate that normal summer ambient temperatures in estuaries within the southern portion of the range for tomcod are in excess of optimum temperatures for physiological functions.

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CHAPTER 6: ALEWIFE

6.1 LIFE HISTORY SUMMARY

The alewife (*Alosa pseudoharengus*) is an anadromous, schooling species indigenous to streams and lakes of the Atlantic coastal drainage of North America from Newfoundland (Scott and Crossman 1973) to South Carolina (Mansueti and Hardy 1967). Landlocked populations occur in the Great Lakes, the Finger Lakes in New York State, and other freshwater lakes (Scott and Crossman 1973). Marine populations of alewives spend most of their lives in the sea, entering freshwater to spawn (Scott and Crossman 1973). Individuals of this gregarious species congregate in schools of thousands of individuals, and apparently a given school holds together during most of its sojourn in saltwater (Bigelow and Schroeder 1953). Bigelow and Schroeder (1953) state it is likely that the majority remain in the general vicinity of the freshwater influence of the stream mouths and estuaries from which they emerged, though large catches have been taken up to 80 mi offshore. In the Atlantic, maturity is reached in 3 years off Massachusetts and 4 years off Maine (Rounsefell and Stringer 1945). Few anadromous alewives spawn more than once (Rounsefell and Stringer 1945), although multiple spawning has been reported for some landlocked populations (Carlander 1969).

Alewives spawn in streams of any size, from very small (with only a few inches of water) to rivers as large as the St. John or the Hudson (Bigelow and Schroeder 1953). Early spawning runs have been reported at temperatures ranging from 4 to 7.5 C (Cooper 1961; Kissil 1974; Richkus 1974). Peak spawning runs typically occur at temperatures of 13-16 C (Richkus 1974; Tyus 1974). Cooper (1961) observed that alewives migrate into spawning areas during daily warming periods, and Collins (1952) presented experimental evidence indicating that migrating adult alewives enter warmer water when offered a choice of two temperatures. Soon after spawning, the spent fish move downstream (Bigelow and Schroeder 1953; Cooper 1961; Kissil 1974). Considerable mortality of post-spawners was observed by Cooper (1961) and Kissil (1974). Kissil (1974) hypothesized that this mortality was due to (1) inability of the fish to acclimate to fluctuating temperatures, (2) osmoregulatory stress, or (3) fatigue due to the large energy expenditure during spawning.

Spawning takes place over a sand or gravel bottom (Mansueti and Hardy 1967; Texas Instruments 1976). Eggs are broadcast at random and are demersal and slightly adhesive immediately after extrusion, but later become nonadhesive (Cooper 1961). Texas Instruments (1976) reported that alewives spawn in the Hudson River estuary at temperatues of 10-17.5 C. Spawning temperatures reported for other areas are similar, as shown below:

Source	Location	Spawning Temp. Range (C)
Smith (1971)	Tributaries to Delaware River	12.0-20.0
Leim and Scott (1966)	Margaree River, Canada	8.9-12.2
Tyus (1974)	Lake Mattamuskeet, North Carolina	12.9-13.1 (peak)
Cianci (1965)	Bride Lake, Connecticut	10.0-15.0

In the Kalamazoo River (tributary to Lake Michigan) Edsall (1970) observed that spawning was interrupted when water temperatures rose above 27.8 C during a week of abnormally high temperatures. He reported that all mature unspawned females captured in the river at these high temperatures contained slightly opaque eggs that could not be fertilized. When water temperature fell below

27.8 C, a new group of alewives with viable eggs and sperm entered the river from the cooler waters of Lake Michigan, and spawning was resumed (Edsall 1970).

After hatching, the young remain in the tributaries and estuaries in which they were spawned during spring and early summer, and then migrate to the sea in successive schools (Bigelow and Schroeder 1953; Texas Instruments 1976). Cooper (1961) observed the first school of young alewives migrating downstream from Bride Lake (Connecticut) 66 days after the mean spawning date. He further reported that downstream migration was correlated with increased currents resulting from rainfall. By fall, the majority of young have moved out to sea (Bigelow and Schroeder 1953; Cooper 1961; Texas Instruments 1976), but some remain within the estuarine nursery area during their first winter, and a few through their second winter (Hildebrand and Schroeder 1928; Hildebrand 1963).

6.2 TEMPERATURE REQUIREMENTS FOR EARLY DEVELOPMENT

Eggs from Lake Michigan alewives were incubated by Edsall (1970) at 79 different temperatures from 5.6 to 30.6 C. Adults were collected and eggs were fertilized at 20-21.1 C. The eggs were incubated at the test temperatures within 5 hours after fertilization; equilibration to the test temperature was accomplished within 30 minutes after incubation. Hatching occurred between 6.9 and 29.4 C and was optimum (38 percent hatch) at about 17.8 C. Below 10.6 C, 69 percent of the larvae that hatched were deformed whereas only 1.7 percent of those hatched at 10.6 C and higher had deformities. Edsall (1970) concluded that the development through hatching of any considerable percentage of alewife eggs may occur only at temperatures somewhat above 10 C and below 26.7 C.

Incubation time for marine stocks of alewife eggs has been reported to be 4.4-4.6 days at 9.4-13.2 C (Cianci 1965), 6 days at 15.5 C (Bigelow and Welsh 1925), 3-5 days at 20 C (Mansueti and Hardy 1967), and 2-4 days at 22 C (Belding 1921). Edsall (1970) reported similar incubation times for Lake Michigan alewives, varying from 13 days at 7.8 C to 2-3 days at 20.0-21.1 C and 1-2 days at 26.7-28.9 C.

6.3 UPPER THERMAL TOLERANCE LIMITS

6.3.1 Incipient Lethal Temperatures

Upper incipient lethal temperatures and median survival times were determined by Otto et al. (1976) for Lake Michigan alewives exposed to constant temperatures for 7 days (10,000 minutes) following an abrupt increase in temperature. Young-of-the-year alewives were somewhat more tolerant of high temperatures than were adults, as shown below:

	Acclimation Temperature (C)	Incipient Lethal Temperature (C)
Adults	10	23.5
	15	23.5
	20	24.5
Young of the year	10-12	26.5
	18-20	30.3
	24-26	32.1

Mortality due to high temperatures was essentially complete for young-of-the-year alewives within 300-500 minutes, while adults continued to die beyond 1,000 minutes of exposure (Otto et al. 1976). These results indicate that, although smaller alewives are more tolerant to higher temperatures than are mature fish, their zone of thermal resistance (temperatures between incipient lethal and instantaneous death limits) is somewhat smaller.

Upper incipient lethal temperatures (83.3-hour exposures) were also determined by Graham (1956) for adult and young-of-the-year alewives from Lake Ontario. His results were generally comparable to studies conducted by Otto et al. (1976) at similar acclimation temperatures, as shown below:

	Acclimation Temperature (C)	Incipient Lethal Temperature (C)
Adults	10	20
	15	23
	20	23
Young of the year	5	15
	9	23

Dorfman and Westman (1970) gradually acclimated Hudson River alewives (young of the year), previously acclimated to 18.9-20.6 C, to higher temperatures at a rate of 0.6-6.7 C per day, using the slower heating rate at higher temperatures. The first mortalities were generally observed as temperatures exceeded 32.0 C. During one test, two of the five fish survived and fed at 34.4 C for two days. Upon increasing the temperature to 35.4 C, the remaining fish died. Stanley and Colby (1971) reported that 30-40 percent of young Lake Michigan alewives acclimated to 16.2 C and subjected to a temperature increase at a rate of 2.5 C per day, died at 30-31 C. These results indicate that the ultimate incipient lethal temperature for young alewife is approximately 31-32 C.

6.3.2 Critical Thermal Maxima

Otto et al. (1973, 1976) exposed Lake Michigan alewives acclimated to temperatures ranging from 5 to 25 C to increasing temperatures at a rate of 0.3 C per minute. A critical thermal maximum (CTM) was identified as the temperature resulting in loss of equilbrium of 50 percent of the test fish. They reported that CTMs for mature adults increased by about 0.4 C for each degree of increase in acclimation temperature, and 0.5 C per degree of increase for young of the year. The CTM results obtained for fish acclimated to 5-30 C are presented below (Otto et al. 1973):

Acclimation Temperature (C)	Critical Thermal Maxima (C)	
	Adult	Y-O-Y
5	24.7	24.7
10	28.7	26.7
15	29.9	29.5
20	31.9	31.9
25	32.8	34.3
30	--	36.7

In further studies, Otto et al. (1976) determined the rate at which heat tolerance is gained or lost by alewife adults following an abrupt 10 C change in temperature. Following transfer from 10 C to 20 C, the CTM increased within 10 percent of the CTM established for fish acclimated to 20 C by the sixth day. Fish acclimated to 20 C and transferred to 10 C acclimated at a much slower rate, achieving a change in the CTM equivalent to 90 percent of the maximum anticipated change by day 11. They concluded that the loss of heat tolerance by alewife following a decrease in temperature occurs at approximately one-half the rate of gain of heat tolerance following a temperature increase.

6.3.3 Thermal Tolerance to Entrainment Exposures--Laboratory Studies

Schubel (1974) subjected alewife eggs to time-temperature histories typically experienced by organisms that are either carried through the once-through cooling system of a power plant, or are entrained into the thermal plume without passing through the plant. The maximum excess temperature tested ranged from 6-10 C above ambient (12-14.5 C) for 2.5-60 minutes, followed by a cooling period ranging from 60-300 minutes. The stages of alewife eggs tested ranged from 4 and 8 cell eggs (3 hours old) to late embryos (91 hours old). Schubel (1974) reported that the hatching success of experimental eggs was not significantly different from that of the controls (at the 1 percent level) under all testing conditions.

6.4 TEMPERATURE AS A FACTOR DETERMINING BEHAVIOR

6.4.1 Temperature Avoidance

Meldrim and Gift (1971), Texas Instruments (1973), and Wyllie et al. (1976) determined the upper avoidance temperatures for estuarine alewives acclimatized to temperatures ranging from 3 to 25 C. Avoidance temperatures ranged from 18.0 to 31.9 C and were consistently lower than the incipient lethal temperatures reported by Otto et al. (1976) at similar acclimation temperatures:

Acclimatization Temperature (C)	Upper Avoidance Temperature (C)	Source
Adults		
10.6	18.0	Texas Instruments (1973)
11.4	17.0	Texas Instruments (1973)
11.7	16.0	Texas Instruments (1973)
11.8	18.0	Texas Instruments (1973)
12.5	18.0	Texas Instruments (1973)
20.4	27.0	Texas Instruments (1973)
Juveniles		
17.0	26.0	Meldrim and Gift (1971)
18.0	24.0	Meldrim and Gift (1971)
25.0	30.0	Meldrim and Gift (1971)
25.0	31.3	Wyllie et al. (1976)
25.0	31.9	Wyllie et al. (1976)

6.4.2 Temperature Preference

Alewife young of the year have been shown to prefer temperatures ranging from 19.0 to 26.5 C when acclimated to ambient temperatures ranging from 1-4 to 26 C (Meldrim and Gift 1971; Otto et al. 1976; Wyllie et al. 1976), as shown in Figure 6-1. Otto et al. (1976) found that adult alewives preferred temperatures ranging from 12 to 21 C over ambient Lake Michigan temperatures of 1-18 C; these temperatures were consistently lower than those preferred by young of the year (Figure 6-1). In addition, Otto et al. (1976) observed definite seasonal trends in temperatures preferred by adults. The maximum preferred temperature of adults (21 C) was observed when water temperatures ranged from 7 to 11 C, corresponding to the initial portion of the spawning period; preferred temperatures then declined despite rising lake temperatures, reaching a summer minimum of 16 C in August. Reutter and Herdendorf (1976) similarly determined a preference temperature of 21.3 C for Lake Michigan alewife adults in spring. Wells (1968) studied the seasonal depth distribution of alewives in Lake Michigan as related to water temperature and observed seasonal movement patterns which closely corresponded to seasonal temperature preferences determined by Otto et al. (1976).

6.5 LOWER THERMAL TOLERANCE LIMITS

Stanley and Colby (1971) observed that alewives acclimated to 16 C and exposed to decreasing temperatures at a rate of 2.5 C per day died or were immobilized when temperatures reached approximately 3 C. They further found that laboratory mortalities were as great for alewives held in sea water as for those held in freshwater, suggesting that the salinity of the sea water or brackish environment does not provide an advantage for alewives to tolerate acute temperature stress. Colby (1973) exposed Great Lake alewives to gradually de-

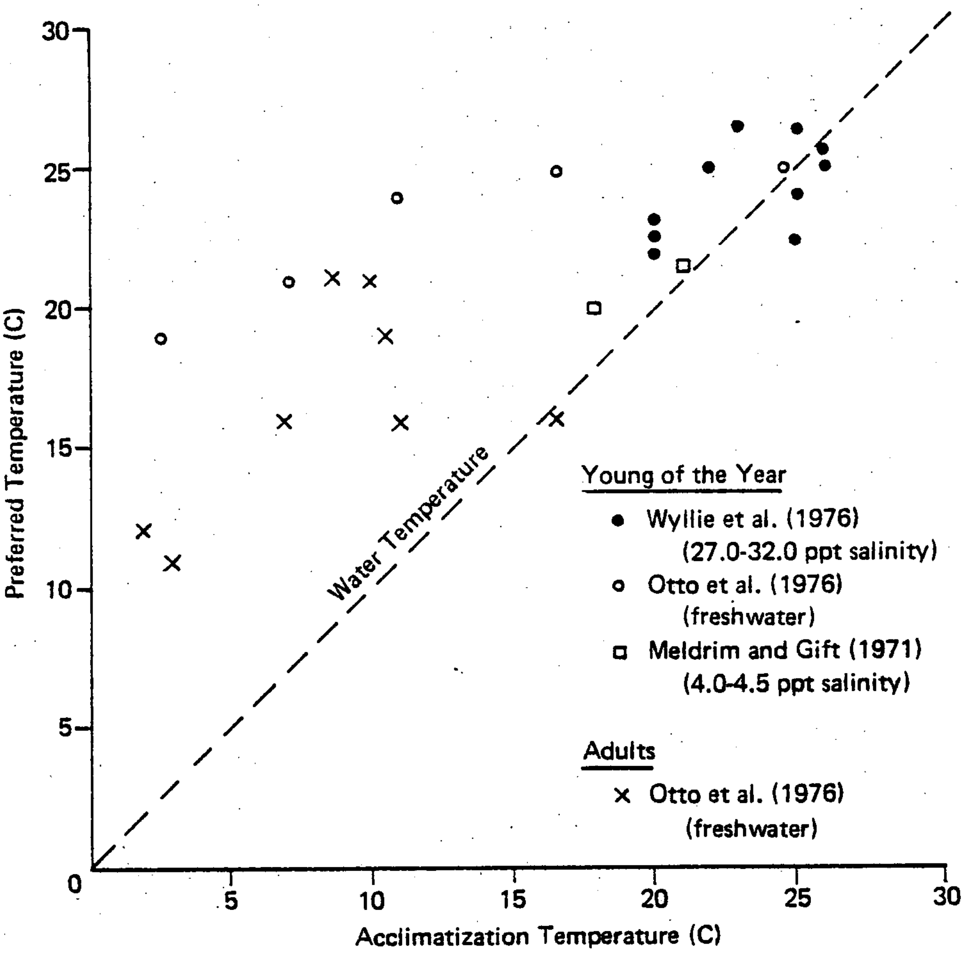

Figure 6-1. Short-term temperature preference of alewife.

creasing temperatures (from 12-18 to 2.2 C) over 2-22 week periods and consistently observed marked increases in mortality as the temperature approached and exceeded 3.0 C. Otto et al. (1976) reported a lower incipient lethal temperature of 8 C (TL60) for adult Lake Michigan alewives acclimated to 21 C, and a lower incipient lethal temperature of 6 C (TL60) for adults acclimated to 15 C. Fish acclimated to temperatures of 5 and 10 C did not appear to be appreciably more tolerant of cold shock than those acclimated to 15 C. No fish survived a transfer to temperatures of 2.5 C or lower regardless of their acclimation state. Based on their results, and those of earlier studies, Otto et al. (1976) estimated that 3 C was the ultimate lower incipient lethal temperature for alewives.

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CHAPTER 7: WHITE CATFISH

7.1 LIFE HISTORY SUMMARY

White catfish (Ictalurus catus) are endemic to coastal streams and rivers from Massachusetts south to Florida, and west along the Gulf coast to the Escambia drainage (Mansueti and Hardy 1967; Carlander 1969). They have been extensively introduced into other areas including California, Lake Erie, and several impoundments and small ponds (LaRivers 1962; Miller 1966). White catfish inhabit both fresh and brackish waters (Carlander 1969) up to a maximum salinity of 14.5 ppt (Kendall and Schwartz 1968), and have been reported to exhibit a greater tolerance for brackish water than other North American ictalurids (Turner and Kelley 1966).

LaRivers (1962) reported that the white catfish can live successfully in a variety of situations, seeming to prefer slower or standing waters, and do well in creeks if they contain large pools. In streams they are most abundant in areas intermediate between the faster waters preferred by channel catfish and the slow waters with silt bottom preferred by bullheads (Trautman 1957). Tagging studies in Clear Lake, California, indicated no apparent seasonal migratory tendencies among white catfish, although they were capable of extensive movement from the tagging sites (McCammon and Seeley 1960; Miller 1966). Marcy (1976) reported that white catfish in the Connecticut River exhibited a definite seasonal migration pattern, overwintering in the tributaries, coves, and attached ponds, and returning to the main river in early spring. In the Hudson River, white catfish are apparently common throughout the tidal portion of the river year-round, but are not abundant (Quirk, Lawler and Matusky Engineers 1973).

White catfish spawn during the spring as water temperatures increase above 20 C (Prather and Swingle 1960; LaRivers 1962; Turner and Kelley 1966). Prather and Swingle (1960) reported that no spawning was observed among white catfish in ponds at temperatures greater than 26.5 C. The eggs are laid in adhesive masses (Breder and Rosen 1966) in nests on sand or gravel bars (Miller 1966). The nest is generally a circular depression 30-36 in. in diameter and 12-18 in. deep (Miller 1966). The eggs hatch in 6-7 days at temperatures averaging 26.5 C (Prather and Swingle 1960). The young are closely guarded by the parents and travel in dense schools until the end of the first summer (Breder and Rosen 1966; Migdalski 1962, cited in Mansueti and Hardy 1967).

7.2 UPPER THERMAL TOLERANCE LIMITS

Laboratory thermal tolerance tests indicate that white catfish are very tolerant of temperature increases. Trembley (1961) exposed 21 species of fish common to the Delaware River to temperature increases of 0.5 and 1.0 C per hour, and identified the temperature resulting in 50 percent mortality. The results for white catfish are presented below:

Acclimation Temperature (C)	Rate of Temperature Increase (C/hour)	Lethal Temperature (C)		
		LD1	LD50	LD100
7.0	0.5	32.0	33.5	35.0
11.0	1.0	35.0	36.0	36.5

White catfish and brown bullheads exhibited similar tolerance levels during the study, and higher tolerance levels were exhibited only by banded killifish. Channel catfish were slightly less tolerant than white catfish.

Laboratory studies on the thermal tolerance of white catfish collected from the Patuxent River, Maryland, and acclimated to 20 C resulted in 12-hour TL50s of 31.0 C for small adults (160-235 mm) and 29.2 C for larger adults (220-300 mm) (Kendall and Schwartz 1968). These tolerance levels were reported to be lower than those found for other ictalurids, in contrast to results reported by Trembley (1961). Moreover, tolerance limits reported by Kendall and Schwartz (1968) are questionable because of high mortality in control aquaria during the test (30 percent for both size groups), especially in light of the relative hardiness of the species.

7.3 TEMPERATURE AS A FACTOR DETERMINING BEHAVIOR

Although laboratory information on the preferred temperatures of white catfish is not available in the literature, field observations indicate that this species is a warmwater fish and will normally prefer above-ambient temperatures throughout the year. Von Geldern (1964) reported that most white catfish in Folsom Lake, California, occurred in waters warmer than 21 C (warmest strata available) during periods of thermal stratification. White catfish have been widely reported to prefer thermally elevated areas in power plant discharge canals (Moore and Frisbie 1972; Marcy and Galvin 1973; Moore et al. 1973; Miller and DeMont 1974; Marcy 1976). This preference has been observed to be most pronounced in the winter and in early spring.

Marcy (1976) reported that white catfish and brown bullheads were collected in the Connecticut Yankee Atomic Plant (CYAP) discharge canal (Connecticut River) in greatest abundance between mid-February and early April. He reported that, with the exception of periods of plant shutdown for refueling purposes in spring, both species generally remained in the canal for about 8 months, or through June, when discharge temperatures rose above 35 C. Neither species was found in the canal again until the following October. However, catch records for white catfish within the discharge canal indicated that they were occasionally abundant in August and September during 2 years of the 5-year study. White catfish were observed to utilize the upper section of the canal where the flow rates were faster, and were most readily collected on ebb tide during the early morning hours.

7.4 OPTIMUM TEMPERATURE FOR PHYSIOLOGICAL FUNCTIONS

Marcy (1976) reported that white catfish overwintering in the CYAP discharge canal represented a closed population until early spring when ambient temperatures rose above 4 C, and the canal populations began to mix with the river populations. During this winter period he investigated the effects of the heated discharge on the condition of white catfish. Catfish overwintering in the canal exhibited significantly lower average weights and condition factors compared with those in the two cooler overwintering areas outside the canal (Salmon River and Chapman Pond). The 22 white catfish tagged in the canal lost weight at an average rate of 0.14 percent per day, or 20.3 percent over the winter season. Ovaries of white catfish collected from the heated water discharge canal in the winter were found to be developing earlier than those of fish collected outside the canal area. No damage to the ovaries as a result of overwintering was ever observed in the canal fish. Observations made by Marcy (1976) indicate that most of the available energy of white catfish that overwinter in the CYAP discharge canal was directed toward gamete production at the expense of other tissue production. Marcy also reported that there was no evidence of earlier spawning by catfish overwintering in the canal, at least through April, and suggested that if earlier spawning did take place after April, sufficient food sources would be available within the river system to insure survival of the young.

7.5 LOWER THERMAL TOLERANCE LIMITS

Laboratory results defining the lower thermal tolerance limits of white catfish are not available in the published literature. However, Marcy (1976) observed that both white catfish and brown bullheads exhibited lethargic behavior near the surface as they were carried from the CYAP canal following plant shutdowns during early spring. No evidence of mortality was observed as a result of these sudden drops in temperature. On several occasions during midwinter, Marcy (1976) placed white catfish collected in the canal (at temperatures of 13-15 C) into live-cars that were towed out into the river and anchored in water of 2.3 C. Body and opercular movements of these fishes became reduced and their coloration faded, but no deaths occurred within a 12-hour period. Fish in one live-car, which was shifted back and forth between the canal and the river several times within a short period, also showed no serious ill effects.

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CHAPTER 8: SPOTTAIL SHINER

8.1 LIFE HISTORY SUMMARY

The spottail shiner (*Notropis hudsonius*) occurs in North America from portions of Canada southward in the United States, to Georgia in the east, and to Iowa and Missouri in the west (Scott and Crossman 1973). It generally inhabits relatively large lakes and rivers, occasionally ascending a short distance into smaller tributaries (Greeley 1930; Greeley and Greene 1931; Scott and Crossman 1973). In estuaries, spottail shiners inhabit the shore zone, occurring predominately in fresh or slightly brackish water (Perlmutter et al. 1967; Carlson and McCann 1969; Texas Instruments 1976). Smith (1971) observed that the distribution of spottail shiners in tidal tributaries of the Delaware River estuary was generally limited to salinities of 5 ppt. He reported that spottail shiners withdrew into the upper reaches of the tributaries during dry, low-flow conditions when saline water penetrated farthest upstream, and moved downstream and into the river during periods of heavy runoff when freshwater conditions prevail. Spottail shiners have been reported from other areas at salinities as high as 10.7 ppt (Mansueti and Hardy 1967). The minimum length for maturity of spottail shiners is 66 mm, and they have been reported to live to a maximum of 4 years and 152 mm (Smith and Kramer 1964; Carlander 1969).

Spottail shiners spawn in spring and early summer, depending on latitude and seasonal weather (Scott and Crossman 1973), and may spawn a second time in late summer (Carlander 1969). Spottail shiner eggs are demersal and extremely adhesive. Spottail shiner have been reported to spawn in large breeding schools near the mouths of small tributaries (Greeley 1930; Greeley and Greene 1931); in shallow, sandy areas along lake shores; and in patches of *Cladophora* at a depth of 4.5 m (Wells and House 1974). Smith (1971) collected ripe adults in the spring at temperatures from 11.5 to 16.8 C over sand and gravel substrates. Spawning has been reported in Lake Erie at about 20 C (Commerical Fisheries Review 1961) and in Lake Champlain at 18.3 C (Greeley 1930). In the Hudson River, major concentrations of juveniles were collected between Hyde Park and Albany (river miles 77-152) (Texas Instruments 1976), indicating that this portion of the river is a major nursery area and possibly a principal spawning ground.

8.2 UPPER THERMAL TOLERANCE LIMITS

Otto et al. (1973) exposed Lake Michigan spottail shiners acclimated to constant temperatures ranging from 5 to 30 C to increasing temperatures at a rate of 0.3 C per minute. A critical thermal maxima (CTM) was identified as the temperature resulting in loss of equilibrium of 50 percent of the test fish. CTMs increased with increasing acclimation temperature, as shown below:

Acclimation Temperature (C)	CTM (C)
5	27.7
10	30.2
15	31.2
20	33.3
25	35.5
30	37.7

Trembly (1961) performed similar experiments on spottail shiners collected from the Delaware River, using much slower heating rates (0.56-1.10 C per hour). Trembly (1961) defined death, rather than loss of equilibrium, as the end point. LD50 results were similar to the CTMs reported by Otto et al. (1973), as shown below:

Acclimation Temperature (C)	Rate of Temperature Rise/Hour (C)	Lethal Temperature		
		LD1	LD50	LD100
7	1.10	28.9	30.6	31.1
11	0.56	27.8	31.1	32.8

Reutter and Herdendorf (1975) exposed Lake Erie spottail shiners acclimated to ambient temperatures ranging from 0.8 to 10.0 C to a sudden temperature increase of 11.1 C, and observed no mortality during the following 60-minute exposure period. After 60 minutes, the temperature was increased at the rate of 3.8-6.0 C per hour, and the CTM was recorded. CTMs obtained in this manner ranged from 27.0 to 29.2 C for fish originally acclimatized to 5.6-10.0 C. These results are comparable to the CTMs reported by Otto et al. (1973) for similar acclimation temperatures. Spottail shiners acclimatized to 18.8 and 21.7 C were also transferred to water 11.1 C greater than ambient (Reutter and Herdendorf 1975). Most of these fish died or lost equilibrium as a result of the thermal shock. Reutter and Herdendorf (1976) identified 32.8 C as the highest CTM observed for spottail shiners, based on results of these tests.

8.3 TEMPERATURE AS A FACTOR DETERMINING BEHAVIOR

8.3.1 Temperature Avoidance

A limited number of tests were performed by Texas Instruments (1973) on spottail shiner avoidance responses to temperature. They reported that upper avoidance temperatures ranged from 8.0 to 17.2 C for adults acclimated to river temperatures ranging from 3.0 to 6.3 C, as shown below:

Acclimatization Temperature (C)	Upper Avoidance Temperature (C)
3.0	8.0
5.5	16.1
5.0	14.9
4.8	14.7
5.8	15.8
6.0	17.8
6.0	16.5
6.3	17.2

8.3.2 Temperature Preference

Reutter and Herdendorf (1975, 1976) determined the final preferenda of spottail shiners in a horizontal gradient during winter and early spring. Preferred temperatures were determined over a 3-4 day observation period and were found to vary by season, as shown below:

Month	Acclimation Temperature (C)	Preferred Temperature (C)	Standard Deviation
FEB	2.0	7.1	4.0
MAR	4.5	10.2	2.8
MAY	13.2	14.3	1.5

Based on these tests, Reutter and Herdendorf (1976) reported a wintertime final preferendum of 9.0 C (mean of February and March tests weighted by number of fish tested) and a final preferendum of 14.3 during spring. Meldrim and Gift (1971) conducted a single short-term preference test on spottail shiners (typically 1-4 hours; James J. Gift, personal communication) and reported a similar preferred temperature of 13.9 C for fish acclimatized to 15 C in early spring (test performed at 6 ppt salinity).

Although spottail shiners are frequently collected in thermal discharges, they do not appear to congregate in the heated waters (Marcy 1976; Stauffer et al.

1976). Trembly (1960) observed young spottail shiner fry swimming in water up to 35 C in a thermal discharge lagoon on the Delaware River. Stauffer et al. (1976) collected spottail shiners at temperatures up to 35 C in a thermal outfall in the New River, Virginia, but did not observe a marked preference for the heated water. Marcy (1976) reported that spottail shiners were present in the Connecticut Yankee Atomic Plant (CYAP) discharge canal during all months of the year, but were most abundant at a station located on the flats slightly upstream of the discharge canal, an area only slightly affected by the heated discharge. Marcy (1976) collected spottail shiners within the CYAP canal at temperatures as high as 39.2 C.

8.4 LOWER THERMAL TOLERANCE LIMITS

Reutter and Herdendorf (1975) acclimated spottail shiners to temperatures 11.1 C above normal Lake Erie ambient temperatures for 1-24 days, and then returned them to ambient lake temperatures to determine the effects of cold shock on plume-resident fish. Only 4 of 81 fish tested (17 separate experiments) died because of sudden decreases to temperatures as low as 0.0 C (exposure time was unspecified). An actual power plant shutdown on Lake Wabamun, Alberta, resulted in the death of an estimated 258,000 spottail shiners when plume temperatures decreased from 21.8 to 4.9 C in 30 minutes, and continued to drop until the discharge canal froze (Ash et al. 1974).

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CHAPTER 9: ATLANTIC STURGEON AND SHORTNOSE STURGEON

9.1 LIFE HISTORY SUMMARY

9.1.1 Atlantic Sturgeon

The Atlantic sturgeon (Acipenser oxyrhynchus) is an anadromous species that is distributed along the Atlantic coast of North America from Labrador to Florida (Scott and Crossman 1973). Spawning occurs in rivers and estuaries, and the young remain in these environs during their early years before migrating to sea where they grow to maturity. The flesh of this species is highly desirable as food and the eggs are marketed as caviar. However, a serious decline in numbers in the United States during the early 1900s caused a sharp reduction in the commercial catch. Scott and Crossman (1973) stated that many factors affected this decline, including sale of the young, destruction of young (less than 5 lb) that damaged shad nets, decrease in demand owing to increased prices, and the use of newer gear that does not capture this species. Curran and Ries (1937) noted that, at about the turn of the century, "a scourge of 'sturgeon cholera'" was reputed to have killed a great number of this species. Although the fishery in the United States has shown considerable recovery in recent years, yearly catches are only about half as large as those of the 1880s (Scott and Crossman 1973).

Atlantic sturgeon spawn in the spring. Bigelow and Schroeder (1953) reported that in the Gulf of Maine adult Atlantic sturgeon enter freshwater rivers and migrate above tidewater where they spawn during May and June and perhaps as late as July. In the Hudson River, mature individuals 10-12 years old have been collected in freshwater portions of the estuary between Highland and Saugerties (RM 76-101) (Greeley 1937). Boyle (1969) stated that adult sturgeon enter the Hudson River to spawn from April through June and possibly in July. In the Delaware River, Atlantic sturgeon were observed spawning in the upper part of the river, where the bottom is hard clay, at temperatures ranging from 13.3 to 17.8 C during late May (Borodin 1925). Female Atlantic sturgeon produce 1-2.5 million eggs for each year's spawning. The eggs are heavy and strongly adhesive, sticking to each other and to the river bed, where they lie in large masses (Dees 1961). Vladykov and Greeley (1963) reported that eggs hatch in about a week at a temperature of 17.8 C.

Sturgeon young live on their yolk sac until about 20 mm long, then begin to feed on planktonic crustacea; at a length of 230 mm (9 in.) they become bottom feeders (Dees 1961). Young Atlantic sturgeon remain in freshwater for several years before going to sea (Scott and Crossman 1973). Greeley (1937) reported collections of immature specimens up to 8 years of age in freshwater portions of the Hudson River estuary near Kingston (RM 93) and indicated that the older individuals would soon migrate to sea, possibly to feed for several years before returning to the river to spawn.

9.1.2 Shortnose Sturgeon

Distribution of the shortnose sturgeon (*Acipenser brevirostrum*) is restricted to the Atlantic coast of North America from the St. John River, New Brunswick, to the St. Johns River, Florida (Vladykov and Greeley 1963). Less migratory than the Atlantic sturgeon, it apparently spends most of its life in large tidal rivers, but has been taken in salt water (Scott and Crossman 1973). Greeley (1937) reported that the shortnose sturgeon "is apparently a permanent resident of the freshwater areas" of the Hudson River and further noted that "there is no evidence that it was ever exceedingly numerous." The U.S. Department of Interior has placed the shortnose sturgeon on its list of endangered species. Boyce Thompson Institute is currently conducting studies to evaluate the current status of the shortnose sturgeon population in the Hudson River.

Dadswell (1975) reported that shortnose sturgeon was probably solely an estuarine fish and identified a definite seasonal migratory pattern within the St. John estuary, New Brunswick. Shortnose sturgeon overwintered in estuarine lakes and deep saline regions of the lower St. John estuary characterized by salinities as high as 20 ppt and water temperatures of 4-8 C. In late April the fish left the overwintering areas and concentrated in the river channels to spawn. Around mid-June, shortnose sturgeon moved upstream and shoreward into feeding grounds characterized by abundant macrophytes, where they fed principally on gastropods. By August the shortnose sturgeon had vacated the channels entirely, and during fall, they returned to the lower estuary where they remained throughout the winter. Dadswell (1975) further reported that, during both summer and winter, shortnose sturgeon selected habitats in the warmest regions available over a salinity range of 1-20 ppt. The highest summer abundance of shortnose sturgeon was in the midestuary where salinities averaged 1 ppt.

Scott and Crossman (1973) reported that shortnose sturgeon spawn in the spring, in the middle reaches of large tidal rivers, from April to early June depending on location. Greeley (1937) collected both ripe and spent shortnose sturgeon in the lower Hudson River during late April, and primarily caught spent fish during May. Dadswell (1975) reported that spawning takes place in the St. John River, New Brunswick, between 15 May and 15 June in the main river channels at temperatures of approximately 10 C. He observed shortnose sturgeon choosing spawning sites in the upper estuary, adjacent to deep, turbulent sections of the river.

Salinity in these areas was between 0.5 and 3 ppt. Like other sturgeon, the shortnose have demersal, adhesive eggs (Vladykov and Greeley 1963).

In the Hudson River, male shortnose sturgeon have been reported to mature at a size of about 52 cm (20 in.) in their fifth year, and females at about 56 cm (24 in.) in their sixth year (Vladykov and Greeley 1963). Dadswell (1975) reported that shortnose in the St. John River appeared to mature at a similar size, but at 7-10 years of age. He further stated that once mature, female shortnose ripen slowly. The minimum time necessary for each spawning period in the St. John River was 3 years after the first or subsequent spawnings (Dadswell 1975).

9.2 TEMPERATURE REQUIREMENTS

To date, the temperature tolerances and requirements of the Atlantic and shortnose sturgeons have not been studied.

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CHAPTER 10: BAY ANCHOVY

10.1 LIFE HISTORY SUMMARY

The bay anchovy (Anchoa mitchelli) is a small, euryhaline, schooling fish that occurs in estuaries and coastal waters of North America from Maine to Yucatan, Mexico (Mansueti and Hardy 1967). Juveniles and adults are found in all types of environments: muddy coves, grassy areas, bayous, off sandy beaches, and in deep offshore waters (Dovel 1971). Thomson et al. (1971) reported that the bay anchovy is probably a year-round resident in Long Island Sound, exhibiting seasonal onshore-offshore movements. Hildebrand and Schroeder (1928) similarly reported that bay anchovy remain in the Chesapeake Bay throughout the year, concentrating in deeper water during colder months. The life span of the bay anchovy is about 2 years (Stevenson 1958). Individuals may spawn when 2.5 and 3 months old (Hildebrand and Cable 1930), although the majority of spawners are yearlings or older (Stevenson 1958).

Bay anchovy spawn primarily in coastal harbors and bays, and in the mouths of estuaries (Perlmutter 1939; Stevenson 1958; Dovel 1971; Texas Instruments 1976); they have also been observed spawning along the outer banks near Beaufort, North Carolina (Kuntz 1914). In Long Island Sound, the spawning season was reported by Perlmutter (1939) to extend from May through August, reaching a peak in late July. Dovel (1971) reported a similar spawning peak in late July in the Chesapeake Bay, and collected eggs as early as 22 April and as late as 27 September. Dovel (1971) observed that most spawning occurred at temperatures extending from 20 C to maximum summer temperatures and salinities of 13-15 ppt, although some eggs were collected at salinities as low as 1 ppt. Perlmutter (1939) found eggs in Long Island Sound at temperatures ranging from 12.2 to 26.7 C, and Texas Instruments (1976) collected eggs in the lower Hudson River estuary (RM 14-33) at temperatures ranging from 25.4 to 27.3 C. Bay anchovy eggs are buoyant when newly spawned, apparently becoming demersal with advancing development, and hatch in 24 hours at 27.2-27.8 C (Kuntz 1914).

After hatching, bay anchovy larvae move upstream into lower salinity nursery areas, and continue this upstream and shoreward movement as juveniles (Dovel 1971; Texas Instruments 1976). Although juveniles have been reported to ascend rivers at least 40 mi above brackish water (Massman 1954), the majority of bay anchovy juveniles remain in waters with salinities ranging from 3 to 7 ppt. Dovel (1971) and Texas Instruments (1976) observed that young bay anchovy appeared to move upstream with increased saltwater intrusion and concentrate within preferred low-salinity regimes. Dovel (1971) reported that 88 percent of all larvae and juveniles collected in the Chesapeake Bay (1963-1967) were taken in water temperatures from 23 to 27 C, and some were found at temperatures up to 31 C. Smith (1971) collected juveniles in tidal tributaries of the Delaware River estuary at temperatures as high as 32.5 C. Juveniles move offshore and downstream as waters cool in fall (Stevenson 1958; Dovel 1971; Smith 1971; Texas Instruments 1976). Texas Instruments (1976) also observed that adults remained in the lower Hudson River estuary until fall, occurring most abundantly in the more saline regions.

10.2 TEMPERATURE REQUIREMENTS FOR EARLY DEVELOPMENT

Houde (1974) reared bay anchovy larvae at four constant temperatures ranging from 24 to 32 C and at salinities from 31 to 35 ppt for 7 days following hatch. The highest growth rate was observed at 32 C when feeding began after hatching, with larvae increasing from 2.9 to 8.16 mm in 7 days. Houde (1974) further concluded that larvae reared at the higher temperatures required food much sooner than those reared at lower temperatures. Larvae reared at 24 C could survive if fed 40 hours after hatching, whereas larvae reared at 32 C required food within 16 hours. These results indicate that the optimum temperature for early development ranges to at least 32 C when adequate amounts of food are available.

10.3 TEMPERATURE AS A FACTOR DETERMINING BEHAVIOR

10.3.1 Temperature Avoidance

Upper avoidance temperatures of bay anchovy adults have been determined by Meldrim et al. (1974) and Wyllie et al. (1976), as summarized in Figure 10-1. Similar results were reported in both studies, with avoidance temperatures ranging from 24 to 32 C for fish acclimated to river temperatures of 15-27 C. Bay anchovy adults were observed avoiding temperatures 3-14.2 C above ambient river temperatures. Wyllie et al. (1976) tested adults acclimated to 10 C, but were unable to determine the upper avoidance temperature due to low thermal responsiveness, indicating that at these low acclimation temperatures bay anchovy are unable to avoid stressful temperatures under laboratory testing conditions.

10.3.2 Temperature Preference

Several short-term preference experiments were conducted by Meldrim and Gift (1971) and Wyllie et al. (1976), as summarized in Figure 10-2. Preferred temperatures ranged from 15.6 to 30.0 C for fish acclimated to river temperatures of 10-22 C; temperatures higher than river ambient were typically preferred. Wyllie et al. (1976) reported that bay anchovy often did not appear to prefer a single temperature, but chose a broad range of preferred temperatures (Figure 10-2).

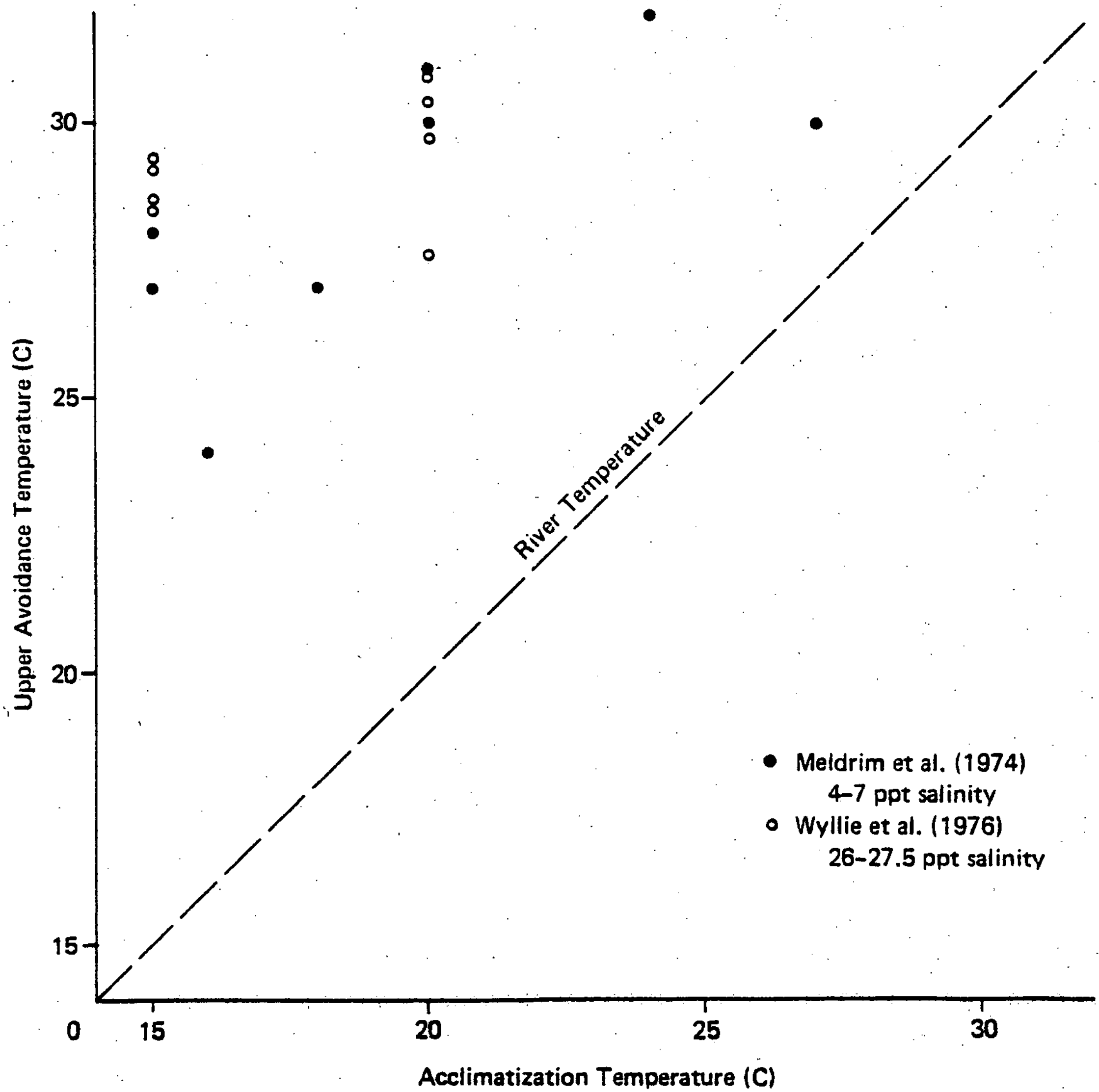

Figure 10-1. Upper avoidance temperatures for bay anchovy adults.

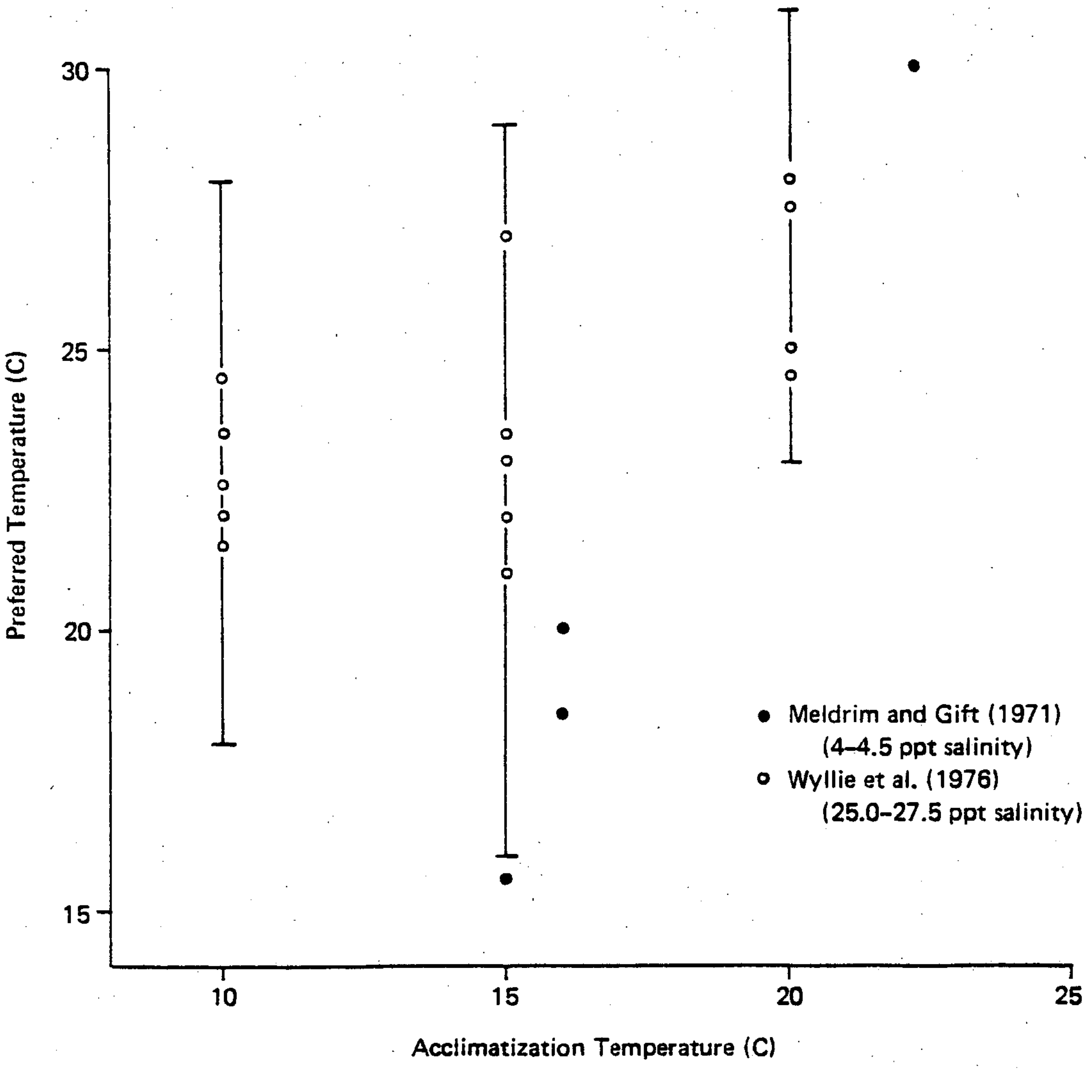

Figure 10-2. Mean preferred temperatures of bay anchovy adults; maximum range bars (I) are shown for results of replicates reported by Wyllie et al. (1976).

Gallaway and Strawn (1974) studied the distribution of bay anchovies in a hotwater discharge in Galveston Bay, Texas, and found that they preferred water temperatures between 24.5 and 32.5 C. Although bay anchovies were collected at temperatures as high as 37 C, they were never abundant in waters with temperatures greater than 33 C.

10.4 LOWER THERMAL TOLERANCE LIMITS

Wyllie et al. (1976) conducted cold shock experiments on bay anchovies (35-90 mm) acclimated to 15 and 20 C at 26-27.5 ppt salinity. The results are shown below:

Acclimation Temperature (C)	Test Temperature (C)	Percent Mortality	Time From Start of Test (Hours)
20	20 (control)	0	168
20	15	0	168
20	10	60	168
20	5	100	1
15	15 (control)	20	168
15	10	40	120
15	7	80	144
15	5	100	46

A sudden decrease in temperature from 15-20 C to 10 C resulted in increased mortality compared to controls. Complete mortality was observed in both tests following a drop in temperature to 5 C. These results indicate that the bay anchovy is relatively intolerant to cold temperatures, which probably explains its migration into the deeper, warmer waters of the lower portions of estuaries and bays during the fall months.

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CHAPTER 11: WEAKFISH

11.1 LIFE HISTORY SUMMARY

The weakfish (Cynoscion regalis) is a marine species occurring along the Atlantic coast of the United States from Massachusetts Bay to eastern Florida, and is an important sport and commercial species in the middle Atlantic area, including New York coastal waters (Perlmutter et al. 1956). The adults generally remain near the coast in shallow waters along open sandy shores and in the larger bays and estuaries (Welsh and Breder 1924; Bigelow and Schroeder 1953).

On the middle Atlantic coast, weakfish spawn primarily in larger estuaries or near their mouths during late spring and summer (Bigelow and Schroeder 1953). Weakfish eggs have been collected at temperatures ranging from 15.5 to 26.5 C and at salinities of 12.1-31.3 ppt (Welsh and Breder 1924; Harmic 1958). The period of incubation at water temperatures of 20-21 C is 36-40 hours (Welsh and Breder 1924). Thomas (1971) stated that, in the Delaware River estuary, newly hatched larvae sink to the bottom and are transported to upstream nursery areas by subsurface tidal flow, where they remain during the warmer summer and fall months; most young-of-the-year weakfish had left the Delaware River by late fall when temperatures dropped below 8 C. In the Hudson River estuary, young weakfish similarly move upstream from coastal spawning areas near the mouth of the estuary into the brackish portion of the estuary where they remain until temperatures decrease during late fall (Texas Instruments 1976).

11.2 TEMPERATURE AS A FACTOR DETERMINING BEHAVIOR

Although no thermal tolerance limits for weakfish have been reported in the literature, extensive behavioral studies have been conducted on preference and avoidance responses to temperature. A continuation of the Meldrim et al. (1974) study has produced results for 60 separate avoidance experiments on juvenile weakfish over a salinity range from 3.5 to 10.5 ppt, and an acclimatization temperature range from 16 to 31 C (Public Service Electric and Gas Company, personal communication). The avoidance temperature was characteristically related to acclimatization temperature, and typically ranged from 3 to 7 C above summer ambient river temperatures. Results of 31 short-term preference tests conducted over similar salinities and acclimatization temperatures indicated that weakfish exhibited an initial preference response ranging from 20 to 29 C. Results of these short-term tests conducted at high acclimatization temperatures closely agreed with the final preferendum (6-day test) of weakfish, 26.7 C, tested at 28 ppt salinity by Wyllie et al. (1976), as shown in Figure 11-1.

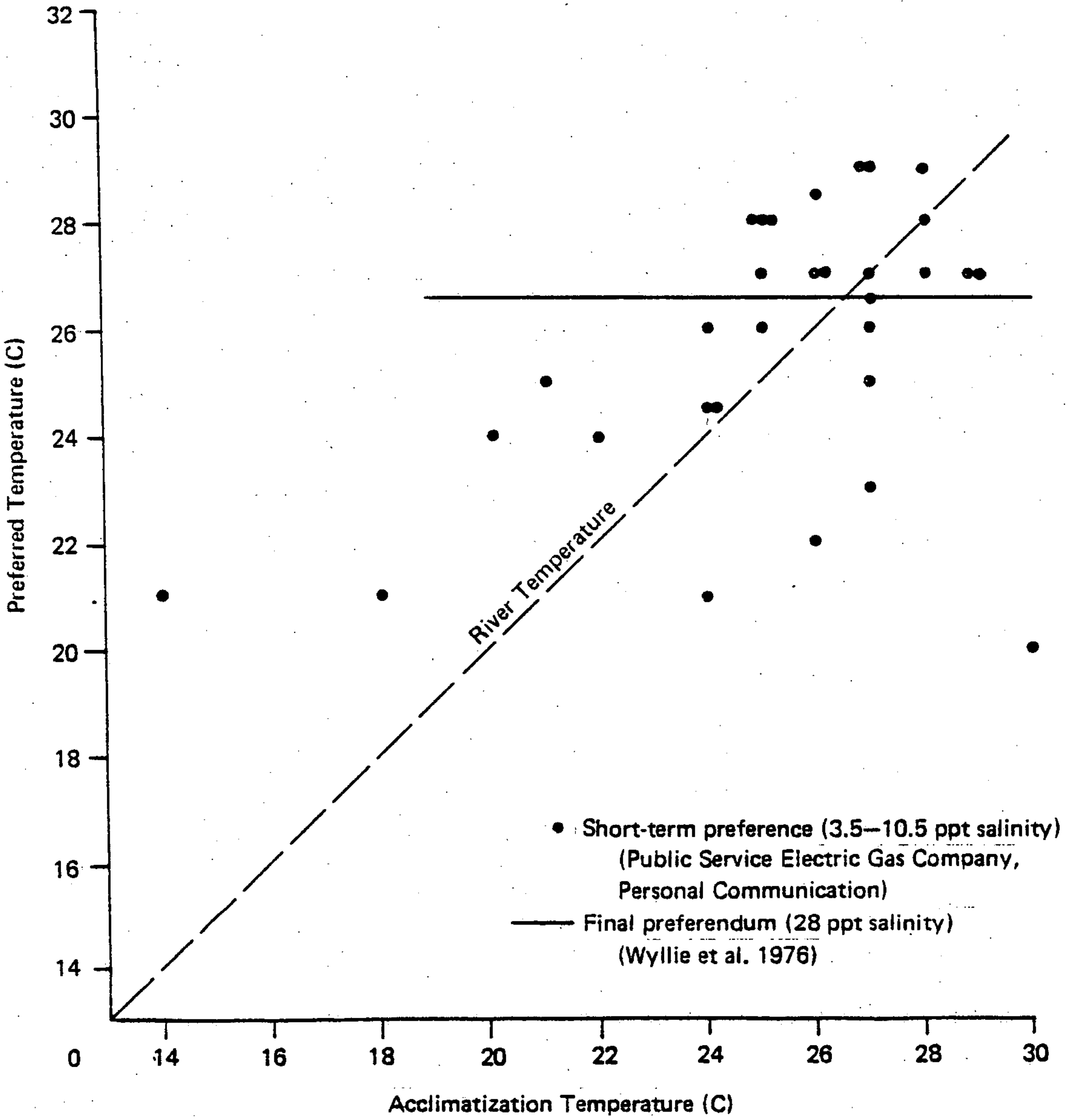

Figure 11-1. Preferred temperatures of juvenile weakfish.

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CHAPTER 12: OPOSSUM SHRIMP

12.1 LIFE HISTORY SUMMARY

The opossum shrimp (Neomysis americana) is the most common mysid inhabiting the northeastern estuaries and inshore coastal waters of the United States (Hopkins 1958) and is the most abundant mysid in the western North Atlantic Ocean. It is strictly a North American species, and ranges from the Gulf of St. Lawrence to northeastern Florida (Williams et al. 1974). The opossum shrimp is a shallow water species most commonly reported from the intertidal zone to depths of 60 m (Wigley and Burns 1971). During the day, opossum shrimp are primarily distributed in the bottom water strata (Herman 1963); however, at night they migrate toward the surface (Hulbert 1957; Herman 1963; Ginn 1977), often exhibiting a midnight sinking and a dawn rise (Herman 1963).

Light intensity has been found to be the most important single factor controlling this diel vertical migration, although migration patterns may be modified slightly by peak summer temperatures. Herman (1963) observed that opossum shrimp ascended normally as light levels decreased during July and August, but then returned to lower, cooler levels when the light disappeared. He also reported that mature opossum shrimp migrated only during the spawning season, whereas immature and young forms migrated throughout most of the year.

In a Hudson River survey from the upper bay of New York Harbor to Poughkeepsie, Hopkins (unpublished) collected opossum shrimp in a wide range of salinities from less than 1 ppt to 25 ppt, and at temperatures ranging from 6.5 to 31 C. In the Bowline Point vicinity of the Hudson River (river mile 38), opossum shrimp have been collected at surface salinities of 0.4 ppt (corresponding to a bottom salinity of 1.5 ppt) while they were totally absent at levels less than 0.2 ppt (Orange and Rockland Utilities 1977). The occurrence of the opossum shrimp at Indian Point (river mile 42) also coincides with summer salt intrusions (Howells et al. 1971; Ginn 1977), with peak abundances occurring at salinities greater than 3-4 ppt (New York University Medical Center 1973; Lauer et al. 1974). Hulbert (1957) reported that the upstream penetration of opossum shrimp into the Delaware River estuary was limited by roughly 4 ppt salinity.

At Indian River Inlet, Delaware, the spawning period of opossum shrimp extends from spring through fall, though females with eggs or larvae have been caught every month of the year (Hopkins 1958). Hopkins (1965) reported three major brood releases: April-May, June, and August. Similar spawning seasons have been reported by Wigley and Burns (1971) for the Georges Bank stocks and by Hulburt (1957) for the Delaware River estuary. Increased numbers of young collected at Indian Point in the Hudson River estuary from August to October (Ginn 1977) indicate that spawning periods in the Hudson River are probably similar to those reported by Hopkins (1958).

12.2 UPPER THERMAL TOLERANCE LIMITS

Mihursky and Kennedy (1967a) reported that the opossum shrimp was the least temperature-tolerant species among seven common estuarine invertebrates tested at an acclimation temperature of 15-16 C. The 24-hour TL50s for opossum shrimp ranged from 15 to 34 C, depending on acclimation temperature (Mihursky and Kennedy 1967b) as shown below:

Acclimation Temperature (T_a)* (C)	24-Hour TL50 (C)	TL50 minus T_a (C)
1-3	15-19	14-16
5	21	16
10	20-22	10-12
15	24-28	9-13
25	28-30	3-5
30	32-34	2-4

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* Salinity not defined

A comparison between 24-hour TL50s for _N_. _americana_ and _Crangon septemspinosa_ reveals that, at higher acclimation temperatures, _N_. _americana_ is slightly more tolerant than _C_. _septemspinosa_. Similar tolerance limits were reported by New York University Medical Center (1973) for short-term exposures conducted to assess Hudson River power plant entrainment impact. The 5- and 30-minute TL50s were 34 and 33 C, respectively, for shrimp acclimated to ambient river temperatures ranging from 24.2 to 25.7 C; TL95s were 32.5 and 31.7 C for 5- and 30-minute exposures, respectively.

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CHAPTER 13: SAND SHRIMP

13.1 LIFE HISTORY SUMMARY

The sand shrimp (*Crangon septemspinosa*) is a common inhabitant of estuaries and nearshore coastal waters and has been collected along the northwestern Atlantic from Newfoundland to eastern Florida (Price 1962; Williams 1965). They are normally found near the bottom in waters ranging from 4.4 to 32.3 ppt salinity and at temperatures ranging from 0.0 to 26.0 C (Price 1962; Sandifer 1972; Embich 1973; Haefner 1973). The larvae have been reported to be pelagic during early stages of their existence (Sage and Herman 1972). Field collections in the Hudson River from the upper bay of New York Harbor to Poughkeepsie revealed that both larval and mature sand shrimp were common in the Hudson River, but never abundant (Hopkins, unpublished). The occurrence of the sand shrimp in the Hudson River near the Indian Point Nuclear Generating Station coincides closely with fluctuations of the saltwater intrusions into the area (New York University Medical Center 1974).

Sand shrimp become sexually mature shortly after their first year and apparently live to a maximum of 2-3.5 years (Price 1962; Embich 1973). In the shore zone of the Delaware Bay, Price (1962) reported that the spawning season extended from March to October, with ovigerous females appearing year-round, except in December, at temperatures ranging from 0.0 to 25.0 C. The percent of females bearing eggs was highest in May and mid-July (39 and 56 percent, respectively); however, the larger egg masses carried in May actually represented a higher index of population production, resulting in a spring spawning peak (Price 1962). Haefner (1976) reported a single extended spawning season from November through June in the southern Chesapeake Bay area, whereas Cowles

(1930) found ovigerous females during all seasons of the year, with lowest incidences during summer.

Reproduction and early development of the sand shrimp appear to be limited to higher salinity areas within estuaries. Price (1962) observed that berried females were collected at salinities of 17.7-29.3 ppt, whereas other adults were collected at salinities ranging from 4.4 to 31.4 ppt. Regnault and Costlow (1970) were not able to rear sand shrimp larvae in the laboratory at salinities of 10 and 15 ppt for more than 24 hours, and at 35 ppt, most larvae died before the first molt. Salinities from 20 to 30 ppt were optimal for larval survival and development (Regnault and Costlow 1970). In other studies, sand shrimp larvae have been collected from estuarine areas at salinities as low as 4-8 ppt during low tide (Embich 1973).

Haefner (1976) reported that sand shrimp in the York River (Chesapeake Bay) appear to migrate to deeper areas within estuaries as water temperatures decrease below 15 C. Maximum concentrations occurred in the channel when bottom temperatures were between 5 and 11 C. Shrimp were restricted to the more saline reaches of the estuary as temperatures fell below 5 C. As temperatures warmed above 10 C in the spring, migration to shallower waters was observed (Haefner 1976). Embich (1973) similarly reported that, in the Penobscot River region of the Gulf of Maine, sand shrimp responded to seasonal rising and falling temperatures with inshore and offshore migrations.

13.2 UPPER THERMAL TOLERANCE LIMITS

Sand shrimp are relatively temperature sensitive compared to other estuarine invertebrate organisms common to coastal areas of the northeastern United States (Mihursky and Kennedy 1967a). The 24-hour TL50s for the sand shrimp ranged from 28 to 31 C; only slight increases in the TL50s with increasing acclimation temperature were exhibited (Mihursky and Kennedy 1967b), as shown below:

Acclimation Temperature (T_a)* (C)	24-Hour TL50 (C)	TL50 minus T_a (C)
15	28	13
20	27-28	7-8
25	29-30	4-5
30	31	1

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* Salinity was not defined.

Sand shrimp acclimated to temperatures ranging from 10.2 to 15 C tolerated a temperature increase at the rate of 1 C per 5 minutes until temperatures approached 30 C (Huntsman and Sparks 1924). Irregular respiratory movements were observed at temperatures ranging from 29 to 30.4 C, and death occurred at temperatures ranging from 30 to 32.5 C.

13.3 OPTIMUM TEMPERATURE FOR PHYSIOLOGICAL FUNCTIONS

Regnault and Costlow (1970) reported that sand shrimp larvae reared at a constant temperature of 25 C and a 24-hour cyclic temperature of 25-30 C did not survive beyond 24 hours. Survival was enhanced by higher salinities when reared at a diurnal temperature cycle ranging from 20 to 25 C; survival at 20 ppt salinity was 6 percent, whereas survival at 30 ppt was 26 percent. A temperature of about 20 C was judged to be optimal for larval development and survival.

Results of 96-hour temperature-salinity tolerance studies conducted by Haefner (1969) on adult sand shrimp indicated that mortality was consistently higher at 23 C than at 4 and 15 C for all salinities tested (ranging from 5 to 40 ppt). Lowest mortality occurred at 35 ppt and 15 C. In similar studies investigating the effect of low dissolved oxygen concentrations (2-3 mg/l) on the temperature-salinity tolerance of the sand shrimp, Haefner (1970) observed a noticeable shift of the tolerance zones toward lower temperatures and higher salinities after a reduction in oxygen concentration.

The growth rate of the sand shrimp in Rhode Island waters was found to be directly proportional to water temperature (Wilcox and Jeffries 1973). For individuals 20-30 mm long, growth was less than 0.4 mm per week during the winter (average water temperature of 5 C) and greater than 1.1 mm per week during the summer (20 C). These findings differ with the observations of Price (1962), who noted that the growth of shrimp in the Delaware Bay was 0.4 mm per week for both winter and summer (0-27 C temperature range). Price (1962) speculated that, since the sand shrimp is a cold water species and the Delaware Bay region is near the southern limit of its range, the expected increase in growth rates with higher temperatures may be reduced by possible increased energy demands of reproduction, and by the high metabolic demands of a species that is generally adapted to low temperatures.

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CHAPTER 14: *GAMMARUS SPP*.

14.1 LIFE HISTORY SUMMARY

Three species of gammarid amphipods found along the Atlantic coast of North America have been reported to inhabit the Hudson River estuary: *Gammarus fasciatus*, *G. tigrinus*, and *G. daiberi* (Ginn 1977; Ristich et al. 1977). *G. fasciatus* is a freshwater species found in coastal drainages from Cape Cod and southern New England south to tributaries of the Chesapeake Bay, in lakes and rivers of the St. Lawrence River system (Bousfield 1958, 1973), and in the Great Lakes (Clemens 1950). *G. daiberi* ranges from the Hudson River to South Carolina. *G. tigrinus* ranges from southern Labrador south to Chesapeake Bay, although it is found intermittently in coastal areas south to Florida (Bousfield 1973).

The distribution of the three species of *Gammarus* that occur in the Hudson River varies with salinity and depth. *G. fasciatus* is a freshwater species generally confined to upriver portions of the Hudson River estuary (Ginn 1977) but can occur at salinities up to 3 ppt (Bousfield 1973). *G. daiberi* is the most abundant amphipod in the Hudson River (Ginn 1977), and occurs at salinities up to 20 ppt, with greatest abundance between 0 and 5 ppt (Feeley and Wass 1971). *G. tigrinus* was the least abundant amphipod collected by Ginn (1977) in the Hudson River estuary, and has been reported to occur at salinities ranging from 1 to 25 ppt (Bousfield 1973). Although each species has been observed to have both a benthic and a pelagic existence, *G. daiberi* is largely pelagic, *G. fasciatus* is benthic and semipelagic, and *G. tigrinus* is essentially benthic (Bousfield 1973). *Gammarus* spp. are generally more abundant in the water column during the night than during the day (Orange and Rockland Utilities 1977).

All three species of Hudson River Gammarus complete their life cycle in a single year (Steele and Steele 1972; Bousfield 1973). The breeding season, as indicated by the occurrence of ovigerous females and the appearance of young, extends from early spring into fall (Embody 1912; Clemens 1950; Bousfield 1973). Females of each species are potentially capable of producing several broods during this breeding season (Embody 1912; Clemens 1950; Bousfield 1973; Ginn 1977).

Based on field studies conducted on Lake Erie, Clemens (1950) reported collecting G. fasciatus females bearing eggs during the early spring at temperatures as low as 4 C and at 10 C in the fall. The period of incubation, as determined from the day of ovulation to the day when the young were released from the brood pouch, ranged from 7 days at 24 C to 22 days at 15 C. The average interval between molts of G. fasciatus from the first to the seventh molt was dependent on temperature, as shown below:

Temperature (C)	Average Interval Between Molts (days)
25	3.1-5.7
21	4.7-11.7
18	6.3-11.4
14-22	6.2-13.3

In the laboratory, Clemens (1950) determined that G. fasciatus required 42-53 days to reach maturity at 21 C, and 66-85 days at temperatures varying from 14 to 22 C.

14.2 UPPER THERMAL TOLERANCE LIMITS

14.2.1 Incipient Lethal Temperatures

Temperature tolerance limits reported for G. fasciatus and Gammarus spp. (G. daiberi and G. tigrinus) vary only slightly over the range of ambient temperatures investigated. The 24- and 48-hour TL50 values ranged from 30.5 C for G. fasciatus acclimated to 10-15 C, to 33 C for Gammarus spp. acclimated to 25 C, as shown below:

Species	Acclimation Temperature (C)	Exposure Time (hours)	TL50 (C)	Reference
G. fasciatus	10	24	30-31 (30.5)	Mihursky and Kennedy (1967)
G. fasciatus	15	24	31-32 (31.5)	Mihursky and Kennedy (1967)
Gammarus spp.	25	48	33	NYU (1973), Ginn et al. (1974)

A 17-day exposure of Gammarus spp. (G. daiberi and G. tigrinus) to a 15.6 C elevation above ambient (10 C) produced no mortality and actually stimulated reproductive activities during November and December when ovigerous females were not normally observed in the river (Ginn et al. 1976; Ginn 1977). Sprague (1963) reported that female G. fasciatus were more resistant to elevated temperatures than were males when acclimated to 10 C, but this difference was small at a 20 C acclimation temperature. He further reported that resistance times decreased with increasing size. Based on thermal tolerance tests performed at 10 and 20 C acclimation temperature, Sprague (1963) estimated the ultimate 48-hour TL50 for G. fasciatus as 33.0 C.

14.2.2 Thermal Tolerance to Entrainment Exposure--Laboratory Studies

The tolerance of Gammarus spp. (G. daiberi and G. tigrinus) exposed to short-term temperature elevations has been investigated for Hudson River species with respect to the effects of power plant entrainment. New York University Medical Center (1973) determined thermal tolerance limits for 5-, 30-, and 60-minute exposure periods in the laboratory. Test organisms acclimatized to 2.5-20.0 C were examined for viability 1 hour after thermal exposure; organisms acclimatized to 25.5 C were held at ambient temperature in the laboratory for examination 24 hours after thermal tolerance tests. Thermal tolerance limits were directly related to acclimatization temperatures, as shown below:

Acclimatization Temperature (C)	5-Minute Exposure (C)		30-Minute Exposure (C)		60-Minute Exposure (C)	
	TL95	TL50	TL95	TL50	TL95	TL50
2.5	--	--	25.5	27.5	--	--
11.0	30.5	33.0	29.0	31.0	28.0	30.0
20.0	34.0	35.5	33.5	34.7	33.0	34.3
25.5	38.0	38.7	37.2	37.8	36.0	36.8

Ginn et al. (1976) reported results for similar experiments, but made latent effects observations over a longer period of time following exposure. He reported that

> Gammarus spp. experienced no increased latent mortalities for periods up to 10 days after being exposed to an 8.3 C delta-T above an ambient temperature of 25.5 C for periods up to 60 minutes. An 11.1 C delta-T above an ambient temperature of 26.5 C resulted in significant reductions in survival in groups of Gammarus spp. exposed for 30 and 60 minutes. No significant mortalities were observed, however, following a 5-minute exposure to the 11.1 C delta-T. At an ambient temperature of 11.7 C, Gammarus spp. exposed to 16.7 C delta-Ts for periods up to 180 minutes displayed no increased mortalities 10 days after exposure.

Ginn et al. (1976) additionally noted that

> reproductive activities were not affected by up to 60-minute exposures of mature *Gammarus* spp. to an 8.3 C delta-T at an ambient temperature of 26.0 C. The same exposure also did not affect the release of young by ovigerous female *Gammarus* spp. An 11.0 C delta-T for 30 minutes resulted, however, in almost no release of young from ovigerous females.

Burton et al. (1976) found that *Gammarus* spp. from the Patuxent River, Maryland, were not affected by temperature exposures simulating entrainment through a steam-electric generating station. *Gammarus* spp. acclimated to 5, 15, and 25 C were exposed to a rapid 5 C increase above ambient, held for 4 minutes at the elevated temperature, and then cooled to the ambient river temperature over a 15-minute period. No immediate or latent mortality (up to 24 hours after exposure) was observed.

14.2.3 Thermal Tolerance to Entrainment Exposure--Field Studies

Actual plume transit studies conducted at the Indian Point Power Station in the Hudson River indicated that *Gammarus* spp. could tolerate entrainment in the discharge plume without adverse effects. Differences in survival between control and experimental organisms were not observed 5 days following plume exposure when discharge temperatures were 32.1 and 33.0 C (when ambient temperatures were 24 and 25.8 C, respectively) (Lanza et al. 1974).

14.3 TEMPERATURE AS A FACTOR DETERMINING BEHAVIOR

Ginn (1977) conducted temperature avoidance tests by observing the distribution of *G. daiberi* for 60 minutes in a thermal gradient with a maximum temperature of 33.7 C and a minimum temperature of 26.4-26.6 C (ambient). He reported that *G. daiberi* exhibited partial avoidance to 29.9 C and nearly complete avoidance to temperatures exceeding 31.7 C (delta-T = 5.3 C). At lower ambient temperatures (15.3-15.7 C), G. daiberi did not exhibit any avoidance response to a temperature of 22.8 C (delta-T = 7.1 C), the highest temperature available in the gradient during the test.

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CHAPTER 15: *CHAOBORUS SPP.*

15.1 LIFE HISTORY SUMMARY

Chaoborus spp., members of the family Diptera, range throughout the continental United States. This group is commonly referred to as the phantom midges and live the majority of their life cycle as larvae in lakes, ponds, and slow-moving water bodies. Two species of *Chaoborus*, *C. punctipennis* and *C. albipes*, have been reported in the Hudson River estuary (Hopkins, unpublished; Orange and Rockland Utilities, 1977). Hopkins (unpublished) reported that *C. albipes* was restricted to the freshwater zone of the estuary.

The adults emerge from the water from mid-spring through summer (Wood 1956; Stahl 1966), lay their eggs on the surface of the water in gelatinous discs (Johannsen 1969), and die. The adults do not feed after emergence (Pennak 1953). After hatching, the larvae are planktonic through the first two instars (Wood 1956). The larvae overwinter in the deeper sediments during the third or fourth (final) instar prior to emerging as adults the following spring and summer (Roth 1968).

The larval instars of *Chaoborus* spp. exhibit a behavioral pattern of diurnal vertical migration. The first two instars are entirely planktonic, whereas the third and fourth instars are usually benthic during the day and planktonic at night (Wood 1956). All four larval instars migrate to the surface waters a short time before sunset and return to the bottom sediments (third and fourth instars) or to a lower strata (first and second instars) shortly before sunrise (Wood 1956). During the day, the older instars remain buried in the mud at a depth determined by the light intensity at the mud-water interface (LaRow 1969). Laboratory experiments revealed that low light intensity stimulated Chaoborus larvae to emerge from the mud (LaRow 1969), while low oxygen concentrations near the mud-water interface stimulated vertical migration (LaRow 1970). This 24-hour rhythm is maintained until water temperatures reach 5 C, when activity ceases; in the spring, when water temperature rises above 5 C, the rhythm begins again (LaRow 1969).

15.2 UPPER THERMAL TOLERANCE LIMITS

Temperature tolerance of Chaoborus spp. was investigated by New York University (1974) for short-term exposures conducted to assess Hudson River power plant entrainment impact. The survival of Chaoborus larvae acclimated to ambient river temperature (25.3 C) following a 30-minute exposure to elevated temperatures is shown below:

Test Temperature (C)	ΔT (C)	Percent Survival
25.3 (control)	0	100
34.5	9.2	100
37.8	12.5	100
38.9	13.6	100
41.1	15.8	76.2
41.7	16.4	4.25

Mortality was assessed 1 hour after exposure. These results indicate that Chaoborus larvae are extremely tolerant to temperature extremes, with a 76.2 percent survival after a 30-minute exposure to 41.1 C.

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