HUDSON RIVER THERMAL EFFECTS STUDIES FOR REPRESENTATIVE SPECIES

Final Report

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CHAPTER 1: INTRODUCTION

1.1 PURPOSE OF REPORT

During 1976 and 1977, Ecological Analysts, Inc. (EA) was contracted by Central Hudson Gas & Electric Corporation, Consolidated Edison Company of New York, Inc., and Orange and Rockland Utilities, Inc., to perform laboratory studies designed to evaluate the thermal effects of heated discharges on Hudson River representative important species (RIS). These RIS (Table 1.1-1) were designated by the EPA as representative of the balanced indigenous community of shellfish, fish, and wildlife in and on the Hudson River. The results of these studies, together with thermal effects information drawn from the general literature as reviewed and summarized by EA (1978a), are used to predictively evaluate the effects of power plant thermal discharges on Hudson River biota which will be addressed in thermal discharge demonstrations pursuant to Section 316(a) of the Federal Water Pollution Control Act Amendments of 1972 (PL92-500).

TABLE 1.1-1 REPRESENTATIVE IMPORTANT SPECIES DESIGNATED BY THE U.S. EPA FOR HUDSON RIVER POWER PLANTS

Common Name	Scientific Name
Striped bass	*Morone saxatilis*
White perch	*Morone americana*
Atlantic tomcod	*Microgadus tomcod*
Alewife	*Alosa pseudoharengus*
White catfish	*Ictalurus catus*
Spottail shiner	*Notropis hudsonius*
Atlantic sturgeon	*Acipenser oxyrhynchus*
Shortnose sturgeon	*Acipenser brevirostrum*
Bay anchovy(a)	*Anchoa mitchilli*
Weakfish(a)	*Cynoscion regalis*
Scud	*Gammarus* spp.
Opossum shrimp(a)	*Neomysis americana*
Sand shrimp(a)	*Crangon septemspinosa*
Phantom midge-fly(b)	*Chaoborus* spp.
Bluegreen algae	Cyanophyta

(a) designated only for the Indian Point and Bowline Generating Stations.
(b) designated only for the Roseton Generating Station.

1.2 SCOPE OF REPORT

Thermal effects studies conducted during this investigation were designed specifically to fulfill information requests for a Type-II 316(a) demonstration, as described in the EPA's 316(a) draft Technical Guidance Manual, issued 30 September 1974. To address these information requests, the following specific study efforts were conducted:

1. Entrainment Simulation Studies--To assess the potential for thermal shock to aquatic organisms resulting from plume (or plant) entrainment, thermal tolerance limits were determined for exposure durations ranging from 10 seconds to 60 minutes.

2. Upper Thermal Tolerance Studies--Thermal tolerance limits were determined for exposure durations of 24-96 hours to identify areas of thermal plumes that are potentially uninhabitable by organisms because of high temperatures.

3. Lower Thermal Tolerance Studies--Lower thermal tolerance limits were determined by subjecting organisms to an abrupt decrease in temperature to assess the potential for mortality as a result of cold shock in the event of a power plant shutdown.

4. Hatching Success and Growth Studies--Temperature requirements for the normal development and growth of early life stages were determined for use in evaluating the effects of thermal discharges on potential spawning and nursery areas.

5. <u>Thermal Preference Studies</u>--Final temperature preferenda were determined as approximations of optimum temperatures for growth and performance of juvenile and adult fish, and for use in predicting the behavior of fish in the vicinity of a thermal discharge.

CHAPTER 2: SUMMARY

The purpose of these studies is to provide data necessary to predictively evaluate whether the thermal discharges from Hudson River power plants will adversely affect representative important species (RIS). Specific study efforts were designed to produce information necessary to evaluate the potential for (1) mortality from excess heat, (2) mortality from cold shock, (3) reductions in reproductive success or growth as a result of plant discharges, and (4) loss of available habitat within the discharge area because of high temperatures. Some of the temperature requirements determined in these studies for each life stage of RIS are summarized in the following sections. Specific details of the experimental procedures and interpretation of results are discussed in Chapters 3-10, and should be consulted before applying these data to the assessment of potential thermal effects resulting from heated discharges. A glossary is provided at the end of the test to define terms as used in this report.

2.1 STRIPED BASS

2.1.1 Eggs

Striped bass eggs spawned at 16.0-19.0 C tolerated abrupt temperature increases ranging from 14.2 to 20.1 C above ambient for 5-minute exposures and 12.5 to 16.8 C above ambient for 30-minute exposures. Thermal tolerance was highest for eggs in the more advanced stages of development. Striped bass eggs in very early stages of development were also incubated at several elevated temperatures until hatch to determine their tolerance to extended thermal exposures. The highest incubation temperature resulting in a high percentage hatch of normal larvae was 23.7 C.

2.1.2 Larvae and Early Juveniles

The tolerance of striped bass larvae to thermal shock varied according to age (or acclimation temperature) and exposure duration. Yolk-sac larvae were generally more tolerant to abrupt temperature increases than post-yolk-sac larvae. Yolk-sac larvae acclimated to 15.5-19.0 C tolerated temperature increases ranging from 15.9 to 18.0 C above ambient for 5-minute exposures and from 11.8 to 15.1 C above ambient for 30-minute exposures. Post-yolk-sac larvae and early juveniles acclimated to 15.0-26.0 C tolerated abrupt temperature increases ranging from 8.8 to 13.3 C above ambient for 5-minute exposures and 9.0 C above ambient for a 60-minute exposure. The 14- and 16-hour TL50s for yolk-sac larvae acclimated to 18.0-19.0 C ranged from 26.4 to 27.9 C; 24-hour TL50s for post-yolk-sac larvae acclimated to 15.0-23.0 C ranged from 26.3 to 32.4 C and were highest for the older larvae.

The optimum temperatures for growth of striped bass post-yolk-sac larvae ranged from 25.1 to 29.6 C. These temperatures corresponded well to the final preferred temperatures of early juveniles, which ranged from 26 to 28 C. The ultimate upper incipient lethal temperature for post-yolk-sac larvae was 33.5 C (16-day TL50), which exceeded the upper limit of the optimum growth range by 3.9 C.

2.1.3 Juveniles

Upper incipient lethal temperatures (96-hour TL50s) for juvenile striped bass ranged from 29.1 C (for subadults acclimatized to 11.5) to 33.2 C (for young of the year acclimatized to 25.0 C). The final thermal preferendum estimated for striped bass juveniles was 27.8 C. The lower thermal tolerance limit (96-hour TL50) for young-of-the-year striped bass acclimated to 17.0 C was 2.2 C.

2.2 WHITE PERCH

2.2.1 Eggs

The hatching success of white perch eggs maintained at elevated temperatures throughout incubation was not impaired by constant exposure to temperatures up to 27.0 C (highest test temperature). Normal hatch occurred for white perch eggs incubated at temperatures as high as 30.5 C, but the degree of hatching success at this temperature was not observed.

2.2.2 Larvae and Early Juveniles

White perch yolk-sac larvae acclimated to 18.0-22.0 C tolerated abrupt temperature increases ranging from 14.7 to 16.7 C above ambient for 5-minute exposures and from 8.7 to 11.9 C above ambient for 60-minute exposures. Tolerance limits generally increased with increasing acclimation temperature; the effects of acclimation temperature were most pronounced for the longer exposure durations. Early juveniles acclimatized to 27.0 C tolerated temperature increases of 8.9-9.7 C above ambient for exposure durations ranging from 5 to 30 minutes. The tolerance limits of white perch yolk-sac larvae to extended thermal exposures (24-hour TL50s) ranged from 30.2 to 31.8 C, remaining fairly constant over the 15.0-22.0 C range of acclimation temperatures tested.

The optimum temperatures for growth of white perch early juveniles ranged from 27.3 to 29.7 C. The growth rate at 32.2 C was also quite high, although not within the optimum range. Final preferred temperatures for similar-sized juveniles ranged from 30 to 32 C, corresponding to the high growth rates observed at 29.7 and 32.2 C. The ultimate upper incipient lethal temperature for white perch early juveniles was 33.8 C (14-day TL50), only slightly higher than the highest temperature resulting in near-optimum growth.

2.2.3 Juveniles and Adults

Upper incipient lethal temperatures (96-hour TL50s) for white perch adults and juveniles acclimatized to 25.0-26.0 C ranged from 32.4 to 34.7 C, and were slightly higher for the young-of-the-year fish. Final preferred temperatures varied according to size, and ranged from 25 to 32 C. Final thermal preferenda were estimated to be 31.2 C for white perch young of the year (<50 mm) and 26.8 C for adults (>150 mm). Lower thermal tolerance limits (96-hour TL50s) for white perch young of the year and adults acclimated to 22.5 and 17.0 C were 5.5 and 3.0-3.6 C, respectively.

2.3 ATLANTIC TOMCOD

2.3.1 Eggs

The tolerance of Atlantic tomcod eggs to thermal shock increased with advancing development and decreased with increasing exposure durations. Tomcod eggs 15-30 days old tolerated abrupt temperature increases ranging from 15.6 to 26.3 C above ambient river temperatures during the spawning season (January) for exposure durations of 10-60 minutes. The tolerance of tomcod eggs to extended exposures was much lower; the upper limit of the optimum temperature range for hatch was 4.9 C (continuous exposure throughout development).

2.3.2 Larvae

Atlantic tomcod larvae acclimated to 2.5-7.5 C tolerated abrupt temperature increases ranging from 25.1 to 25.4 C above ambient for 10-second exposures and from 17.9 to 20.4 C above ambient for 60-minute exposures. Only slight differences in thermal tolerance were observed among larvae of various ages. Twenty-four-hour TL50s for Atlantic tomcod larvae acclimated to 2.5-3.0 C ranged from 16.1 to 17.8 C. The highest growth rate observed for Atlantic tomcod larvae (>9 percent per day) reared from hatch to post-yolk-sac larvae was at 10.9 C, the highest temperature tested.

2.3.3 Juveniles and Adults

Upper incipient lethal temperatures (72- and 96-hour TL50s) for juvenile and adult Atlantic tomcod ranged from 17.0 C for adults acclimatized to 3.0 C during the winter to 26.8 C for juveniles acclimatized to 24.0 C in the summer. The ultimate upper incipient lethal temperature for juveniles during summer months was estimated to be 26.6 C. The final preferred temperature for juvenile tomcod tested during the summer was 10.0 C, much lower than ambient river temperatures. Adults tested during the winter generally preferred the coldest temperatures available in the thermal gradient. The lower thermal tolerance limit (96-hour TL50) for Atlantic tomcod adults acclimated to 10.0 C during the winter was less than 0.2 C.

2.4 ALEWIFE

2.4.1 Eggs

Alewife eggs spawned at 12.0-13.0 C tolerated abrupt temperature increases ranging from 15.3 to 21.4 C above ambient for 5-minute exposures and from 11.2 to 18.7 C above ambient for 30-minute exposures. Thermal tolerance was highest for eggs in the more advanced stages of development. The upper limit of the optimum temperature range for normal hatch of alewife eggs maintained at elevated temperatures throughout incubation was 23.9 C.

2.4.2 Larvae

Alewife yolk-sac larvae acclimated to 14.0-18.0 C tolerated abrupt temperature increases ranging from 12.7 to 22.3 C above ambient for 5- to 60-minute exposure durations. The tolerance of yolk-sac larvae to thermal shock (delta-T above ambient) decreased as exposure durations increased and was highest at the lower acclimation temperatures. Twenty-four-hour TL50s for alewife yolk-sac larvae acclimated to 14.0-24.0 C ranged from 30.7 to 33.5 C, remaining fairly constant over the range of acclimation temperatures tested.

The optimum temperature for net biomass gain (combination of optima for survival and growth) of alewife larvae reared to an advanced post-yolk-sac stage from hatch was 26.4 C. Although 29.1 C was the optimum temperature for growth, mortality was also much higher than at lower rearing temperatures. Final preferred temperatures for advanced post-yolk-sac larvae ranged from 26 to 27 C, corresponding closely to the optimum temperature for net biomass gain.

2.4.3 Juveniles and Adults

Upper incipient lethal temperatures (96-hour TL50s) for young-of-the-year alewife acclimatized to 23.0 and 25.0 C were 31.7 and 32.6 C, respectively. The final thermal preferendum for juvenile alewife was determined to be 19.5 C. For adults acclimatized to 14.5 and 20.5 C, upper incipient lethal temperatures were 25.5 and 28.4 C, respectively. Avoidance temperatures for alewife adults acclimatized to 16.0 and 20.0 C were 26 and 30 C, respectively. Although these avoidance temperatures exceeded the upper thermal tolerance limits determined at similar acclimatization temperatures, adult alewife were allowed to acclimate gradually to higher temperatures in the avoidance apparatus during the 4-day tests.

2.5 WHITE CATFISH

2.5.1 Larvae and Early Juveniles

White catfish post-yolk-sac larvae and early juveniles tolerated abrupt temperature increases ranging from 10.0 to 12.1 C above a 24.5-25.0 C ambient river temperature for 5-60 minutes. The ultimate upper incipient lethal temperature for white catfish larvae, 33.0 C (21-day TL50 for normal survival), was only slightly less than the tolerance limits determined for the much shorter exposure durations. The optimum temperatures for growth of white catfish larvae and early juveniles ranged from 27.3 to 32.2 C, and corresponded quite closely to the final preferred temperature of 30 C determined for early juveniles.

2.5.2 Juveniles and Adults

Upper incipient lethal temperatures (72- and 96-hour TL50s) for white catfish adults ranged from 27.9 to 34.7 C at acclimatization temperatures of 12.5-26.0 C. The ultimate upper incipient lethal temperature for adults was estimated to be 34.2 C. The final preferendum of adults tested from June through March was determined to be 28.7 C, which was exceeded by the ultimate upper incipient lethal temperature by 5.5 C. The final preferendum for young of the year, 30.5 C, was somewhat higher than the final preferendum for adults. The lower thermal tolerance limit (96-hour TL50) for young-of-the-year white catfish acclimated to 16.5 C was 1.6 C.

2.6 SPOTTAIL SHINER

2.6.1 Early Juveniles

The tolerance of spottail shiner early juveniles to thermal shock ranged from 9.8 to 13.0 C above ambient river temperatures of 23.0-26.0 C for 5- to 30-minute exposure durations. The ultimate upper incipient lethal temperature for early juveniles was 33.1 C (21-day TL50 for normal survival). Optimum temperatures for growth of early juveniles ranged from 25.0 to 32.2 C, corresponding closely to the final preferendum of 29 C determined for juveniles of similar size.

2.6.2 Juveniles and Adults

Upper incipient lethal temperatures (96-hour TL50s) for young-of-the-year and adult spottail shiner acclimatized to 5-26 C ranged from 22.6 to 34.4 C. Size was a significant ($p = 0.05$) factor in determining the thermal tolerance of spottail shiner for exposure durations up to 48 hours. Final thermal preferenda for spottail shiners varied according to both size and season. During summer months, the final preferenda for young of the year and adults were 28.2 and 20.1 C, respectively. Lower thermal tolerance limits (96-hour TL50s) for spottail shiner juveniles and adults acclimated to 17.0 and 22.0 C were 2.1-2.3 and 6.7 C, respectively. All spottail shiner adults acclimated to 10.0 C survived an abrupt decrease to temperatures as low as 0.0 C.

2.7 GAMMARUS SPP.

The tolerance of *Gammarus* spp. to thermal shock ranged from 8.2 C above an ambient temperature of 26.0 C for a 10-minute exposure to 23.2 C above an ambient temperature of 19.0 C for a 10-second exposure. The 24-hour TL50 for *Gammarus* spp. acclimatized to 25.0 C was 33.8 C.

2.8 <u>NEOMYSIS AMERICANA</u>

Neomysis americana acclimatized to 24.0-24.5 C tolerated abrupt temperature increases ranging from 7.2 to 9.0 C above ambient for 10-minute exposures to 4.8-7.3 C above ambient for 30-minute exposures. The 24-hour TL50 for *N. americana* acclimatized to 24.0 C was 29.4 C.

2.9 CRANGON SEPTEMSPINOSA

The tolerance of *Crangon septemspinosa* to thermal shock ranged from 6.3 to 7.8 C above an ambient river temperature of 24.0 C for 10- to 30-minute exposures. *C. septemspinosa* acclimatized to 19.0 C tolerated temperature increases ranging from 17.9 C above ambient river temperatures for a 10-second exposure to 12.6 C above ambient for a 60-minute exposure.

2.10 CHAOBORUS SPP.

Chaoborus spp. was the most thermally tolerant invertebrate tested, tolerating abrupt temperature increases ranging from over 29.0 C above an ambient temperature of 19.0 C for a 10-second exposure to 8.6 C above an ambient temperature of 26.0 C for a 30-minute exposure. Twenty-four-hour TL50s for *Chaoborus* spp. acclimatized to 26.0 C ranged from 36.1 to 37.5 C.

2.11 OTHER REPRESENTATIVE IMPORTANT SPECIES

Atlantic sturgeon juveniles acclimatized to 8.5 C preferred temperatures ranging from 16 to 22 C (modal preferred temperature was 18 C). Bay anchovy juveniles acclimatized to 24.0 C and 8 ppt salinity preferred temperatures ranging from 21 to 24 C and exhibited an incipient lethal temperature (93-hr TL50) of 33.0 C. Weakfish juveniles could not be collected in sufficient numbers for experimentation. No attempts were made to collect or test shortnose sturgeon and bluegreen algae.

CHAPTER 3: DESCRIPTION OF FACILITY

Experiments were conducted in two mobile laboratory units located at the Roseton Generating Station on the Hudson River. The main laboratory was designed for determining the thermal tolerance of juvenile and adult fishes, conducting behavioral tests, and holding fish. The second facility (the larval laboratory) was designed for incubating fish eggs, rearing fish larvae, and conducting thermal tolerance tests on invertebrates and early life stages of fish.

Both laboratories were supplied with a continuous flow (up to 60 gpm) of Hudson River water. Since the high turbidity of raw river water would interfere with the survival of incubating fish eggs and prevent observations in the behavioral tests, it was necessary to clarify the water before pumping it to the laboratories. Therefore, the water supply was treated by flocculation, settling, and mixed media filtration. Biodegradable flocculant and coagulant aids (American Cyanimid Magnifloc 515C and 572C) were added to the raw river water to facilitate removal of colloidal particles suspended in the water. Concentrations of 515C and 572C injected into the water supply prior to filtration were maintained at or below 50 ppm and 2 ppm, respectively (EPA recommended levels for drinking water supplies). Conductivity of the laboratory water supply ranged from 88 to 230 μmho, pH ranged from 6.2 to 8.6, and dissolved oxygen ranged from 5.3 to 12.0 mg/l throughout the course of the investigation (Appendix A). Because the intake was located in an area influenced by the lower isotherms of the Roseton plant thermal plume, the laboratory water temperatures often exceeded ambient river temperatures b by approximately 0.5-1.0 C.

The facility was equipped with temperature modification apparatus which supplied continuous flows of hot and cold river water to the laboratory, in addition to ambient-temperature water. River water was heated with steam via a heat exchanger or cooled with chilled glycol, also via a heat exchanger. The temperatures of the hot and cold water could be set at any desired levels by regulating the amount of steam or glycol allowed into the heat exchangers with pneumatic valves operated by Foxboro temperature controllers. In the laboratories, hot and cold (or ambient) water were mixed to produce the desired test temperatures with thermostatic mixing valves. These valves generally restricted temperature fluctuations to within 1.0 C.

For tests performed in the spring and summer of 1976, test temperatures were recorded to the nearest 0.1 C with precalibrated thermometers. In the fall of 1976, an Esterline Angus computerized data acquisition system was installed. This instrument recorded the output of thermister probes placed in each test tank once per hour throughout the test, and recorded the data on magnetic cassette tapes. The thermister probes were calibrated on a regular basis, and recorded temperatures accurate to within 0.25 C. Temperature data were analyzed by computer for range, mean, and variance.

The main laboratory was equipped with two banks of lights which were turned on and off by timers to simulate natural lighting conditions. Vera-lux fluorescent bulbs, with a spectrum similar to natural sunlight, came on at sunrise and turned off at sunset. A bank of incandescent lights was adjusted with a dimmer to simulate dusk and dawn lighting conditions, and turned on 30 minutes before sunrise and off 30 minutes after sunset. The larval laboratory was equipped with Vera-lux fluorescent lights which generally remained on for 16 hours during the day and off for 8 hours at night.

Specific descriptions of the fish holding and rearing facilities and the experimental apparatus are given in subsequent chapters.

CHAPTER 4: COLLECTION AND HANDLING OF TEST ORGANISMS

Temperature requirements were determined primarily for representative important species (RIS) collected from the Hudson River in the vicinity of the Roseton and Danskammer Point plants, and to a lesser extent for brackish-water species collected and transported to the laboratory from more saline areas in the lower estuary. The procurement of fish eggs and larvae and the collection and handling of juvenile and adult fish and invertebrates are discussed in the following sections. No attempts were made to collect and test shortnose sturgeon or bluegreen algae.

4.1 FISH EGGS AND LARVAE

Fish eggs were obtained by artificially spawning adults collected from the Hudson River and from fish that deposited their eggs in holding tanks in the laboratory. Artificial propagation was accomplished by fertilizing eggs stripped from ripe females with milt from ripe males according to the dry method described by Davis (1961). Most eggs were then incubated in polyvinyl chloride (PVC) incubation containers 7.6 cm in diameter and 9.4 cm deep with screened bottom and sides and placed in flow-through water baths (Figure 4.1-1). Water baths were supplied with ambient-temperature river water or adjusted to higher incubation temperatures with thermostatic mixing valves. Incubation containers were supported off the bottom by runners along the sides of the water baths to allow water to flow under the eggs, preventing stagnation within the incubation containers. McDonald-type hatching jars were employed for incubating striped bass eggs and some Atlantic tomcod eggs. It was often necessary to treat eggs with a 500 ppm malachite green solution for 10-15 seconds during incubation to prevent mortality resulting from fungus (Hoffman and Meyer 1974).

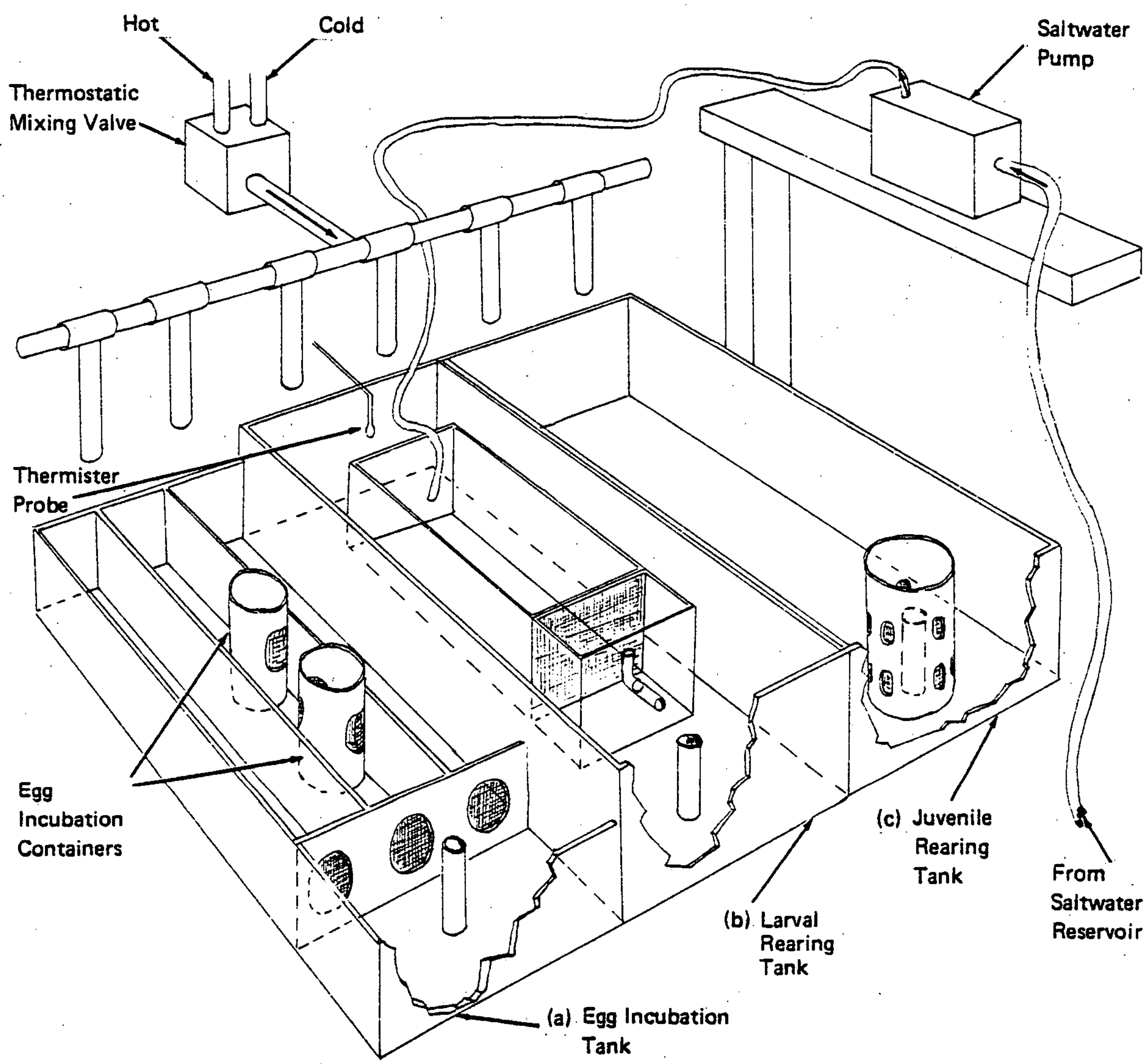


Figure 4.1-1. Water bath including incubation and rearing facilities. The laboratory contained six water baths equipped with thermostatic mixing valves (as shown here) and two similar water baths provided with ambient-temperature water.

Larvae were reared from hatch to various stages of development in flow-through water baths or aquaria maintained at ambient river temperatures or at the desired acclimation temperature (Figure 4.1-1). Larvae were fed appropriate food items consisting of brine shrimp nauplii (Artemia), zooplankton collected from the Hudson River (copepods, cladocerans, and ostracods), live Tubifex worms, and dehydrated brine shrimp. Specific rearing procedures are presented in Chapter 9 for selected RIS.

The availability of eggs and larvae was necessarily restricted to the spawning season of each species. The procurement of eggs and larvae for experimentation, including observations on spawning dates and temperatures, is summarized for each species in the following subsections.

4.1.1 Striped Bass

Striped bass eggs and larvae from Hudson River stock were obtained from a hatchery operated by Texas Instruments, Inc., at Verplanck, New York, during May and June of 1976 and 1977. Eggs and larvae were incubated in the laboratory at ambient river temperatures and tested at various stages of development.

4.1.2 White Perch

White perch eggs were obtained by artificially spawning adults collected in the vicinity of the Roseton and Danskammer Point plants. Ripe adults were generally collected near the mouth of tributaries during late May and early June of 1976 and 1977. River temperatures at which ripe white perch were collected and artificially spawned ranged from 16.0 to 19.0 C in 1976 and 19.0 to 23.0 C in 1977. Tests were performed on eggs and yolk-sac larvae; no larvae were reared to the post-yolk-sac larval stage. Some white perch eggs were incubated at above-ambient temperatures of 24.0-30.5 C to determine the effects of incubation (acclimation) temperature on the tolerance of white perch yolk-sac larvae.

4.1.3 Atlantic Tomcod

During the winter of 1976-1977, ripe Atlantic tomcod adults were collected from the Danskammer Point plant intake canal and artificially spawned. Adults in spawning condition were collected mostly during January, at temperatures of 0.5-1.5 C. Eggs and yolk-sac larvae were incubated and tested in fresh water; post-yolk-sac larvae were reared and tested at 1-3 ppt salinity. Atlantic tomcod larvae were not successfully reared through the post-yolk-sac stage in fresh water under laboratory conditions.

4.1.4 Alewife

Alewife eggs were obtained by artificially spawning adults collected in shallow shore zones of the main river in the vicinity of the Roseton and Danskammer Point plants during late May and early June of 1976, and in tributaries located upstream of the plants during late April and early May of 1977. Water temperatures at which ripe adults were collected and artificially spawned ranged from 13.0 to 19.0 C. Tests were performed on eggs, yolk-sac larvae, and, to a limited extent, on post-yolk-sac larvae. Some alewife eggs were incubated at temperatures up to 24.0 C to determine the effects of incubation (acclimation) temperature on the thermal tolerance of yolk-sac larvae.

4.1.5 White Catfish

Because the eggs and milt of catfish cannot be stripped from adults, white catfish were allowed to spawn naturally in the laboratory. Spawning adults were collected primarily during June and July from the mouth of a nearby tributary (Wappinger's Creek). Large males and females in spawning condition were paired together in 50-gallon holding tanks and provided with a shelter for spawning. In 1976, brood fish were held at ambient river temperatures; two pairs spawned at 25.0-26.0 C during early July. One female captured on 29 June 1976 was injected with chorionic gonadotrophin (600 IU/lb) according to procedures described by Sneed and Clemons (1959), and spawned 9 days later. In 1977, mature adults were collected in early June at river temperatures of approximately 20.0 C and held at 24.0-25.0 C until spawning occurred; three pairs spawned 8-13 days after capture. Since white catfish eggs are deposited in large adhesive masses, temperature requirements of eggs could not be determined. Tests were performed on larvae and early juveniles reared in the laboratory.

4.1.6 Spottail Shiner

Spottail shiner eggs could not be obtained for experimentation because of difficulties encountered in stripping eggs and milt from adults owing to their small size and the low abundance of ripe females in the vicinity of the laboratory. Gravid females in prespawning (green) condition and ripe males were abundant in shore zone habitats near the laboratory throughout May and June of both 1976 and 1977; however, very few spawning adults were collected in the area during late June and early July. Attempts to artificially spawn the few ripe spottail shiner collected in the area were unsuccessful. On the basis of the ambient river temperatures at which the abundance of gravid females decreased markedly and temperatures at which spent fish were first collected, most spawning appeared to take place over a temperature range of approximately 18.0-22.0 C. In 1977, gravid adults were collected during early June and held in the laboratory to induce natural spawning in holding tanks. Some eggs and larvae were obtained in this fashion, but the numbers were too low for experimental purposes. Therefore, temperature requirements of spottail shiner eggs and larvae were not determined.

4.1.7 Other Species

Eggs and larvae of four other Hudson River species were obtained and tested to a limited extent. Yellow perch (Perca flavescens) and a pair of brown bullheads (Ictalurus nebulosis) spawned in holding tanks in the laboratory at 15.0 C and 25.0-27.0 C, respectively. A single female goldfish (Carassius auratus) and several female pumpkinseed sunfish (Lepomis gibbosus) were artificially spawned at temperatures of 19.0 and 23.0 C, respectively, during the spring of 1977. The larvae of these species were reared and tested for thermal tolerance. Attempts were made to collect bay anchovy eggs and larvae from spawning areas in the lower regions of the estuary and transport them to the laboratory for testing, but the numbers of eggs and larvae that survived were too low for experimental purposes.

4.2 JUVENILE AND ADULT FISH

Juvenile and adult fish were collected from the Hudson River primarily in the vicinity of the Roseton and Danskammer Point plants (+3 river miles) with beach seines and fyke nets. Electrofishing gear was also used to a limited extent. Fish were transported from the field to the laboratory soon after capture in 130-liter plastic barrels. Oxygen was used to aerate the holding vessels during transport. Species somewhat sensitive to handling (i.e., white perch, alewife, and striped bass) were transported in a 3-ppt saline solution. Upon arrival at the laboratory, these fish were held in water adjusted to 3 ppt salinity for 2-24 hours, and then slowly returned to ambient fresh water over a 6-8 hour period.

Some species (e.g., bay anchovy, Atlantic tomcod juveniles, Atlantic sturgeon) were collected from the brackish regions of the lower estuary by beach seining or trawling and transported to the laboratory in a 750-liter tank aerated with oxygen. The salinity of the water in the transportation vessel was adjusted to the salinity at which the fish were collected. At the laboratory, most species were held at these salinities for 2-24 hours, after which the salinities were reduced to that of ambient fresh water for testing. However, bay anchovy and, in one case, Atlantic tomcod were maintained and tested at the higher salinities after the experimental facilities had been modified for closed-system operation. Although a few weakfish juveniles were collected from the lower estuary, the numbers were too low for experimental purposes.

Fish holding facilities consisted of several 190- and 570-gallon oval tanks supplied with a continuous flow of ambient river water, and two 940-gallon circular tanks which could be either supplied with a continuous flow of ambient water or maintained at higher salinities via closed-system operation employing a sand filter and a submersible pump. The interiors of all experimental and holding tanks were painted black with a waterproof epoxy paint.

Fish were generally tested within 24-72 hours after capture, and were often placed directly into the experimental facilities upon arrival from the field. However, to perform experiments on fish acclimatized to low temperatures, several species were collected in the fall and held in the laboratory at ambient river temperatures for several weeks. Fish held in the laboratory longer than 4 days prior to testing were fed suitable live food or frozen brine shrimp. For most lower thermal tolerance (cold shock) tests and a few heat shock tests, fish were acclimated to temperatures higher than ambient river temperature by increasing the holding temperatures approximately 1.0 C per day and maintaining the fish at the desired acclimation temperature for 1-2 weeks before testing.

Disease was occasionally manifested as a result of handling stress, particularly at the high summer temperatures. When disease was evident, fish were treated with 2-4 ppm of potassium permanganate for 1-3 hours or with 22 ppm of Furacin for 2-6 hours (Snieszko and Axelrod 1971; Bonn et al. 1976). All unhealthy fish were discarded from the holding tanks daily. Care was taken to select only healthy and undamaged fish for testing. Prophylactic treatments were not administered during tests.

The physiological state of most juvenile and adult fish prior to testing was determined by the natural conditions of the environment. Therefore, the term "acclimatization temperature," as defined by Fry (1971), is used to report results of tests on juvenile and adult fish collected from the river and tested soon after capture. For results of tests on fish acclimated in the laboratory to temperatures other than ambient, the term "acclimation temperature" is used. (Because eggs and larvae were reared under controlled laboratory conditions, the term "acclimation temperature" has been retained for reporting results of these tests even when the test organisms were reared at ambient river temperatures.)

4.3 INVERTEBRATES

Chaoborus spp., *Gammarus* spp., and *Daphnia* spp. were collected from the Hudson River in the vicinity of the Roseton plant during the summer and fall of 1976. *Chaoborus* spp. and *Gammarus* spp. were obtained mainly by recovering live organisms pumped from the river near the intake of the Roseton plant, according to entrainment survival sampling procedures described by EA (1978b). *Daphnia* spp. and some *Gammarus* spp. were obtained from culture vessels supplied with a continuous flow of unfiltered river water. To determine if salinity would alter the thermal tolerance of *Chaoborus* spp. and *Gammarus* spp., some organisms were held in water baths adjusted to 3 ppt salinity for 24 hours prior to testing.

Neomysis americana and *Crangon septemspinosa* were collected from the brackish regions of the lower estuary by trawling during the summer and fall of 1976. These organisms were transported to the laboratory in water adjusted to salinities similar to those at which the organisms were collected. At the laboratory, *N. americana* and *C. septemspinosa* were held in closed-system aquaria adjusted to these higher salinities and maintained at ambient river temperatures for 24 hours prior to testing.

CHAPTER 5: ENTRAINMENT SIMULATION STUDIES

Power plants located on the Hudson River employ once-through cooling systems to dissipate waste heat. In the cooling sequence, river water is pumped through a condenser, where heat is transferred from the exhaust steam to the cooling water, and the warmed water is then returned to the river. Once-through, open circuit cooling systems expose aquatic organisms to sudden temperature increases during two events: (1) entrainment through the power plant with the cooling water and (2) entrainment with the dilution water into the thermal plume created by the discharge. Entrainment exposures are generally limited to planktonic species or life stages. For plant entrainment, the length of exposure and the magnitude of the temperature increase to which organisms would be exposed varies according to the transit time through the plant, the volume of cooling water utilized, and the plant generation load. For plume entrainment, the time-temperature exposure depends on where the planktonic organisms enter the plume, the temperature of the thermal plume at the point of entry, and the time it takes for the discharge to cool to near-ambient temperatures. To evaluate the potential thermal effects of plant and plume entrainment on Hudson River organisms, tolerance limits of fish eggs, fish larvae, and invertebrates of representative important species (RIS) were determined for exposure periods ranging from 10 seconds to 60 minutes. The actual assessment of entrainment impact on RIS, based on the laboratory studies reported here and on other field and laboratory studies, is presented and discussed in 316(a) and 316(b) demonstrations for the Danskammer Point and Roseton Generating Stations, the Bowline Point Generating Station, and the Indian Point Generating Station.

5.1 METHODS AND MATERIALS

5.1.1 Experimental Procedures

Fish eggs and larvae were reared in the laboratory and tested for short-term thermal tolerance at several stages of development. For some tests, small young-of-the-year fish (early juveniles) were obtained from nursery areas near the laboratory. Thermal tolerances of invertebrates were determined for organisms collected from the Hudson River in the vicinity of the laboratory and from brackish regions of the lower estuary. Organisms were usually held or reared at ambient river temperatures prior to testing. However, some fish eggs were incubated at above-ambient temperatures to examine the effects of incubation (acclimation) temperature on the thermal tolerance of yolk-sac larvae. Organisms collected or reared at low salinities were held and tested in water adjusted to those salinities.

Thermal tolerance experiments were conducted by subjecting test organisms to an abrupt thermal shock from a temperature to which the organisms were acclimated to a series of higher temperatures followed by continuous exposure to the test temperatures for time periods ranging from 10 seconds to 60 minutes. At the end of the exposure period, organisms were abuptly returned to their orginial acclimation temperature and thermal tolerance limits were determined from mortality assessments made 24 hours after the exposure. For fish eggs and larvae, test organisms represented a mixture of eggs or larvae from more than one female unless otherwise noted. Specific details of the experimental facilities and procedures were modified from Hoss et al. (1974), and are as follows (in chronological order):

1. Test organisms were transferred from holding facilities into one of three types of test containers prior to the experiment, depending on the size of the organisms. For yolk-sac larvae and small post-yolk-sac larvae, approximately 15-25 organisms were placed in containers 5 cm in diameter and 5 cm deep. The upper portion of the container (4 cm) was constructed with 0.25-mm screening to allow water to pass through the container. The lower portion of the cup retained 1 cm of water to prevent organisms from being exposed to the air during transfer of the cups from the holding facilities to the testing aquaria. Eggs, larger post-yolk-sac larvae, and invertebrates were tested in polyvinyl chloride (PVC) containers 7.6 cm in diameter and 9.4 cm deep with screened (0.5 mm) bottoms and sides. For larvae and invertebrates, approximately 10-20 organisms were placed in each test container. For eggs, samples of 50 per container were used. These containers were transferred to the testing aquaria in glass bowls to prevent the organisms from being exposed to the air. Early juvenile fishes were tested in small buckets 20 cm in diameter and 15 cm deep with perforations in the sides approximately 2 cm from the bottom to allow most of the water to be drained from the container for transfer to the test aquaria. Tests on early juveniles were conducted with approximately 10-15 fish in each container. Containers with the test organisms were held in water baths adjusted to the acclimation temperature until initiation of the test. When sufficient numbers of test organisms were available, the sample sizes were increased by simultaneously testing organisms in two or more containers at each test temperature.

2. The experiment was initiated by transferring the test containers to insulated 30-gallon aquaria adjusted to the desired test temperatures with submersible heaters (Figure 5.1-1). A basket was suspended from the top of each aquarium to keep the small containers from submerging entirely beneath the surface of the water. For testing early juvenile fishes, these baskets were removed and the the test containers were suspended in the aquaria. Prior to transfer, most of the water in the test containers was drained so that the heat shock would be instantaneous. In addition, each container was flushed several times with water from the test aquaria. Temperature equilibration was achieved within 60-90 seconds after the initiation of the test. The test temperature was recorded with a calibrated thermometer placed directly in the test container after equilibration. Temperature fluctuations during the test were maintained within 0.1-0.3 C, depending on the length of the exposure.

3. At the end of the exposure, the test containers were returned to water baths adjusted to the acclimation temperature. Rapid temperature equilibration was achieved by employing procedures similar to those used at the initiation of the test.

4. Control organisms were treated in the same fashion except that the test aquaria contained water adjusted to the acclimation temperature rather than a higher test temperature.

5. Mortality was assessed 24 hours after the thermal shock to account for latent effects. During this period, organisms were held in the test containers without feeding. Organisms that were alive but had obvious tissue damage or were stunned (i.e., did not respond normally) were

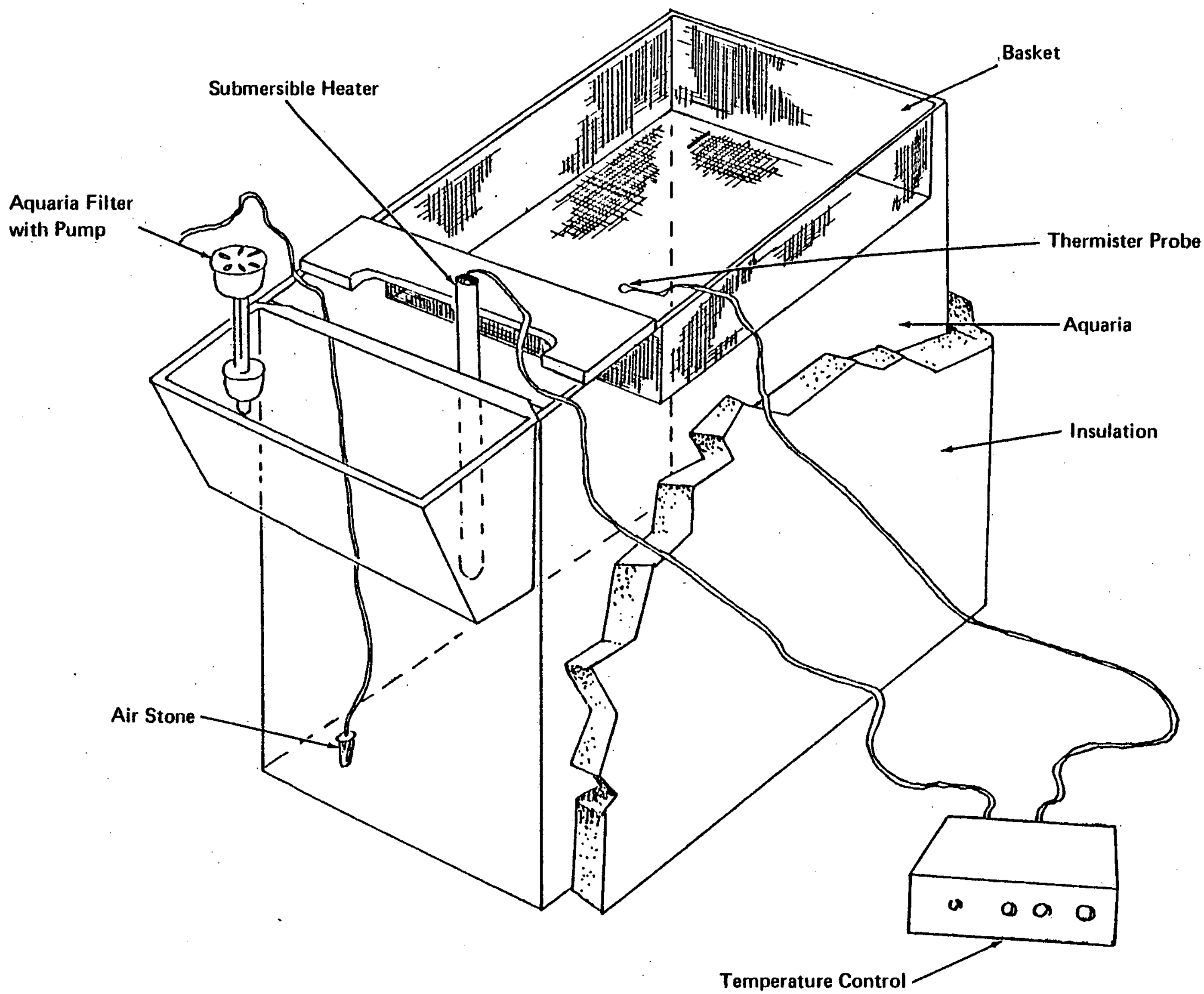


Figure 5.1-1. Apparatus used for heat shock experiments on invertebrates and fish eggs and larvae.

classified as dead and included in the mortality assessment. For eggs, a mortality assessment was also made at hatch; all dead eggs and larvae and all deformed larvae were included in the mortality assessments.

5.1.2 Analytical Procedures

The temperature resulting in 50 percent survival (TL50) was interpolated from a linear regression of percent mortality versus temperature for each test. The TL95 and TL5 were also determined. The TL95 is the temperature resulting in 95 percent survival, and the TL5 is the temperature resulting in 5 percent survival.* An example of the results of a thermal tolerance test is presented in Table 5.1-1. Figure 5.1-2 shows the regression of percent mortality versus temperature for these results.

Prior to regression analysis, the observed percent survival at each test temperature was adjusted for control mortality according to the following equation:

$$P_s = \frac{P_{se}}{P_{sc}}$$

where

P_s = probability of surviving test temperature
P_{se} = probability of surviving experiment (observed survival)
P_{sc} = probability of surviving control

* In Appendix B, these designations have been reversed (i.e., percent mortality, rather than percent survival, follows "TL").

TABLE 5.1-1 EXAMPLE OF EXPERIMENTAL RESULTS FROM AN ENTRAINMENT SIMULATION TEST (FROM TABLE B-316 IN APPENDIX B)

PRELIMINARY INFORMATION:

INCUBATION TEMPERATURE (C)				
MIN	MAX	MEAN	VARIANCE	NO.
11.8	14.9	12.7	0.26	175

LIFESTAGE: YOLK-SAC LARVAE

AGE (DAYS): 1

EXPERIMENT DURATION: 10 MINUTES 0 SECONDS

SALINITY (PPT): 0.0

MORTALITY ASSESSED 24 HOURS AFTER EXPOSURE

ACCLIMATION TEMPERATURE (C): 14.0

NUMBER OF DIFFERENT TEMPERATURES: 7

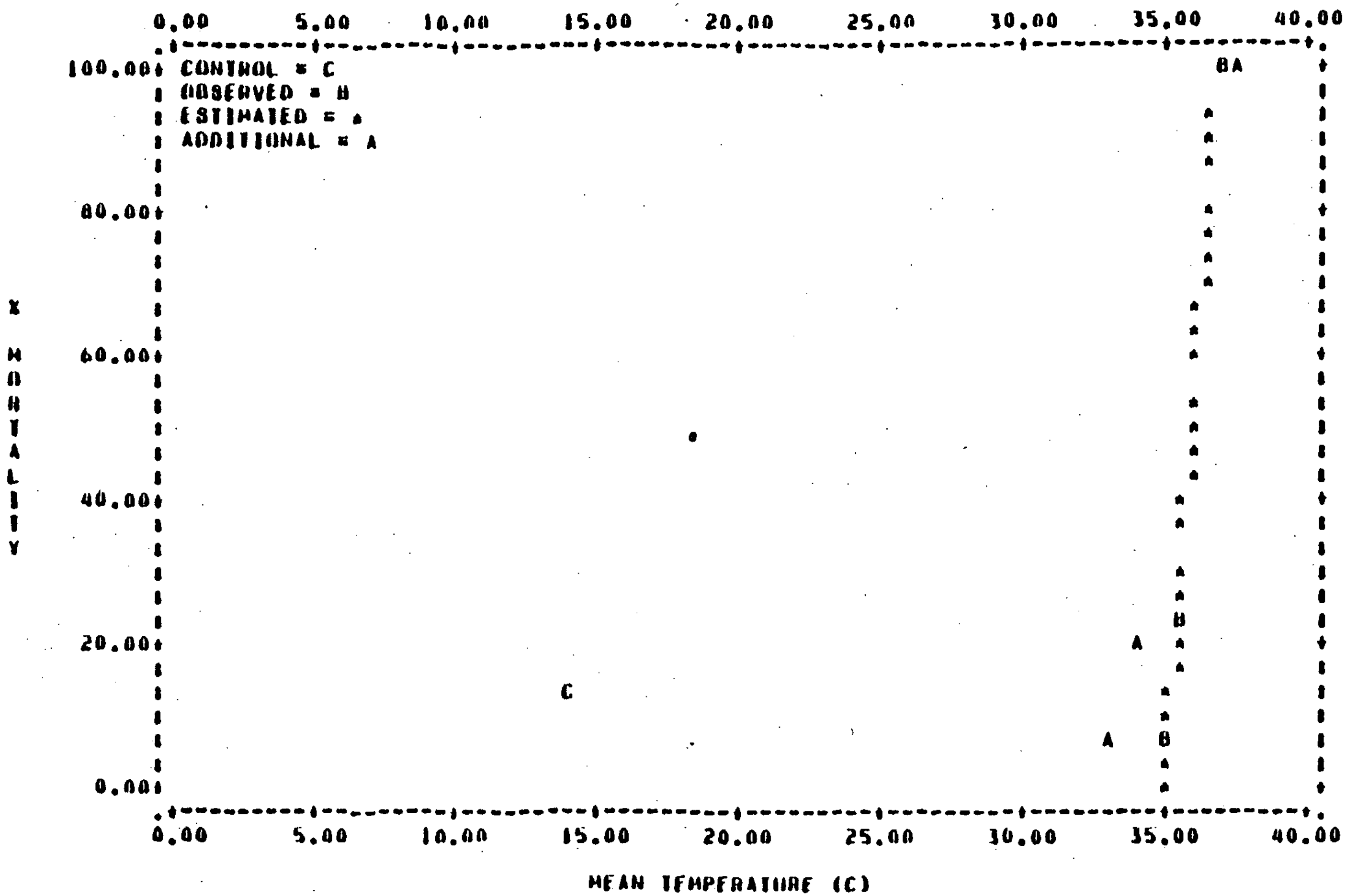
FEMALE NUMBER 1

EXPERIMENTAL RESULTS:

CATEGORY (A)	MEAN TEMPERATURE	SAMPLE SIZE	NO. DEAD
C	14.0	81	12
	32.8	25	5
	33.8	42	13
I	35.0	42	9
I	35.6	47	16
I	36.8	22	22
	37.5	16	16

(A): C = CONTROL
I = INCLUDED IN REGRESSION ANALYSIS
BLANK = NOT INCLUDED IN REGRESSION ANALYSIS

FIGURE 5.1-2 EXAMPLE OF REGRESSION ANALYSIS OF DATA PRESENTED IN TABLE 5.1-1 (FROM FIGURE B-316 IN APPENDIX B)



The Regression Equation:
% Mortality = -1859.30 + 53.15 x Mean Temperature
Correlation coefficient: 0.98
TL95: 35.1 C   TL50: 35.9 C   TL5: 36.8 C

and

$$P_{se} = \frac{\text{observed no. surviving test temperature}}{\text{sample size}}$$

$$P_{sc} = \frac{\text{no. surviving control}}{\text{sample size}} .$$

This correction was necessary in order to determine accurately the effects of temperature shock on the survival of organisms without biasing the results by the mortality attributable to handling and holding stresses incurred during the test. Control mortality typically ranged from 10-20 percent for most organisms, but was occasionally higher for the more sensitive life stages and species (e.g., eggs in the blastula and gastrula stages, striped bass yolk-sac larvae, and larvae that were in transition from yolk-sac to post-yolk-sac life stages). The corrected percent mortality was plotted versus the test temperature as shown in Figure 5.1-2; the actual percent control mortality is also shown (point C).

The regression analysis included only those points that contributed significantly to the prediction of the tolerance limits. When two or more test temperatures resulted in complete mortality, only the lowest was included in the regression. On the lower end of the temperature scale, the percent mortality was occasionally observed to be greater at lower test temperatures than at somewhat higher test temperatures. Since the expected response at higher test temperatures is additional mortality, the higher mortality observed at these low test temperatures was apparently due to experimental error; therefore, these test temperatures were not included in the regression analysis. Examples of both situations are shown in Table 5.1-1 and Figure 5.1-2. Test temperatures used in the regression analysis example are indicated in Table 5.1-1 by an I under the "category" heading, and are indicated in the dosage-mortality plot (Figure 5.1-2) by a B. Points not included in the regression analysis are indicated by an A ("additional") in the dosage-mortality plot.

Thermal tolerance limits were determined by predicting the temperatures that would result in 95, 50, or 5 percent survival from the linear regression equation. In a few cases, the test temperatures selected were not sufficient to allow accurate estimates of the TL95 and the TL5 (i.e., all test temperatures were too high or too low, or the differences between the test temperatures were too great over critical temperature ranges). The TL95 and TL5 values predicted by the regression equation for these tests were therefore omitted from the analysis of results.

5.2 RESULTS AND DISCUSSION

Thermal shock tolerance was investigated primarily for the life stages of RIS that are most susceptible to entrainment exposures. In addition, most tests were performed at acclimation temperatures representative of ambient river temperatures during times of the year when these species or life stages are abundant in the Hudson River. In general, thermal tolerance limits were not strongly influenced by acclimation temperature or age, and were normally higher for the shorter exposure durations.

In order to evaluate the magnitude of the temperature increase that could be tolerated by organisms during plant or plume entrainment, the differences between the TL95s and the acclimation temperatures were determined. The TL95 estimates the highest temperature that results in no appreciable mortality (threshold lethal limit), and, for these tests, represents a safe temperature that accounts for 24-hour latent mortality and includes stunned larvae in the mortality assessment (see Subsection 5.1.1). Because thermal tolerance limits generally varied little over the range of acclimation temperatures tested, the maximum safe temperature increase was usually smaller at the higher acclimation temperatures than at the lower acclimation temperatures. Thermal tolerance limits and maximum safe temperature increases for each species are discussed in the following subsections.

5.2.1 Striped Bass

Five developmental stages of striped bass eggs were tested for 5- and 30-minute exposures at acclimation (incubation) temperatures ranging from 16.0 to 19.0 C. Median thermal tolerance limits (TL50s) ranged from 31.5 C to 38.5 C, generally increasing with development and decreasing with exposure time;

however, striped bass eggs in the late embryo stage of development were slightly less tolerant than those in the tail-free stage (Table 5.2-1) (see also Tables and Figures B-90 through B-105 in Appendix B). Eggs in the earlier stages of development were also less tolerant to longer exposure durations than eggs in later developmental stages. Differences between 5-minute TL50s and 30-minute TL50s decreased steadily from 5.3 C for eggs in the gastrula stage to 2.2 C for eggs in the late embryo stage. On the basis of the TL95s for these tests, striped bass eggs spawned at 16.0-19.0 C can tolerate temperature increases ranging from 14.2 to 20.1 C above ambient for 5 minutes and 12.5 to 16.8 C above ambient for 30 minutes, depending on the developmental stage of the egg.

The tolerance of striped bass larvae to thermal shock was investigated extensively for 5-, 10-, and 30-minute exposure durations, with a few tests extending to 60 minutes. The ages of larvae tested ranged from newly hatched yolk-sac larvae to 35-day-old post-yolk-sac larvae. Acclimation temperatures were generally representative of the ambient river temperatures at which the various ages of larvae are normally abundant in the Hudson River. In addition, early juveniles collected from the river in the vicinity of the laboratory during July were tested for a 5-minute exposure duration. Median thermal tolerance limits ranged from 30.6 to 37.5 C for exposure durations of 5-60 minutes and acclimation temperatures ranging from 15.0 to 26.0 C (Table 5.2-2) (see also Tables and Figures B-106 through B-150 in Appendix B).

No consistent trends in the thermal tolerance limits of striped bass larvae were observed with varying ages and acclimation temperatures (Figure 5.2-1). In general, older larvae were tested at the higher acclimation temperatures and younger larvae at the lower acclimation temperatures.

TABLE 5.2-1 SUMMARY OF THERMAL TOLERANCE LIMITS FOR STRIPED BASS EGGS AT FIVE STAGES OF DEVELOPMENT*

Exposure Duration	Developmental Stage	Acclimation Temperature (C)	Age (hr)	No. of Test Temperatures	Range of Test Temperatures (C)	Thermal Tolerance at Hatch (C)			Test Code
						TL95	TL50	TL5	
5 minutes	Blastula	16.0	13	11	26-36	30.2	33.0	35.7	LS074
	Gastrula	18.5	11	14	28-41	34.4	37.0	39.6	LS075
	Tail-bud embryo	16.5	28	11	30-40	36.6	38.0	39.4	LS078
	Tail-free embryo	19.0	32	7	34-40	38.0	38.5	38.9	LS080
	Late embryo	17.0	49	7	35-41	35.6	37.1	38.5	LS082
30 minutes	Gastrula	16.0	16	10	25-34	30.2	31.9	33.6	LS077
	Gastrula	18.5	11	9	26-34	31.0	31.5	31.9	LS076
	Tail-bud embryo	16.5	28	10	28-37	32.5	34.0	35.5	LS079
	Tail-free embryo	19.0	32	6	33-38	34.1	35.2	36.2	LS081
	Late embryo	17.0	49	6	33-38	33.8	34.9	36.0	LS083

* Each stage was tested in replicate on eggs from a single female.

TABLE 5.2-2 SUMMARY OF THERMAL TOLERANCE LIMITS FOR STRIPED BASS LARVAE AND EARLY JUVENILES

Life Stage	Age (days)	Acclimation Temperature (C)	Exposure Duration (minutes)	No. of Test Temperatures	Range of Test Temperatures (C)	Thermal Tolerance Limits (C) TL95	TL50	TL5	Test Code
Yolk-sac	1	19.0	5(a)	8	31-38	37.0	37.5	38.0	LS-048
			10(a)	8	30-37	35.7	36.4	37.0	
			30(a)	8	28-35	34.0	34.5	35.1	
Yolk-sac	1	18.0	5(b)	7	31-37	34.3	35.7	37.0	LS-049
			10(b)	8	30-37	34.8	35.3	35.8	
			30(b)	7	29-35	32.4	33.2	34.1	
Yolk-sac	1	16.0	5(b)	8	30-38	33.8	35.1	36.3	LS-050
			10(b)	7	30-37	33.0	34.1	35.2	
			30(b)	6	30-35	31.1	31.9	32.7	
Yolk-sac(c)	2	15.5	10	3	27-33	--	26.8	29.1	LS-015
			30	3	27-33	--	29.7	33.0	
Yolk-sac	3	15.5	5(b)	10	27-36	31.4	33.3	35.1	LS-051
			10(b)	10	27-36	32.7	33.1	33.6	
Yolk-sac	3	15.5	10	4	26-37	35.0	36.0	37.1	LS-016
			30	4	24-35	27.3	31.3	35.3	
Post-yolk-sac	6	20.0	5	6	32-37	33.3	35.0	36.7	LS-053
Post-yolk-sac	15	15.0	10	5	31-38	33.8	35.8	37.8	LS-018
			30	4	27-34	31.6	32.9	34.2	
			60	3	27-34	--	30.6	34.4	
Post-yolk-sac	16	15.0	10	4	33-39	35.1	36.1	37.2	LS-019
			30	3	30-35	30.8	33.0	35.2	
Post-yolk-sac	18	21.0	5(b)	12	32-35	33.1	34.9	36.7	LS-054
			10(b)	10	32-34	33.1	33.4	33.8	
			30(b)	13	30-34	33.3	33.8	34.3	
Post-yolk-sac	21	20.0	5	6	31-36	32.1	33.0	33.9	LS-052
			10	7	30-36	31.7	32.7	33.8	
			30	7	29-35	30.9	32.3	33.6	

(a) Four replicates combined.
(b) Two replicates combined.
(c) Tests may have been biased owing to experimental error; results are not included in analysis.

Note: Dashes indicate that data were insufficient for accurate determinations of tolerance limits.

TABLE 5.2-2 (CONT.)

Life Stage	Age (days)	Acclimation Temperature (C)	Exposure Duration (minutes)	No. of Test Temperatures	Range of Test Temperatures (C)	Thermal Tolerance Limits (C)			Test Code
						TL95	TL50	TL5	
Post-yolk-sac	24	22.0	5(b)	9	29-35	32.6	33.9	35.2	LS-065
			10(b)	8	29-34	32.7	33.3	34.0	
			30(b)	8	29-34	31.6	32.9	34.2	
Post-yolk-sac	30	22.0	10	5	30-40	32.9	33.5	34.1	LS-021
			30(b)	7	23-37	--	32.0	34.4	
Post-yolk-sac	30	23.5	5(b)	10	30-36	33.3	34.7	36.1	LS-111
			10(b)	9	30-35	32.6	34.3	36.0	
			30(b)	8	30-35	32.9	33.6	34.0	
Post-yolk-sac	35	23.0	10	4	34-40	34.9	36.4	38.0	LS-025
			30	6	31-36	34.0	35.0	36.0	
			60	4	30-36	32.0	34.0	36.1	
Early juvenile	(52 mm mean total length)	26.0	5	4	35-38	34.8	36.6	38.3	LS-120

(a) Four replicates combined.
(b) Two replicates combined.

Note: Dashes indicate that data were insufficient for accurate determinations of tolerance limits.

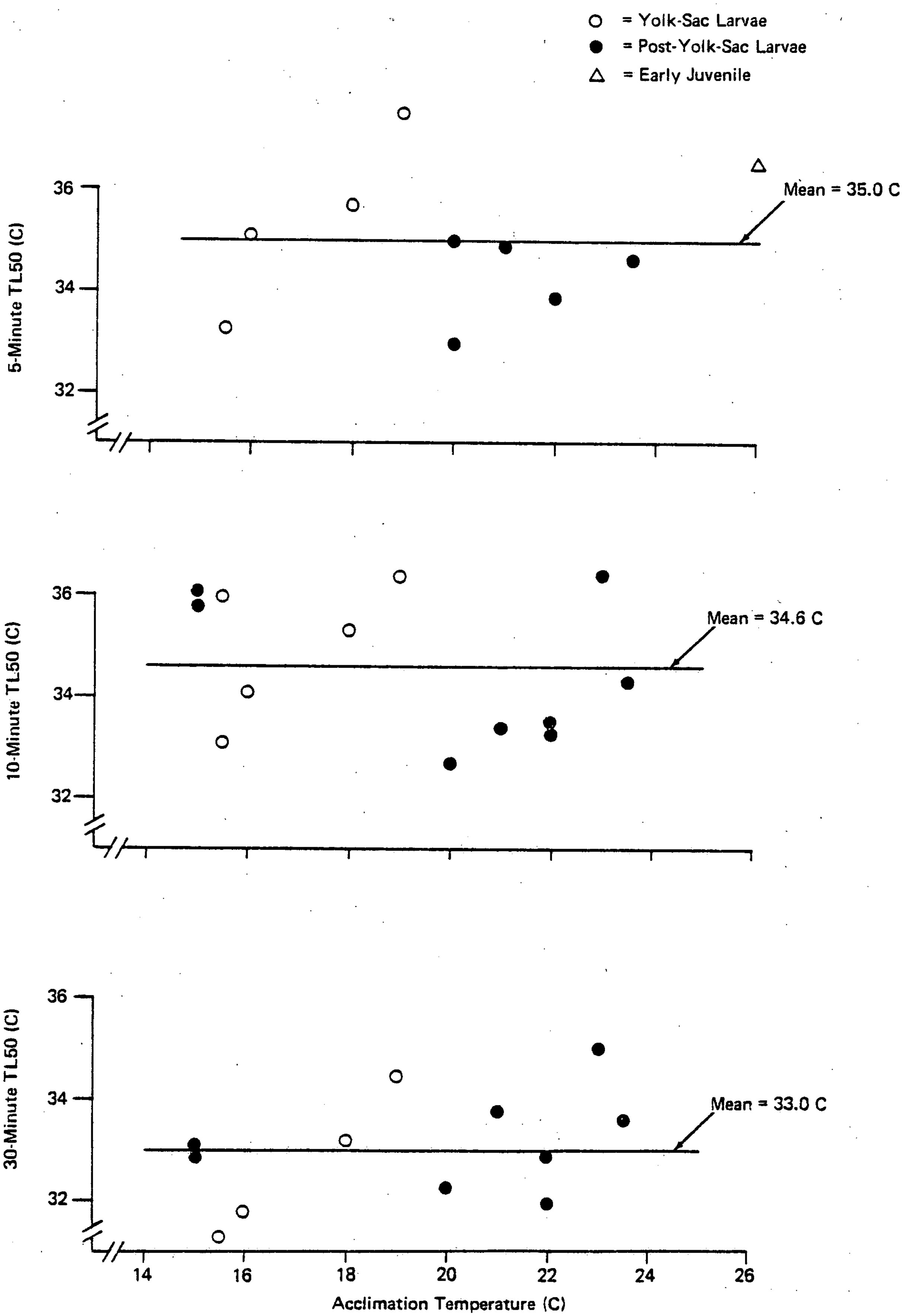


Figure 5.2-1. Thermal tolerance limits (TL50) versus acclimation temperature for young striped bass. Larvae ranged in age from 1 to 35 days.

Linear regression analysis of acclimation temperatures versus TL50s for all ages of striped bass larvae tested indicated that acclimation temperature was not a significant variable ($p = 0.05$) at any exposure duration. In addition, differences between the highest and lowest TL50s for all acclimation temperatures and ages of larvae tested were only 4.5 C for 5-minute exposures, 3.7 C for 10-minute exposures, and 3.2 C for 30-minute exposures. These variations among the TL50s for different exposure durations are relatively small, considering the broad range of acclimation temperatures and ages tested. However, the 5-minute TL50 for early juveniles tested at the highest acclimation temperature (26.0 C) was slightly higher than the 5-minute TL50s for post-yolk-sac larvae tested at lower acclimation temperatures. Therefore, acclimation temperature or age may influence thermal tolerance limits to a limited extent. The mean, the standard deviation, and the range of TL50s for striped bass larvae are the following.

	Mean (C)	Standard deviation (C)	Range (C)
5-minute TL50	35.0	1.39	33.0-37.5(a)
10-minute TL50	34.6	1.39	32.7-36.4
30-minute TL50	33.0	1.08	31.3-34.5

(a) Including early juveniles.

Because no large differences in thermal tolerance limits (i.e., TL50s) of striped bass larvae were detected over the ranges of acclimation temperatures and ages tested, the magnitude of the temperature increase that can be tolerated by young striped bass would be expected to decrease as ambient river temperatures and the age of the larvae increase. This general trend is illustrated in Figure 5.2-2 by plotting age versus 10- and 30-minute TL95s, with

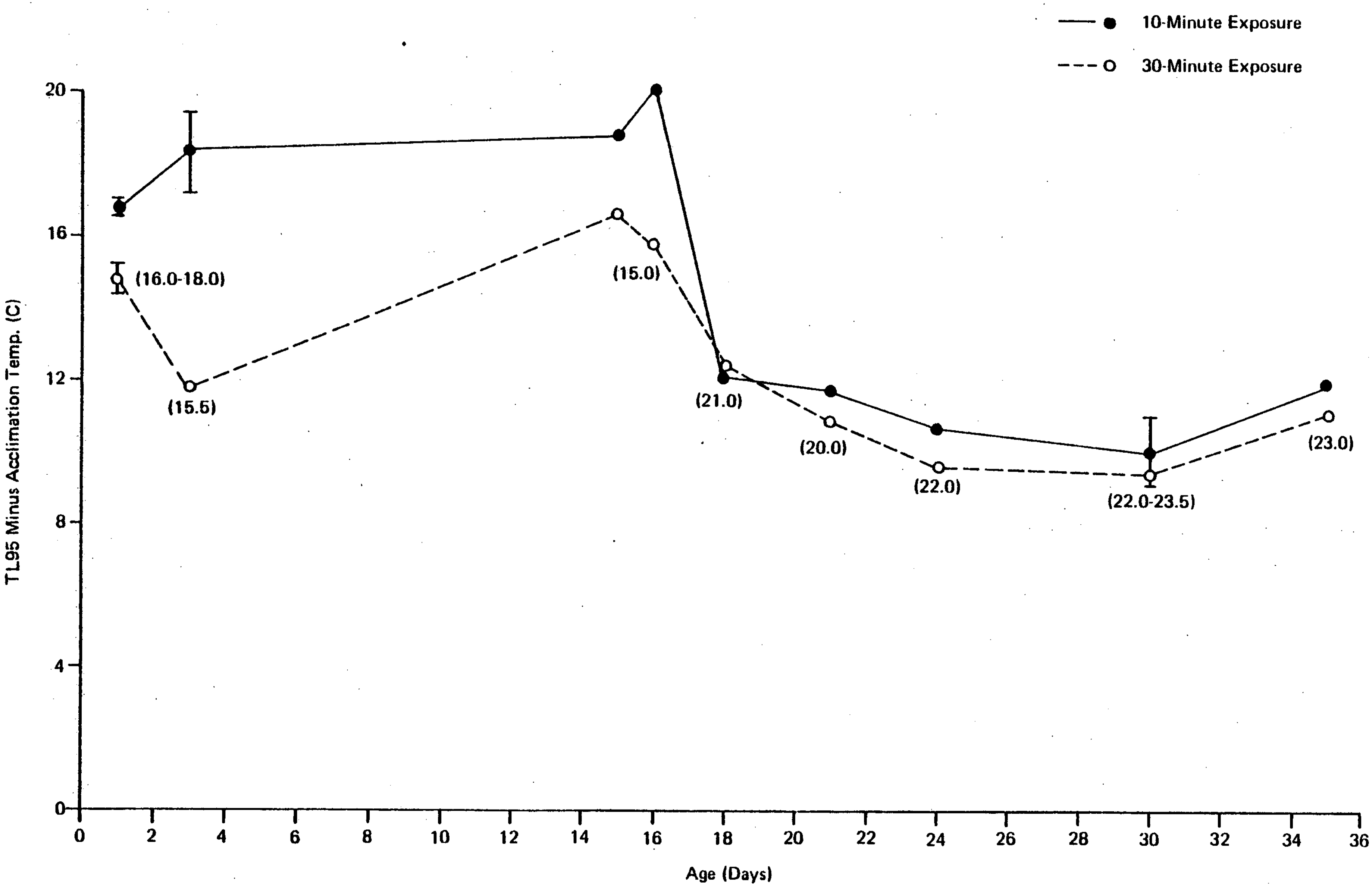


Figure 5.2-2. Maximum temperature increases above ambient that can be tolerated by striped bass larvae. Acclimation temperatures are given in parentheses.

the acclimation temperatures indicated for each group of tests. Yolk-sac larvae and the younger post-yolk-sac larvae, which were tested at the lower acclimation temperatures, were typically more tolerant to thermal shock than older larvae tested at the higher acclimation temperatures. The ranges of maximum safe temperature increases above ambient river temperatures for striped bass yolk-sac larvae and post-yolk-sac larvae are the following.

	TL95 minus acclimation temperature (C)	
	Yolk-sac larvae	Post-yolk-sac larvae
5-minute exposures	15.9-18.0	8.8-13.3(a)
10-minute exposures	16.7-19.5	9.1-20.1
30-minute exposures	11.8-15.1	9.4-16.6
60-minute exposures	--	9.0

(a) Including early juveniles.

A definite trend of decreasing thermal tolerance limits with increased exposure duration was evident for striped bass larvae, though the differences between the tolerance limits determined for the shorter exposure durations and those for the longer exposure durations were not large. The effects of exposure duration on thermal tolerance were most pronounced for the younger striped bass larvae (Table 5.2-2, Figure 5.2-2).

5.2.2 White Perch

The tolerance of young white perch to thermal shock was investigated primarily for yolk-sac larvae. A limited number of tests were also performed with early juveniles collected from the river in the vicinity of the laboratory. Exposure durations ranged from 5 to 60 minutes, and acclimation temperatures ranged from 15.0 to 30.5 C. Most tests on yolk-sac larvae were conducted at acclimation (incubation) temperatures within the range of normal spawning temperaures; however, some white perch eggs were incubated at higher temperatures to determine the effects of acclimation temperature on the tolerance of newly hatched larvae. All early juveniles tested were acclimated to ambient river temperatures during the warmest summer period. Median thermal tolerance limits (TL50s) of young white perch ranged from 31.4 to 39.3 C for the life stages and acclimation temperatures tested (Table 5.2-3) (see also Tables and Figures B-1 through B-45 in Appendix B).

Thermal tolerance limits for white perch yolk-sac larvae generally increased as acclimation temperatures increased, and decreased as exposure durations increased. The increase in thermal tolerance with increasing acclimation temperatures was generally quite small, but it was most pronounced at the longer exposure durations (Figure 5.2-3). Linear regression analysis of acclimation temperature versus TL50 for 10-, 30-, and 60-minute exposures indicated that acclimation temperature was a statistically significant variable ($p = 0.05$) only for the 30-minute exposure tests. The following are linear regression equations for the three exposure durations:

10-minute TL50 = 34.7 + 0.11 (acclimation temperature)
30-minute TL50 = 28.0 + 0.32 (acclimation temperature)
60-minute TL50 = 24.5 + 0.46 (acclimation temperature).

Although the thermal tolerance limits for white perch yolk-sac larvae were highest at the higher acclimation temperatures, the magnitude of the temperature increase tolerated by white perch decreased steadily with increasing acclimation temperature. For acclimation temperatures within the upper range of the normal spawning temperatures for white perch (18.0-22.0 C), yolk-sac larvae tolerated temperature increases ranging from 12.0 to 18.2 C above ambient for 5- to 30-minute exposure durations (on the basis of TL95s). At acclimation temperatures of 23.0-30.5 C, maximum safe temperature increases for yolk-sac

TABLE 5.2-3 SUMMARY OF THERMAL TOLERANCE LIMITS FOR WHITE PERCH LARVAE AND EARLY JUVENILES

Life Stage	Age (days)	Acclimation Temperature (C)	Exposure Duration (minutes)	No. of Test Temperatures	Range of Test Temperatures (C)	Thermal Tolerance Limits (C) TL95	TL50	TL5	Test Code
Yolk-sac	1	30.5	10	4	34-39	37.0	37.9	38.9	LS-026
Yolk-sac	1	27.5	10	4	35-39	36.3	37.6	38.9	LS-029
Yolk-sac	1	25.5	10	4	33-39	33.7	36.5	39.2	LS-028
			30	4	31-37	33.0	34.9	36.7	
Yolk-sac	1	24.0	10	6	30-41	37.1	38.0	38.9	LS-010
			30	4	30-37	34.5	36.1	37.6	
			60	4	30-38	33.6	35.4	37.1	
Yolk-sac	1	23.0	10	3	35-39	35.3	37.1	38.9	LS-027
Yolk-sac	1	22.0	10	3	35-39	35.7	37.4	39.2	LS-031
			30	5	31-37	35.4	36.4	37.4	
			60	4	31-38	30.7	34.0	37.3	
Yolk-sac	1	21.5	10	3	34-39	36.7	37.8	38.8	LS-030
			30	3	32-37	--	35.3	36.7	
Yolk-sac	1	21.0	10	3	38-40	38.2	39.3	40.3	LS-011
			30	3	33-38	33.0	34.0	35.1	
			60	3	33-38	32.9	35.6	38.4	
Yolk-sac	1	20.0	5	5	35-39	36.7	37.6	38.4	LS-056
			10	5	34-38	35.7	36.7	37.7	
Yolk-sac	1	20.0	5	6	33-38	34.7	36.2	37.7	LS-059
			10	6	33-38	34.2	35.5	36.8	
			30	5	32-36	32.4	34.0	35.5	
Yolk-sac	1	20.0	5	6	33-38	35.0	36.2	37.4	LS-060
Yolk-sac	1	20.0	5	10(a)	34-38	--	>38.0	--	LS-057
Yolk-sac	1	19.5	5	6	34-39	36.1	37.4	38.7	LS-055
Yolk-sac	1	19.0	5	7	31-37	--	>36.5	--	LS-058
			10	8	30-37	34.9	35.9	36.9	
			30	8	29-36	32.8	34.3	35.8	
Yolk-sac	1	18.0	10(b)	7	33-39	36.2	37.7	39.1	LS-012
			30(b)	7	29-37	34.6	35.6	36.7	
			60(b)	7	29-37	29.7	32.4	35.0	

(a) Two replicates with larvae from separate females. Test temperatures selected did not result in greater than 50% mortality.
(b) Two replicates combined.

Note: Dashes indicate that data were insufficient for accurate determinations of tolerance limits.

TABLE 5.2-3 (CONT.)

Life Stage	Age (days)	Acclimation Temperature (C)	Exposure Duration (minutes)	No. of Test Temperatures	Range of Test Temperatures (C)	Thermal Tolerance Limits (C) TL95	TL50	TL5	Test Code
Yolk-sac	1	15.0	10	5	31-39	--	35.6	36.8	LS-013
			30	4	30-37	--	31.4	32.8	
Yolk-sac	3	22.0	10	4	31-38	33.3	34.1	34.9	LS-032(c)
			30	3	31-35	--	34.2	--	
Early juvenile	(34 mm)(d)	27.0	5	5	35-39	36.0	37.2	38.4	LS-117
Early juvenile	(32 mm)(d)	27.0	10	4	36-38	35.9	36.8	37.7	LS-118
Early juvenile	(34 mm)(d)	27.0	30	4	35-38	36.7	37.2	37.7	LS-119
Early juvenile	(41 mm)(d)	26.0	5	3	36-39	--	36.4	39.0	LS-116

(a) Two replicates with larvae from separate females. Test temperatures selected did not result in greater than 50% mortality.
(b) Two replicates combined.
(c) High control mortality due to transition from yolk-sac to post-yolk-sac life stage. Results not included in analysis.
(d) Mean total length.

Note: Dashes indicate that data were insufficient for accurate determinations of tolerance limits.

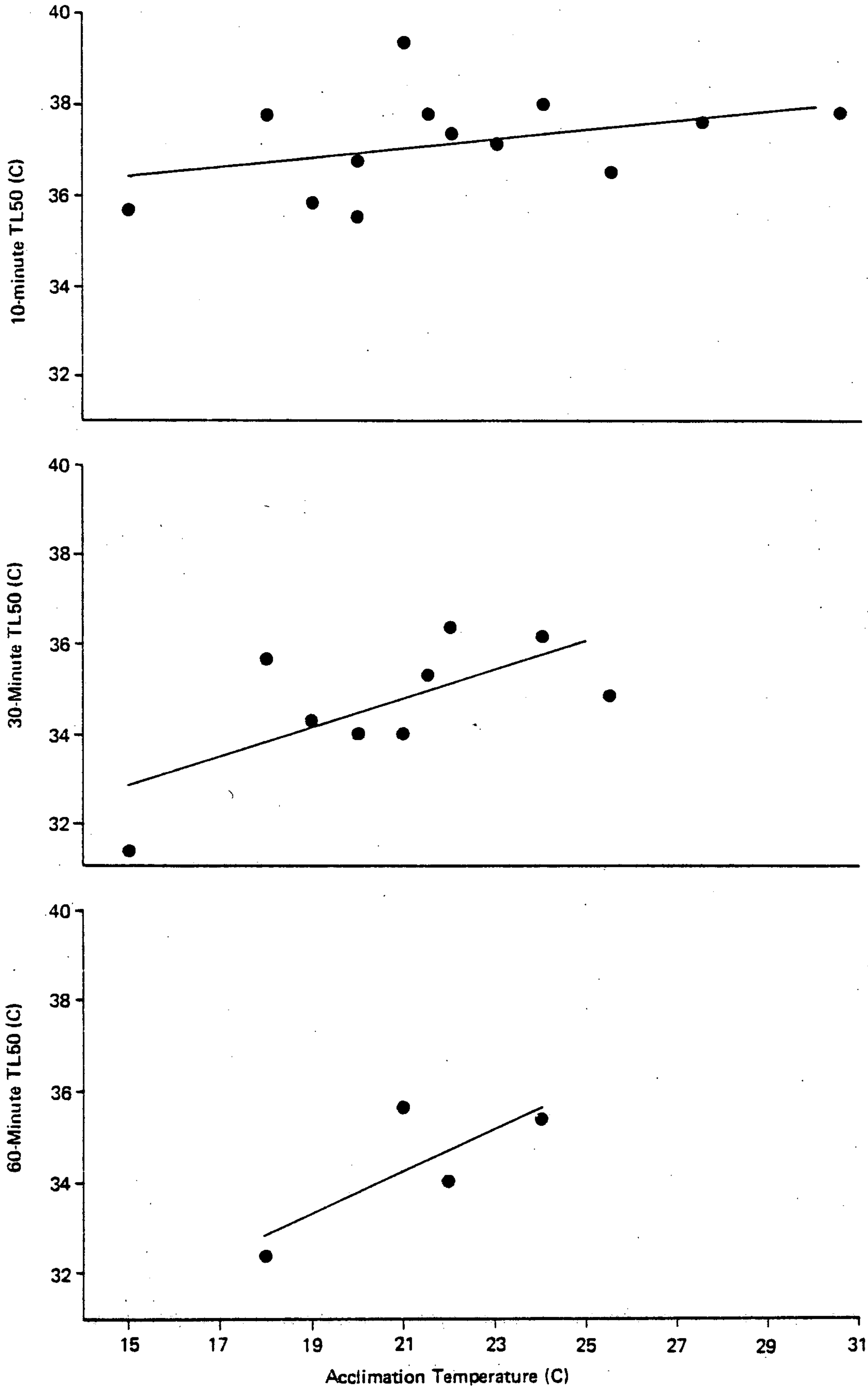


Figure 5.2-3. **Thermal tolerance limits of white perch yolk-sac larvae for exposure durations of 10-60 minutes. Trends are shown by regression lines. Only the regression for 30-minute exposures was significant (p=0.05).**

larvae ranged from 6.5 to 13.1 C above acclimation temperatures for similar exposure durations. Early juveniles acclimated to 27.0 C tolerated temperature increases similar to those for yolk-sac larvae acclimated to 25.5 C and 27.5 C, which indicated that tolerances of young white perch to thermal shock may not be strongly influenced by age or life stage. This observation is only tentative, however, without actual thermal tolerance data on post-yolk-sac larvae. The following are the ranges of maximum safe temperature increases for young white perch.

	TL95 minus acclimation temperature (C)		
	Yolk-sac larvae		Early juveniles
Acclimation Temperature (C)	18.0-22.0	23.0-30.5	27.0
5-minute exposures	14.7-16.7	--	9.0
10-minute exposures	13.7-18.2	6.5-13.1	8.9
30-minute exposures	12.0-16.6	7.5-10.5	9.7
60-minute exposures	8.7-11.9	9.6	--

5.2.3 Atlantic Tomcod

The tolerance of Atlantic tomcod eggs to thermal shock was investigated for eggs in the tail-bud (15 days old) and the eyed-up (30 days old) stages of embryonic development at acclimation temperatures of 2.0-3.0 C and exposure durations of 10-60 minutes. Median thermal tolerance limits (TL50s) ranged from 19.8 to 31.2 C, depending on the exposure duration and the developmental stage of the egg (Table 5.2-4) (see also Tables and Figures B-171 through B-182 in Appendix B). Eggs in the earlier stage of development were less tolerant to temperature increases than eggs in the later stage; TL50s for eggs 30 days old were 4.4-4.6 C higher than TL50s for eggs 15 days old at all exposure durations (Figure 5.2-4). Thermal tolerance also decreased as exposure durations increased, but there was no evidence that exposure duration had a more pronounced effect on eggs in the earlier stage of development as observed

TABLE 5.2-4 SUMMARY OF THERMAL TOLERANCE LIMITS FOR ATLANTIC TOMCOD EGGS AT TWO STAGES OF DEVELOPMENT*

Exposure Duration	Developmental Stage	Age (days)	No. of Test Temperatures	Range of Test Temperatures (C)	Thermal Tolerance at Hatch (C) TL95	TL50	TL5	Test Code
10 min	Tail-bud embryo	15	6	17-29	24.3	26.8	29.4	LS-044
	Eyed-up embryo	30	8	21-35	29.3	31.2	33.1	LS-045
30 min	Tail-bud embryo	15	5	17-27	20.8	23.2	25.8	LS-044
	Eyed-up embryo	30	8	17-31	25.3	27.9	30.5	LS-045
60 min	Tail-bud embryo	15	3	19-23	18.6	19.8	21.1	LS-044
	Eyed-up embryo	30	6	17-27	21.5	24.2	26.9	LS-045

* Each stage was tested in replicate with a mixture of eggs from four females. Eggs were incubated at 2.0-3.0 C before and after exposure.

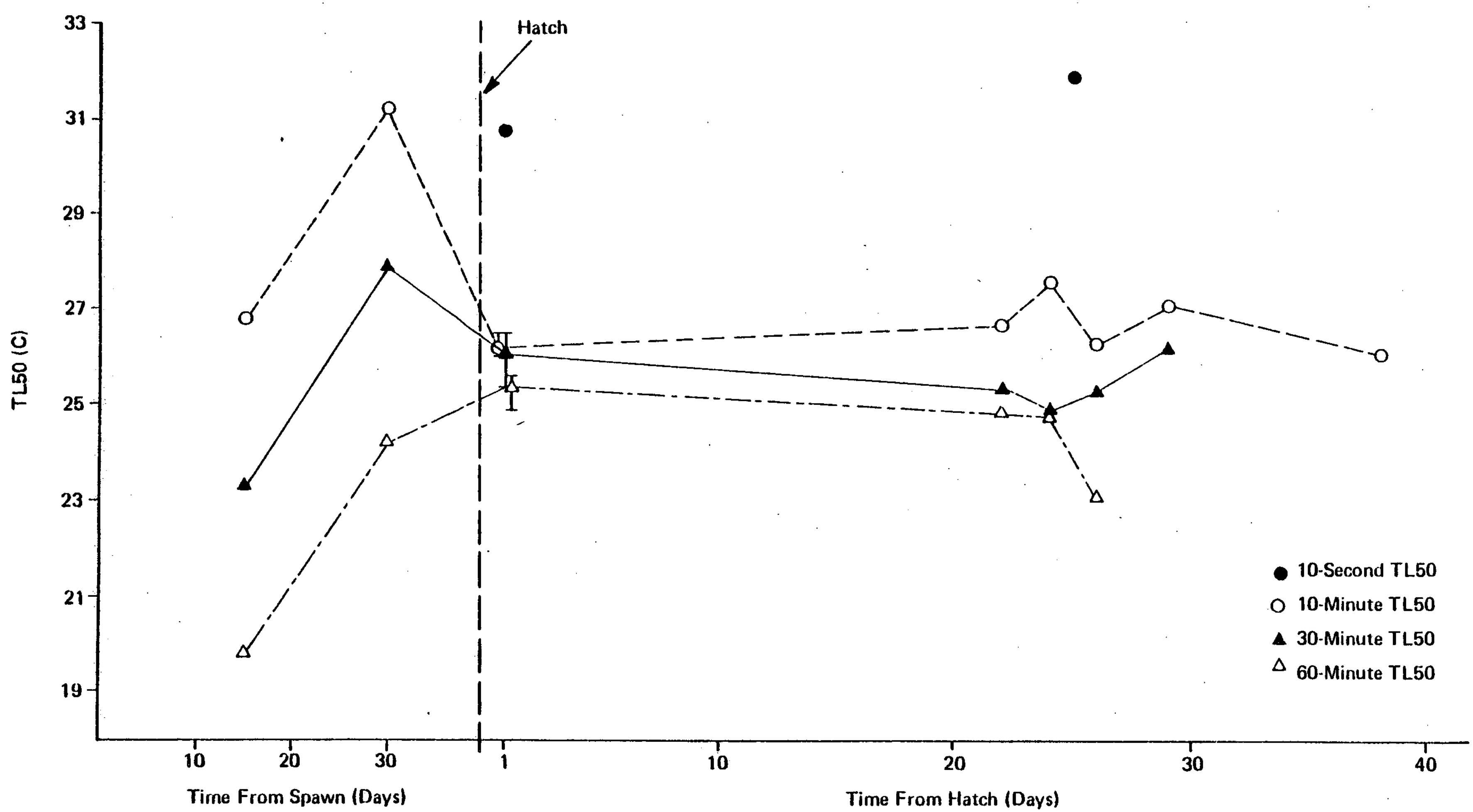


Figure 5.2-4. Thermal tolerance limits of Atlantic tomcod eggs and larvae for exposure durations ranging from 10 seconds to 60 minutes. Acclimation temperatures ranged from 2.0 to 7.5 C, and generally increased with increasing age.

for striped bass eggs. On the basis of the TL95s for these tests, Atlantic tomcod eggs 15-30 days old can tolerate temperature increases ranging from 15.6 to 26.3 C above ambient river temperatures during the spawning season (January), for 10-60 minute exposures, depending on the developmental stage of the egg.

Yolk-sac and post-yolk-sac Atlantic tomcod larvae acclimated to 2.5-7.5 C were tested for exposure durations ranging from 10 seconds to 60 minutes. Since tomcod larvae could not be reared in fresh water in the laboratory, tests on post-yolk-sac larvae were conducted at 1.0-3.0 ppt salinity. Median thermal tolerance limits (TL50s) ranged from 23.1 C for a 60-minute exposure to 31.9 C for a 10-second exposure (Table 5.2-5) (see also Tables and Figures B-183 through B-207 in Appendix B).

Thermal tolerance limits varied little among larvae ranging in age from 1 to 38 days at each exposure duration, as shown in Figure 5.2-4. For the range of acclimation temperatures and ages of larvae tested, TL50s varied by only 1.6 C, 1.7 C, and 2.5 C for 10-, 30-, and 60-minute exposure durations, respectively. The shorter exposure durations usually resulted in higher thermal tolerance limits, but the differences were generally small (Figure 5.2-4). The ranges of maximum safe temperature increases above the acclimation temperatures tested are the following.

	TL95 minus acclimation temperature (C)	
	Yolk-sac larvae	Post-yolk-sac larvae
Acclimation temperature (C)	2.5 - 5.0 C	3.0-7.5 C
10-second exposure	25.1	25.4
10-minute exposure	19.0-22.5	15.7-25.4
30-minute exposure	18.8-23.0	16.7-18.5
60-minute exposure	19.6-20.4	17.9-19.8

TABLE 5.2-5 SUMMARY OF THERMAL TOLERANCE LIMITS FOR ATLANTIC TOMCOD LARVAE

Life Stage	Age (days)	Acclimation Temperatures (C)	Salinity (ppt)	Exposure Duration (minutes)	No. Test Temperatures	Range of Test Temperatures (C)	Thermal Tolerance Limits (C) TL95	TL50	TL5	Test Code
Yolk-sac	1	5.0	0.0	10	8	17-31	24.0	26.5	29.1	LS-038
				30	7	17-29	23.8	25.3	26.8	
				60	7	17-29	24.6	25.6	26.7	
Yolk-sac	1	3.0	0.0	10	5	24-32	24.5	26.0	27.4	LS-039
				30	5	22-30	25.7	26.6	27.6	
				60	5	20-27	23.0	24.9	26.9	
Yolk-sac	1	2.5	0.0	(10 seconds)	6	27-37	27.6	30.7	33.9	LS-037
				10	5	23-31	24.0	26.1	28.1	
				30	5	22-30	25.5	26.5	27.6	
				60	5	22-30	22.9	25.6	28.3	
Post-yolk-sac	22	3.5	3.0	10	5	22-30	24.3	26.7	29.0	LS-043
				30	5	20-28	21.3	25.4	--	
				60	5	20-28	21.5	24.9	28.2	
Post-yolk-sac	24	3.0	1.0	10	4	22-30	25.6	27.6	29.7	LS-040
				30	4	19-28	21.1	24.9	28.8	
				60	5	20-28	22.8	24.9	27.0	
Post-yolk-sac	25	3.0	1.0	(10 seconds)	4	27-34	28.4	31.9	35.5	LS-041
Post-yolk-sac	26	3.0	1.0	10	3	26-30	--	26.3	27.4	LS-042
				30	4	21-28	21.5	25.3	--	
				60	4	21-28	20.9	23.1	25.3	
Post-yolk-sac	29	7.5	1.0	10	5	20-28	25.9	27.1	28.3	LS-047
				30	5	20-28	24.2	26.2	28.1	
Post-yolk-sac	38	7.5	1.0	10	5	20-28	23.2	26.1	28.9	LS-046

Note: Dashes indicate that data were insufficient for accurate determinations of tolerance limits.

5.2.4 Alewife

Three developmental stages of alewife eggs spawned at 12-13 C were tested for 5- and 30-minute exposure durations. Two to four replicates were performed for each developmental stage, with each replicate representing eggs from a different female. Thermal tolerance limits were calculated for each replicate separately and for all replicates combined. Median thermal tolerance limits (TL50s) ranged from 25.5 to 37.2 C, increasing with advancing development and decreasing with exposure time (Table 5.2-6) (see also Tables and Figures B-237 through B-280 in Appendix B). The TL50s (combined replicates) of alewife eggs tested at the blastula stage were 6.0-7.9 C lower than those determined for more advanced developmental stages, but TL50s for eggs in the tail-bud embryonic stage were only 0.7-1.5 C less than TL50s for tail-free embryos. This lower thermal tolerance of eggs in the earlier stages of development was most pronounced for the longer exposure durations; differences between 5-minute and 30-minute TL50s (combined replicates) were 4.3 C, 3.9 C, and 3.1 C for eggs in the blastula, tail-bud, and tail-free stages of embryonic development, respectively. Although eggs from female D were consistently more tolerant than eggs from other females tested (Table 5.2-6), paired group t-tests revealed no significant difference between TL50s at $p = 0.05$. On the basis of the TL95s for combined replicates, alewife eggs spawned at 12.0-13.0 C can safely be exposed to temperature increases ranging from 15.3 to 21.4 C above ambient for 5 minutes and to increases from 11.2 to 18.7 C above ambient for 30 minutes, depending on the developmental stage of the egg.

The tolerance of alewife larvae to thermal shock was investigated primarily for yolk-sac larvae. A limited number of tests were also performed on advanced post-yolk-sac larvae reared in the laboratory. Exposure durations ranged

TABLE 5.2-6 SUMMARY OF THERMAL TOLERANCE LIMITS FOR ALEWIFE EGGS AT THREE STAGES OF DEVELOPMENT*

Exposure Duration	Developmental Stage	Age (hr)	No. of Test Temperatures	Range of Test Temperatures (C)	Thermal Tolerance at Hatch (C) TL95	TL50	TL5	Test Code
5 min	Blastula	24	8	26-40	28.3	30.3	32.3	LS-086
	Replicate A	24	8	26-40	30.2	31.1	32.0	LS-084
	Replicate B	24	8	26-40	27.9	29.8	31.7	LS-085
	Tail-bud embryo	76	8	24-38	34.2	36.3	38.5	LS-093
	Replicate A	76	8	24-38	29.6	34.6	39.5	LS-090
	Replicate B	76	8	24-38	36.1	37.0	37.9	LS-091
	Replicate D	76	8	24-38	36.1	37.0	37.9	LS-092
	Tail-free embryo	105-123	9	30-40	34.4	37.0	39.6	LS-102
	Replicate A	105	5	30-38	34.2	36.9	--	LS-98
	Replicate B	105	5	30-38	--	>37.0	--	LS-99
	Replicate D	105	5	30-38	36.2	37.2	38.2	LS-100
	Replicate E	123	6	35-40	34.5	36.7	38.9	LS-101
30 min	Blastula	24	8	24-36	24.2	26.0	27.8	LS-089
	Replicate A	24	8	24-36	24.8	26.6	28.5	LS-087
	Replicate B	24	8	24-36	23.7	25.5	27.3	LS-088
	Tail-bud embryo	76	5	28-36	29.2	32.4	35.6	LS-097
	Replicate A	76	5	28-36	29.1	32.2	35.3	LS-094
	Replicate B	76	5	28-36	29.2	32.2	35.2	LS-095
	Replicate D	76	5	28-36	28.7	32.7	36.6	LS-096
	Tail-free embryo	105	5	30-36	31.7	33.9	36.1	LS-106
	Replicate A	105	5	30-36	29.4	32.5	35.6	LS-103
	Replicate B	105	5	30-36	32.2	34.1	36.0	LS-104
	Replicate D	105	5	30-36	37.5	34.4	36.4	LS-105

* Tolerance limits were calculated for combined replicates and for each replicate separately. Replicates represent eggs from different females. Eggs were incubated at 12-13 C before and after exposure.

Note: Dashes indicate that data were insufficient for accurate determinations of tolerance limits.

from 5 to 60 minutes and acclimation temperatures ranged from 14.0 to 24.0 C. Most tests on yolk-sac larvae were conducted at acclimation (incubation) temperatures within the upper range of normal spawning temperatures; however, some alewife eggs were incubated at higher temperatures to determine the effects of acclimation temperature on the tolerance of newly hatched larvae. Post-yolk-sac larvae were acclimated to temperatures similar to those at which advanced post-yolk-sac larvae occur in the Hudson River during late spring. Median thermal tolerance limits of alewife young ranged from 30.9 to 38.6 C for the life stages and acclimation temperatures tested (Table 5.2-7) (see also Tables and Figures B-281 through B-345 in Appendix B).

Thermal tolerance limits for alewife yolk-sac larvae remained fairly constant over the range of acclimation temperatures tested (Figure 5.2-5). The shorter exposure durations generally resulted in higher thermal tolerance limits, but the differences were not large. Median thermal tolerance limits of post-yolk-sac larvae were typically 3-5 C lower than those for yolk-sac larvae, indicating that the older alewife larvae are somewhat more sensitive to thermal shock than newly hatched alewife. The mean and range of TL50s for alewife yolk-sac larvae acclimated to 14.0-24.0 C and post-yolk-sac larvae acclimated to 20.0-22.5 C are the following.

	Yolk-sac larvae		Post-yolk-sac larvae	
	Mean (C)	Range (C)	Mean (C)	Range (C)
5-minute TL50	37.1	36.4-38.6	31.4	30.9-31.8
10-minute TL50	36.1	35.0-37.0	--	--
30-minute TL50	34.5	32.1-35.8	31.3	--
60-minute TL50	33.4	32.7-34.5	--	--

Because thermal tolerance limits for alewife larvae were not influenced by acclimation temperature, the magnitude of the temperature increase that could

TABLE 5.2-7 SUMMARY OF THERMAL TOLERANCE LIMITS FOR ALEWIFE LARVAE

Life Stage	Age (days)	Acclimation Temperature (C)	Exposure Duration (minutes)	No. of Test Temperatures	Range of Test Temperatures (C)	Thermal Tolerance Limits (C)			Test Code
						TL95	TL50	TL5	
Yolk-sac	1	24.0	10	4	31-39	32.2	35.8	39.5	LS-009
			30	3	27-33	--	>33.0	--	
			60	4	27-35	30.7	33.2	35.7	
Yolk-sac	1	24.0	10	5	33-39	33.3	36.9	--	LS-008
			30	6	30-37	30.1	33.5	37.0	
			60	6	30-37	--	33.9	35.1	
Yolk-sac	1	21.0	30	4	30-37	33.8	35.8	--	LS-006
			60	3	31-37	31.2	34.5	37.9	
Yolk-sac	1	20.0	10	6	27-39	28.6	35.0	--	LS-007
			30	4	30-38	30.8	34.9	--	
			60	4	27-35	31.1	33.3	35.4	
Yolk-sac	1	18.0	10	5	33-41	33.8	36.7	39.7	LS-003
			30	4	30-37	33.7	35.7	37.8	
			60	3	30-35	30.7	33.8	36.9	
Yolk-sac(a)	1	18.0	5	6	34-39	36.0	37.8	39.5	LS-071
			10	8	32-39	33.8	35.7	37.6	
Yolk-sac(a)	1	18.0	5	6	34-39	37.8	38.3	38.8	LS-072
			10	8	32-39	35.0	36.4	37.9	
Yolk-sac(a)	1	18.0	5	5	34-39	35.6	36.6	37.7	LS-073
			10	8	32-39	35.0	36.3	37.6	
Yolk-sac	1	18.0	10	10(b)	26-39	31.4	36.3	--	LS-004
			30	9(b)	26-37	33.0	34.8	36.7	
			60	4(b)	30-37	31.1	33.3	35.5	
Yolk-sac	1	15.0	10	8(b)	33-41	33.9	37.0	--	LS-001
			30	7(b)	30-37	31.0	34.0	36.9	
			60	8(b)	29-37	30.9	33.2	35.4	
Yolk-sac	1	15.0	10	3	35-41	34.4	35.8	37.2	LS-002
			30	3	33-37	33.1	35.0	37.0	
			60	3	30-35	32.9	33.7	34.5	

(a) Larvae from eggs of a single female.
(b) Two replicates combined.

Note: Dashes indicate that data were insufficient for accurate determinations of tolerance limits.

TABLE 5.2-7 (CONT.)

Life Stage	Age (days)	Acclimation Temperature (C)	Exposure Duration (minutes)	No. of Test Temperatures	Range of Test Temperatures (C)	Thermal Tolerance Limits (C) TL95	TL50	TL 5	Test Code
Yolk-sac(a)	1	14.0	5	6	34-38	35.2	36.4	37.6	LS-069
			10	6	33-37	35.1	35.9	36.8	
			30	7	31-37	32.8	33.8	34.8	
			60	6	30-35	31.4	32.7	34.1	
Yolk-sac(a)	1	14.0	5	6	34-38	36.0	36.7	37.4	LS-068
			10	6	33-37	35.1	35.9	36.7	
			30	7	31-37	31.1	33.3	35.5	
			60	6	30-35	32.3	32.9	33.5	
Yolk-sac[a]	1	14.0	5	6	34-38	36.3	36.9	37.5	LS-070
			10	6	33-37	34.4	35.7	37.1	
			30	7	31-37	32.5	33.9	35.3	
			60	6	30-35	31.9	33.2	34.5	
Yolk-sac	2	18.0	10	3	38-40	--	38.6	40.1	LS-005
			30	5	30-37	--	32.1	35.1	
Post-yolk-sac	41 (17 mm)(c)	20.0	5	5	30-33	29.1	30.9	32.6	LS-063
Post-yolk-sac	≈ 60 (30 mm)(c)	22.5	5	4	30-33	30.3	31.8	33.4	LS-066
Post-yolk-sac	≈ 60 (31 mm)(c)	22.5	30	4	30-32	30.1	31.3	32.6	LS-067

(a) Larvae from eggs of a single female.
(b) Two replicates combined.
(c) Mean total length.

Note: Dashes indicate that data were insufficient for accurate determinations of tolerance limits.

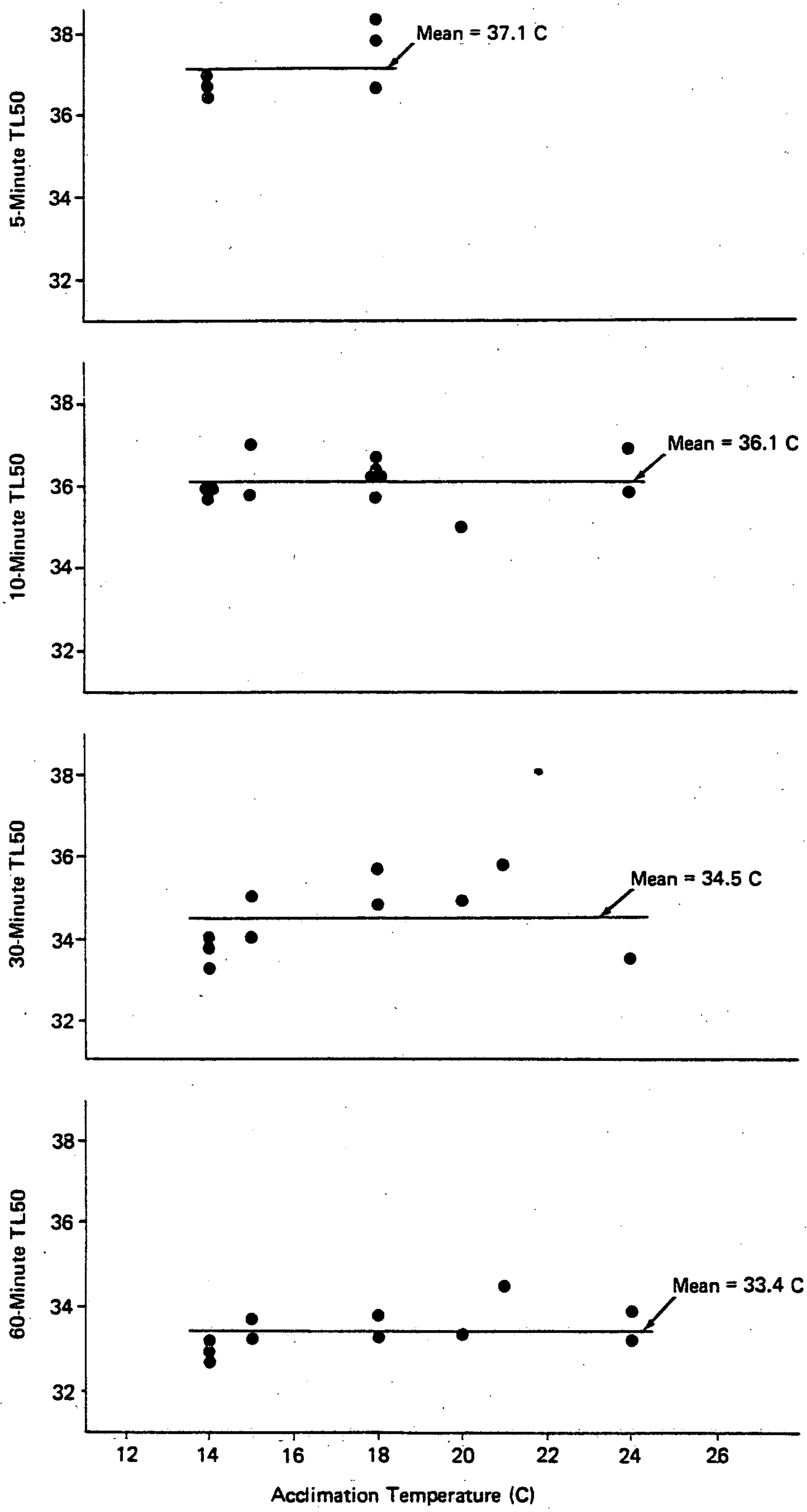


Figure 5.2-5. Thermal tolerance limits of alewife yolk-sac larvae (1 day old) for exposure durations of 5-60 minutes.

be tolerated by alewife larvae decreased steadily as acclimation temperatures increased. For acclimation temperatures within the upper range of the normal spawning temperatures for alewife (14.0-18.0 C), yolk-sac larvae tolerated temperature increases (based on TL95s) ranging from 12.7 to 21.1 C above ambient for 10- to 60-minute exposure durations. At acclimation temperatures of 20.0-24.0 C, maximum safe temperature increases for yolk-sac larvae ranged from 6.1 to 12.8 C at similar exposure durations. The following are the ranges of maximum safe temperature increases above ambient temperatures for alewife larvae at each exposure duration:

	TL95 minus acclimation temperature		
	Yolk-sac larvae		Post-yolk-sac larvae
Acclimation temperature (C)	14.0-18.0	20.0-24.0	20.0-22.5
5-minute exposures	17.6-22.3	--	7.8-9.1
10-minute exposures	13.4-21.1	8.2-9.3	--
30-minute exposures	15.0-18.8	6.1-12.8	7.6
60-minute exposures	12.7-18.3	6.7-11.1	--

5.2.5 White Catfish

The tolerance of young white catfish to sudden temperature increases was determined for post-yolk-sac larvae and early juveniles reared in the laboratory at 24.5-25.0 C. Median thermal tolerance limits (TL50s) ranged from 36.0 to 38.1 C for exposure durations of 5-60 minutes (Table 5.2-8) (see also Tables and Figures B-363 through B-371 in Appendix B). Although thermal tolerance generally decreased with increasing exposure durations, the difference between the 5-minute TL50 and the 60-minute TL50 was less than 2.0 C. On the basis of the TL95s for these tests, young white catfish can tolerate temperature increases of 10.0-12.1 C above a 24.5-25.0 C ambient river temperature for 5-60 minutes.

TABLE 5.2-8 SUMMARY OF THERMAL TOLERANCE LIMITS FOR WHITE CATFISH LARVAE AND EARLY JUVENILES

Life Stage	Age (days)	Acclimation Temperature (C)	Exposure Duration (minutes)	No. of Test Temperatures	Range of Test Temperatures (C)	Thermal Tolerance Limits (C)			Test Code
						TL95	TL50	TL5	
Post-yolk-sac	6	25.0	10	4	35-39	37.0	37.4	37.8	LS-036
			30	4	34-37	35.0	36.0	37.0	
Early juvenile	10	25.0	10	3	36-38	37.1	37.6	38.0	LS-035
			30	3	36-38	36.3	37.3	38.2	
			60	3	35-37	35.8	36.3	36.8	
Early juvenile	15	24.5	5	5	35-39	37.2	38.1	39.0	LS-113
			30	4	35-38	35.9	36.4	36.8	

5.2.6 Spottail Shiner

Since spottail shiner eggs and larvae could not be obtained, the tolerance of young spottail shiner to thermal shock was investigated for early juveniles collected from the Hudson River. Most tests were performed on juveniles acclimatized to an ambient river temperature of 23.0 C and collected at the earliest possible stage permitting speciation of living specimens. Additional tests were conducted on somewhat larger juveniles acclimatized to 26.0 C. Median thermal tolerance limits (TL50s) ranged from 36.0 to 38.1 C for 5-30 minute exposures (Table 5.2-9) (see also Tables and Figures B-407 through B-414 in Appendix B). The tolerance limits of spottail shiner to thermal shock decreased slightly as exposure durations increased, and were somewhat higher at the higher acclimatization temperatures. Maximum safe temperature increases for spottail shiner early juveniles (on the basis of TL95s) ranged from 9.8 to 13.0 C above ambient temperatures of 23.0-26.0 C for 5-30 minute exposures.

5.2.7 Other Hudson River Fishes

Goldfish, brown bullhead, pumpkinseed sunfish, and yellow perch larvae that were reared in the laboratory were also tested for thermal shock tolerance to a limited extent (Table 5.2-10) (see also Tables and Figures B-505 through B-507, B-515, and B-517 through B-526 in Appendix B). Acclimation temperatures generally reflected the ambient river temperatures at which each species was most abundant in the Hudson River. The maximum safe temperature increases above the acclimation temperatures tested are given below for the larvae of each species.

TABLE 5.2-9 SUMMARY OF THERMAL TOLERANCE LIMITS FOR SPOTTAIL SHINER EARLY JUVENILES

Life Stage	Mean Length (mm)	Acclimatization Temperature (C)	Exposure Duration (minutes)	No. of Test Temperatures	Range of Test Temperatures (C)	Thermal Tolerance Limits (C)			Test Code
						TL95	TL50	TL5	
Early juvenile	36	26.0	5	4	36-39	37.3	38.1	38.8	LS-115
			10	5	35-39	37.1	37.9	38.7	
			30	4	35-38	35.8	36.8	37.8	
Early juvenile	13	23.0	5	5	31-35	--	>35.0	--	LS-110
Early juvenile	14	23.0	5	6	34-39	35.9	36.9	37.9	LS-107
Early juvenile	14	23.0	10	6	34-38	35.1	36.0	36.9	LS-109
Early juvenile	20	23.0	5	5	35-38	36.9	37.6	38.4	LS-114
			30	5	33-37	35.0	36.0	37.0	

Note: Dashes indicate that data were insufficient for accurate determinations of tolerance limits.

TABLE 5.2-10 SUMMARY OF THERMAL TOLERANCE LIMITS FOR LARVAE OF OTHER HUDSON RIVER FISHES

Species	Life Stage	Age (days)	Acclimation Temperature (C)	Exposure Duration (minutes)	No. of Test Temperatures	Range of Test Temperatures (C)	Thermal Tolerance Limits (C) TL95	TL50	TL5	Test Code
Goldfish	Yolk-sac	1	20.5	5	7	35-41	39.8	40.3	40.8	LS-064
				10	7	34-40	38.2	39.4	40.6	
				30	7	33-39	37.0	37.9	38.8	
	Post-yolk-sac	13	23.0	5	5	36-40	37.8	38.3	38.8	LS-108
				10	5	36-40	36.2	37.5	38.8	
				30	5	35-39	36.3	37.1	37.8	
Brown bullhead	Post-yolk-sac	9	25.0	10	4	35-39	37.2	38.2	39.1	LS-033
				30	4	34-37	36.0	36.4	36.8	
				60	5	33-37	35.9	36.4	36.9	
	Early juvenile	17	26.0	10	3	36-38	37.1	37.6	38.2	LS-034
				30	3	35-37	35.9	36.5	37.2	
Pumpkinseed sunfish	Post-yolk-sac	6	23.0	5	10	34-38	34.3	36.1	37.9	LS-112
Yellow perch	Yolk-sac	1	15.0	10	4	27-35	30.1	32.4	34.7	LS-023
				30	4	27-35	--	30.0	33.3	
	Post-yolk-sac	10	15.0	10	4	30-37	--	>35.0	--	LS-024
				30	3	27-33	30.6	32.5	34.4	

Note: Dashes indicate that data were insufficient for accurate determinations of tolerance limits.

	TL95 minus acclimation temperature (C)			
	Goldfish	Brown bullhead	Pumpkinseed Sunfish	Yellow Perch
Acclimation temperature (C)	20.5-23.0	25.0-26.0(a)	23.0	15.0
5-minute exposures	14.8-19.3	--	11.3	--
10-minute exposures	13.2-17.7	11.1-12.2	--	15.1
30-minute exposures	13.2-16.5	9.9-11.0	--	15.6
60-minute exposures	--	10.9	--	--

(a) Including early juveniles.

5.2.8 Invertebrates

Tolerance to thermal shock was investigated for five Hudson River invertebrates (Table 5.2-11) (see also Tables and Figures B-527 through B-538 in Appendix B). Gammarus spp., Chaoborus spp. larvae, and Daphnia spp. were collected from the Hudson River in the vicinity of the laboratory and tested at acclimatization temperatures ranging from 19.0 to 26.0 C. Neomysis americana and Crangon septemspinosa were collected in the brackish portion of the lower estuary and tested at 3.0-4.0 ppt salinity and acclimatization temperatures of 16.0-24.5 C. Most of the tests were conducted on organisms acclimatized to high ambient river temperatures. To determine the effects of salinity on the thermal tolerance of Gammarus spp. and Chaoborus spp., an additional series of tests were performed on these species after they had been held in water adjusted to 3.0 ppt salinity for 24 hours prior to experimentation.

The invertebrate species most tolerant to thermal shock was Chaoborus spp. (Figure 5.2-6). Median thermal tolerance limits (TL50s) for Chaoborus spp. ranged from 38.9 C for a 30-minute exposure to over 50.0 C for a 10-second exposure at acclimatization temperatures of 19.0-26.0 C. Gammarus spp. was also quite tolerant to thermal shock, with TL50s ranging from 35.1 C for a 60-minute exposure to 44.2 C for a 10-second exposure. There was no apparent

TABLE 5.2-11 SUMMARY OF THERMAL TOLERANCE LIMITS FOR INVERTEBRATES

Species	Acclimatization Temperature (C)	Salinity (ppt)	Exposure Duration (minutes)	No. of Test Temperatures	Range of Test Temperatures (C)	Thermal Tolerance Limits (C) TL95	TL50	TL5	Test Code
Daphnia spp.	25.0	0.0	10	5	32-41	33.0	36.6	40.1	IS-009
			30	5	32-41	--	35.7	40.1	
			60	5	32-41	--	35.8	40.0	
	26.0	0.0	10	4	33-39	34.4	39.1	--	IS-008
			30	4	33-39	34.2	37.1	39.9	
			60	4	33-39	35.7	37.5	39.2	
Crangon septemspinosa	24.0	3.0	10	4	30-36	30.3	32.3	34.2	IS-015
			30	4	30-36	31.8	32.8	33.8	
	16.0	4.0	(10 sec)	5	34-42	33.9	37.6	41.3	IS-020
			10	4	26-33	28.7	31.2	33.7	
			30	5	26-33	29.0	31.4	33.8	
			60	5	26-33	28.6	30.7	32.9	
Chaoborus spp.	26.0	0.0	10	7	34-44	39.8	41.7	43.6	IS-004
			30	5	34-41	34.6	38.9	43.2	
			60	5	34-41	38.2	39.5	40.9	
	26.0	0.0	10	5	36-45	36.8	40.3	43.8	IS-002
			30	4	37-42	37.9	40.0	42.2	
	26.0	0.0	10	5	36-45	39.1	42.5	45.9	IS-001
			30	5	34-43	37.4	40.3	43.3	
			60	3	36-42	37.0	39.3	41.6	
	24.0	3.0	10	5	33-41	--	>41.0	--	IS-011
			30	5	33-41	--	>41.0	--	
			60	5	33-41	38.0	40.1	--	
	19.0	0.0	(10 sec)	4	44-50	>48.0	>50.0	--	IS-019
			10	8	36-46	41.7	43.3	44.8	
			30	4	35-41	>39.4	>41.0	--	
			60	4	35-41	38.6	41.2	--	
Neomysis americana	24.5	3.0	10	4	31-38	31.7	33.8	35.9	IS-012
	24.0	3.0	10	5	30-36	33.0	34.4	35.9	IS-013
			30	5	30-36	31.3	32.6	34.0	
	24.0	3.0	10	5	28-36	31.8	32.8	33.7	IS-016
			30	5	28-35	28.8	31.2	33.6	
Gammarus spp.	26.0	0.0	10	5	33-41	34.2	37.7	41.2	IS-006
	25.5	0.0	10	4	35-41	35.7	38.3	40.8	IS-005
			30	3	35-39	37.1	37.8	38.5	
			60	3	35-39	34.5	36.7	38.8	
	25.0	0.0	10	4	35-41	37.5	39.0	40.6	IS-007

TABLE 5.2-11 (CONT.)

Species	Acclimatization Temperature (C)	Salinity (ppt)	Exposure Duration (minutes)	No. of Test Temperatures	Range of Test Temperatures (C)	Thermal Tolerance Limits (C) TL95	TL50	TL5	Test Code
			30	3	35-38	35.6	37.0	38.4	
			60	3	35-38	35.1	36.8	38.5	
Gammarus spp.	24.0	3.0	10	5	33-41	36.0	37.8	39.7	IS-010
			30	4	33-40	35.7	37.5	39.4	
			60	4	33-40	36.0	37.5	39.0	
	22.0	0.0	(2 sec)	4	41-46	--	>46.0	--	IS-017
			(10 sec)	5	36-44	40.7	42.6	44.4	
			10	4	34-40	36.5	38.3	40.1	
	19.0	0.0	(10 sec)	10	40-47	42.2	44.2	46.2	IS-018
			10	4	32-39	34.9	36.6	38.4	
			30	4	32-38	33.0	35.6	38.1	
			60	4	33-38	33.3	35.1	37.0	
	24.5	3.0	10	5	34-42	36.6	38.5	40.5	IS-014

Note: Dashes indicate that data were insufficient for accurate determinations of tolerance limits.

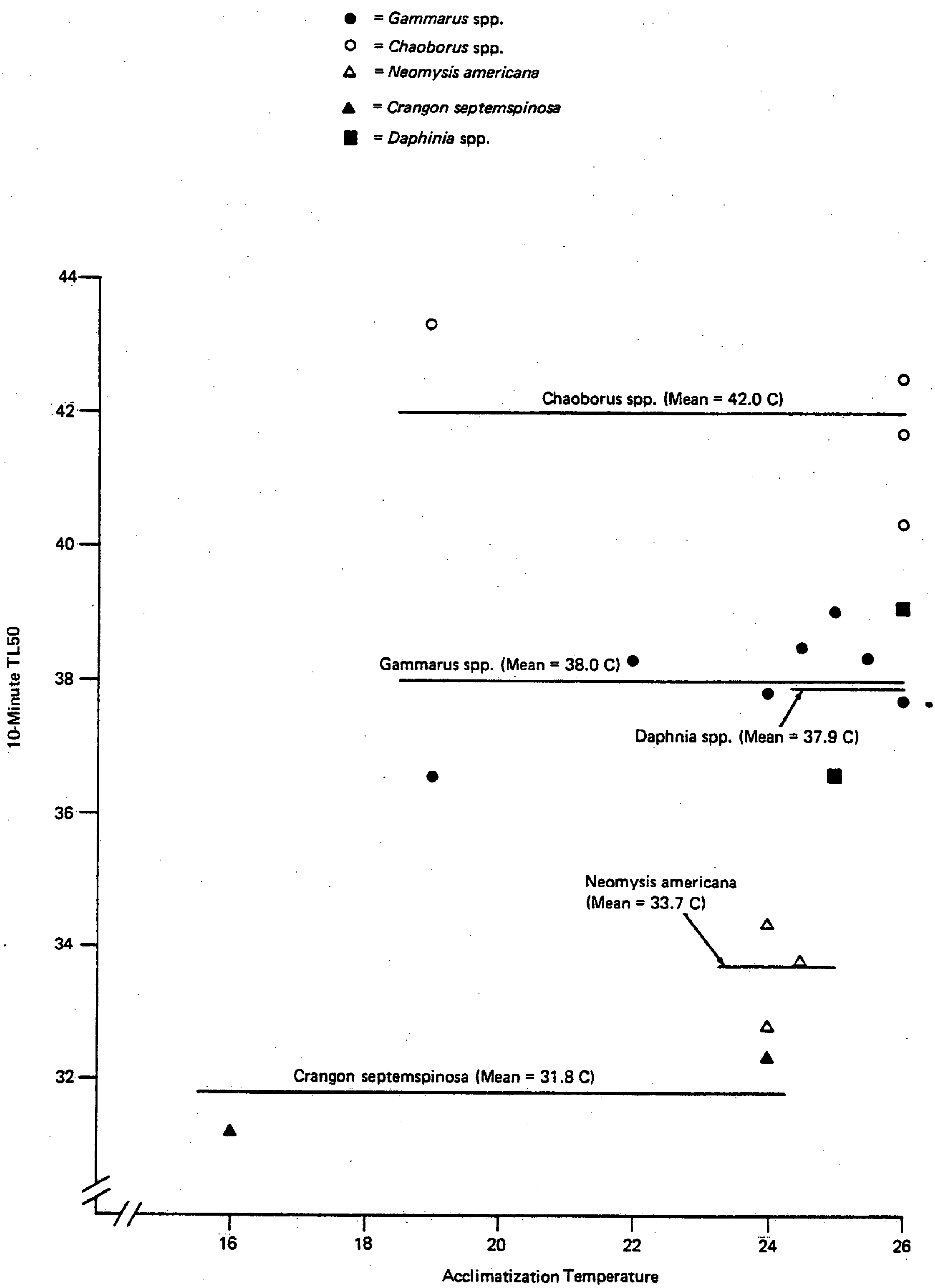


Figure 5.2-6. Relative tolerance of five Hudson River invertebrates to thermal shock. The mean 10-minute TL50 is shown as a solid line spanning the acclimation temperatures tested for each species.

difference in thermal tolerance limits for *Chaoborus* spp. or *Gammarus* spp. at the higher salinities. The least tolerant invertebrate was *C. septemspinosa*, with TL50s ranging from 30.7 for a 60-minute exposure to 37.6 for a 10-second exposure. *N. americana* was only slightly more tolerant than *C. septemspinosa*.

Acclimatization temperatures did not appear to strongly influence the thermal tolerance of any invertebrate species over the range of acclimatization temperatures tested (Figure 5.2-6). Thermal tolerance limits generally decreased with increasing exposure durations, but the differences were usually quite small among the tests performed at exposure durations of 10-60 minutes. Tolerance limits for 10-second exposure durations, however, were much greater than tolerance limits determined for the longer exposure durations. Maximum safe temperature increases for each species acclimatized to high ambient river temperatures ranging from 24.0 to 26.0 C are the following.

	TL95 minus acclimatization temperature (C)				
	Chaoborus spp.	*Gammarus* spp.	*Daphnia* spp.	*Neomysis americana*	*Crangon septemspinosa*
10-minute exposures	10.8-13.8	8.2-12.5	8.0-8.4	7.2-9.0	6.3
30-minute exposures	8.6-11.9	10.6-11.7	8.2	4.8-7.3	7.8
60-minute exposures	11.0-14.0	9.0-12.0	9.7	--	--

CHAPTER 6: UPPER THERMAL TOLERANCE STUDIES

Power plants employing once-through cooling systems return cooling water to the receiving water body at elevated temperatures, creating thermal plumes. If the temperature increases are large enough, they may render zones of the thermal plume uninhabitable for aquatic organisms. Actual mortality would not be expected to occur within these areas, since most mobile macroscopic organisms have been shown to actively avoid temperatures that exceed requirements for survival (Meldrim and Gift 1971; TI 1976; EA 1978a). The extent of the available habitat within the area of the discharge that becomes unavailable to aquatic organisms depends on the location of the discharge, the volume of cooling water employed, the magnitude of the temperature increase, the dilution rate of the discharge water, and the upper limit of the temperature range permitting survival of the aquatic organisms. To evaluate predictively the extent to which the thermal plumes created by Hudson River power plants may exclude aquatic organisms from the available habitat because of high temperatures, thermal tolerance limits of representative important species were determined for extended exposures ranging from 24 to 96 hours. The areas and volumes of the thermal plumes from the Bowline Point and Indian Point Generating Stations and the combined plume from the Danskammer Point and Roseton Generating Stations in which these temperature requirements are exceeded are presented and discussed in 316(a) demonstrations for the respective plants.

6.1 METHODS AND MATERIALS

6.1.1 Experimental Procedures

The tolerances of organisms to extended thermal exposures were determined primarily for juvenile and adult fish, and to a lesser extent for invertebrates and fish larvae.

Thermal tolerance experiments on juvenile and adult fish were conducted by abruptly exposing test organisms to a series of elevated test temperatures and then exposing them continuously to the test temperatures for 96 hours. Tests were usually conducted on fish within 24-72 hours after capture. For a few tests performed during late fall and winter, test organisms were collected several weeks before the tests and maintained at ambient river temperatures in the laboratory. In order to determine the effects of acclimatization temperature on thermal tolerance, tests were conducted on several species during all seasons of the year. Fish collected from the brackish regions of the lower estuary, with the exception of three tests on Atlantic tomcod juveniles, were tested at salinities similar to those at which the fish were collected. Specific details of the experimental facilities and procedures were modified from Brett (1941), and are as follows (chronological order):

1. Ten to twenty fish were transferred directly from the river or from holding tanks to the test tanks and held at ambient river temperatures 24 hours prior to initiation of the test. Three series of insulated test tanks were available for tests: (1) six 75-liter square tanks, (2) six 190-liter oval tanks, and (3) five 570-liter oval tanks. The majority of tests were performed with the 190-liter tanks; the 75-liter and the 570-liter series were used for small young-of-the-year and

large adult fish, respectively. Each test tank was provided with a continuous flow of ambient river water (used for holding fish prior to the test) and water adjusted to the desired test temperature via a thermostatic mixing valve (used during tests) (Figure 6.1-1).

2. At the initiation of the test, "instantaneous" exposure to the test temperatures was accomplished by draining most of the ambient water from the test tanks and immediately replacing it with water adjusted to the test temperatures. For this purpose, each tank was equipped with a secondary standpipe connected to a valve, allowing the water level to be lowered to a depth of 5-10 cm. Temperature equilibration was achieved within 5-10 minutes after initiation of the test.

3. A few tests were conducted on fish acclimated to temperatures greater than ambient river temperatures. For these tests it was not possible to employ the above procedures, and fish were transferred directly from holding tanks to test tanks containing water adjusted to the appropriate test temperatures.

4. Each test tank was aerated and flow rates were maintained at approximately 6-12 liters per minute throughout the test.

5. Control fish were treated in the same manner as experimental fish, but were held at ambient river temperatures throughout the test. For tests conducted on fish acclimated to temperatures greater than ambient river temperatures, control fish were held in test tanks adjusted to the acclimation temperature.

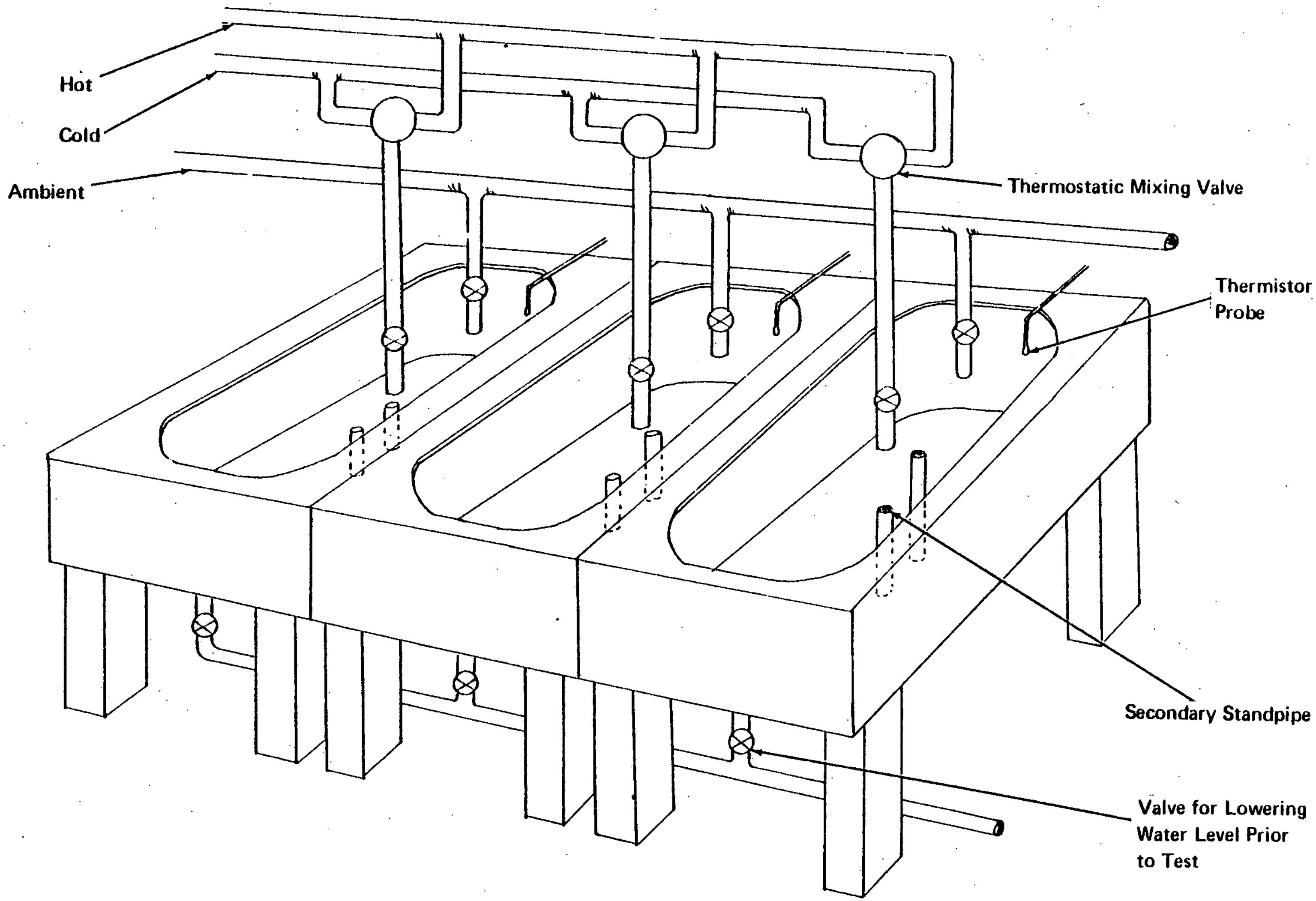


Figure 6.1-1. Apparatus used for conducting thermal tolerance experiments on adult and juvenile fish.

6. For tests performed in the spring and summer of 1976, test temperatures were recorded to the nearest 0.1 C several times throughout the test with precalibrated thermometers. After these early tests, temperatures were monitored hourly with thermister probes placed in each tank and were recorded by a computerized data acquisition system (Chapter 3). Test temperatures were typically maintained within ±0.5 C.

7. Mortality was assessed at 1, 24, 48, and 96 hours after the initiation of the test. All test fish were weighed to the nearest 1.0 g and total lengths were determined to the nearest 1.0 mm.

Testing procedures for fish larvae and invertebrates were similar to those outlined in Subsection 5.1.1. However, the exposure duration was extended to 24 hours and the test organisms were not returned to ambient-temperature water baths after the exposure. Thermal tolerance limits for these tests were calculated on mortality assessed immediately after the 24-hour exposure, rather than 24 hours after the end of the test.

6.1.2 Analytical Procedures

Thermal tolerance limits for juvenile and adult fish were calculated on mortality assessments made 1, 24, 48, and 96 hours after the initiation of the test according to procedures outlined in Subsection 5.1.2. Actual test temperatures were determined as the mean test temperature recorded during each "exposure duration." For these tests, only dead organisms were included in the mortality assessment; most "stunned" fish (those that had lost equilibrium) either died or recovered by the end of the 96-hour exposure period. For fish larvae and invertebrates, only 24-hour thermal tolerance limits were determined, and "stunned" organisms were included in the mortality assessment.

6.2 RESULTS AND DISCUSSION

Upper thermal tolerance limits for extended exposures were determined primarily for juvenile and adult fish. These tolerance limits can be used to identify zones of a thermal plume that are generally unsuitable for fish because of excessive temperatures. Limited tests were also performed on fish larvae, which are predominantly planktonic, in order to examine relationships between thermal tolerance and life stages, or ages, of fishes. The tolerances of invertebrates to extended thermal exposures were also determined to evaluate the extent to which discharges would exclude these species from bottom areas that may be influenced by thermal plumes.

Tests were usually conducted for 96 hours in order to estimate incipient lethal temperatures for each species. The incipient lethal temperature has been defined as "that temperature which, when a fish is brought rapidly to it from a different temperature, will kill a stated fraction of the population (generally 50 percent) within an indefinitely prolonged exposure" (Coutant 1970). However, some tests were terminated prior to 96 hours, primarily for two reasons: (1) equipment failure resulting in the inability to maintain test temperatures within specifications, and (2) significant mortality resulting from nonthermal stresses (as reflected by high control mortality). Thermal tolerance limits for tests with greater than 20 percent control mortality were omitted from the analysis of results (a few exceptions are noted).

The most useful parameter for defining the upper limit of the temperature range permitting survival of an organism is the ultimate upper incipient lethal temperature. The ultimate upper incipient lethal temperature, defined as the temperature lethal to a species that has fully extended its ability to acclimate to higher temperatures, is determined as the temperature at which further increases in acclimation (acclimatization) temperatures fail to produce higher incipient lethal temperatures. Upper incipient lethal temperatures determined for fish acclimated to temperatures that produce incipient lethal temperatures lower than the ultimate incipient lethal temperature would not actually exceed the temperature requirements of an organism if the organism were allowed sufficient time to acclimate to the higher temperatures. Therefore, fish may be able to reside within thermal discharges at temperatures greater than the incipient lethal temperatures, if available, during the cooler times of the year. In addition, fish can tolerate temperatures somewhat higher than the ultimate upper incipient lethal temperature for shorter periods of time (e.g., in the zone of thermal resistance, defined as the zone where temperatures are between incipient lethal and instantaneous death limits). Thermal tolerance limits for exposure duration less than 96 hours are useful for defining thermal tolerance within the zone of thermal resistence (Coutant 1970).

Tests were not performed on all species at acclimatization temperatures high enough to determine ultimate upper incipient lethal temperatures. However, incipient lethal temperatures determined for organisms acclimated to high ambient river temperatures represent conservative estimates of this parameter. Thermal tolerance limits and the relative tolerance of each life stage to extended thermal exposures are discussed in the following subsections for each species.

6.2.1 Striped Bass

Thermal tolerance tests were conducted on all life stages of striped bass except adults (Table 6.2-1) (see also Tables and Figures B-151 through B-166, B-118, B-122, B-126, and B-136 in Appendix B). Incipient lethal temperatures

TABLE 6.2-1 UPPER THERMAL TOLERANCE LIMITS FOR STRIPED BASS

Age Group	Mean Length (mm)	Date	Accl. Temp. (C)	Exposure Duration (hours)	Thermal Tolerance Limits (C) TL95	TL50	TL5	Test Code
Yolk sac larvae	(1 day old)	24 MAY 77	18.0	16(a)	25.9	26.4	26.9	LS-049
Yolk sac larvae	(1 day old)	28 MAY 77	19.0	14(b)	27.1	27.9	28.8	LS-048
Post-yolk-sac larvae	(15 days old)	2 JUN 76	15.0	24	22.6	26.3	30.1	LS-019
Post-yolk-sac larvae	(35 days old)	22 JUN 76	23.0	24	30.6	32.4	34.3	LS-025
Young of the year	59	4 AUG 76	25.0	1	34.1	35.2	36.2	TT-020
				24	33.1	34.4	35.8	
				48	32.3	33.6	34.9	
				96	32.6	33.2	33.9	
Young of the year	63	29 SEP 76	21.0	1	32.4	33.9	--	TT-036
				24	31.9	32.9	33.9	
				48	31.8	32.9	33.9	
				96	29.2	31.8	34.4	
Yearling	139	1 SEP 76	24.0	1	33.0	34.3	35.7	TT-029
				24	31.1	32.5	34.0	
				48	30.9	32.3	33.8	
Subadult	235	24 OCT 76	11.5	1	28.9	30.6	--	TT-039
				24	28.8	29.8	30.8	
				48	27.6	29.3	31.1	
				96	26.3	29.1	31.9	

(a) 4 replicates combined.
(b) 2 replicates combined.

Note: Dashes indicate that data were insufficient for accurate determinations of tolerance limits.

(96-hr TL50s) for juvenile striped bass ranged from 29.1 C (for subadults acclimatized to 11.5 C) to 33.2 C (for young of the year acclimatized to 25.0 C). The limits of tolerance of striped bass larvae to extended thermal exposures (14- to 24-hour TL50s) ranged from 26.3 to 32.4 C at acclimation temperatures of 15.0-23.0 C.

Striped bass larvae were generally less tolerant to extended thermal exposures than juveniles. Figure 6.2-1 illustrates the relative thermal tolerance of the various size groups to 24-hour exposures (tests on yolk-sac larvae extended only 14 and 16 hours.) Yolk-sac larvae and 16-day-old post-yolk-sac larvae exhibited tolerance limits 4-5 C lower than the expected TL50s for juvenile striped bass at similar acclimation temperatures. However, the 24-hour TL50 for 35-day-old post-yolk-sac larvae was similar to juvenile thermal tolerance, indicating an increase in thermal tolerance to extended exposures with advancing development. A similar increase in thermal tolerance to longer exposure durations was observed with advancing development for striped bass eggs and larvae exposed to elevated temperatures for 5-30 minutes (Subsection 5.2.1) The following is the regression of 24-hour TL50s for juvenile striped bass versus acclimization temperatures ranging from 11.5 to 25.0 C:

24-hour TL50 = 26.49 + 0.290(acclimatization temperature [C]).

Striped bass juveniles can tolerate temperatures greater than the incipient lethal temperature for time periods less than 96 hours. One-hour TL50s for striped bass juveniles were 1.5-2.1 C higher than the incipient lethal temperatures (Figure 6.2-2). Linear regressions of both 1-hour and 96-hour TL50s versus acclimatization temperatures over the range tested for juvenile striped bass are given in the following equations:

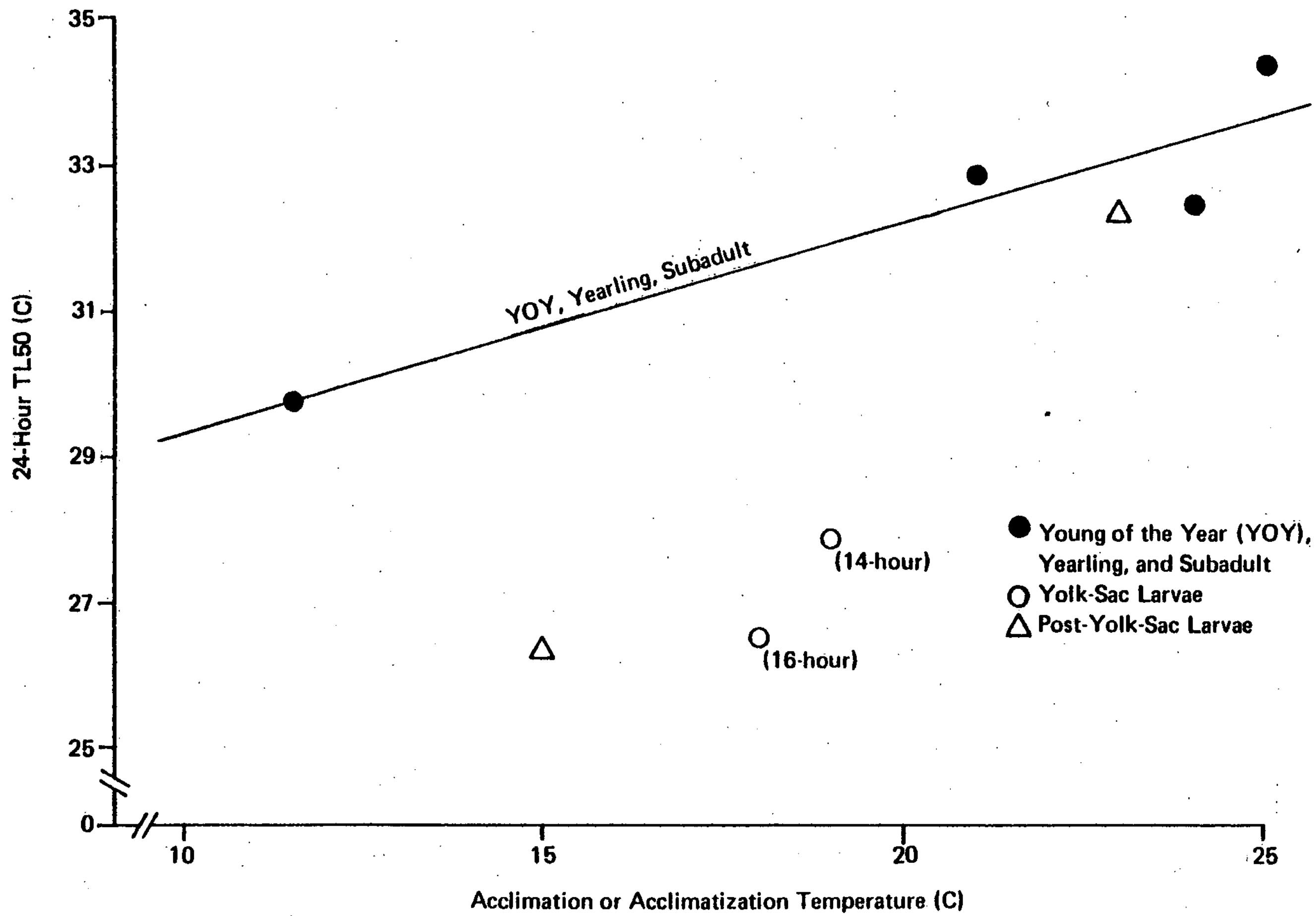


Figure 6.2-1. Relative thermal tolerance of striped bass yolk-sac larvae, post-yolk-sac larvae, and juveniles to 24-hour exposures. Regression line shown is for juveniles only.

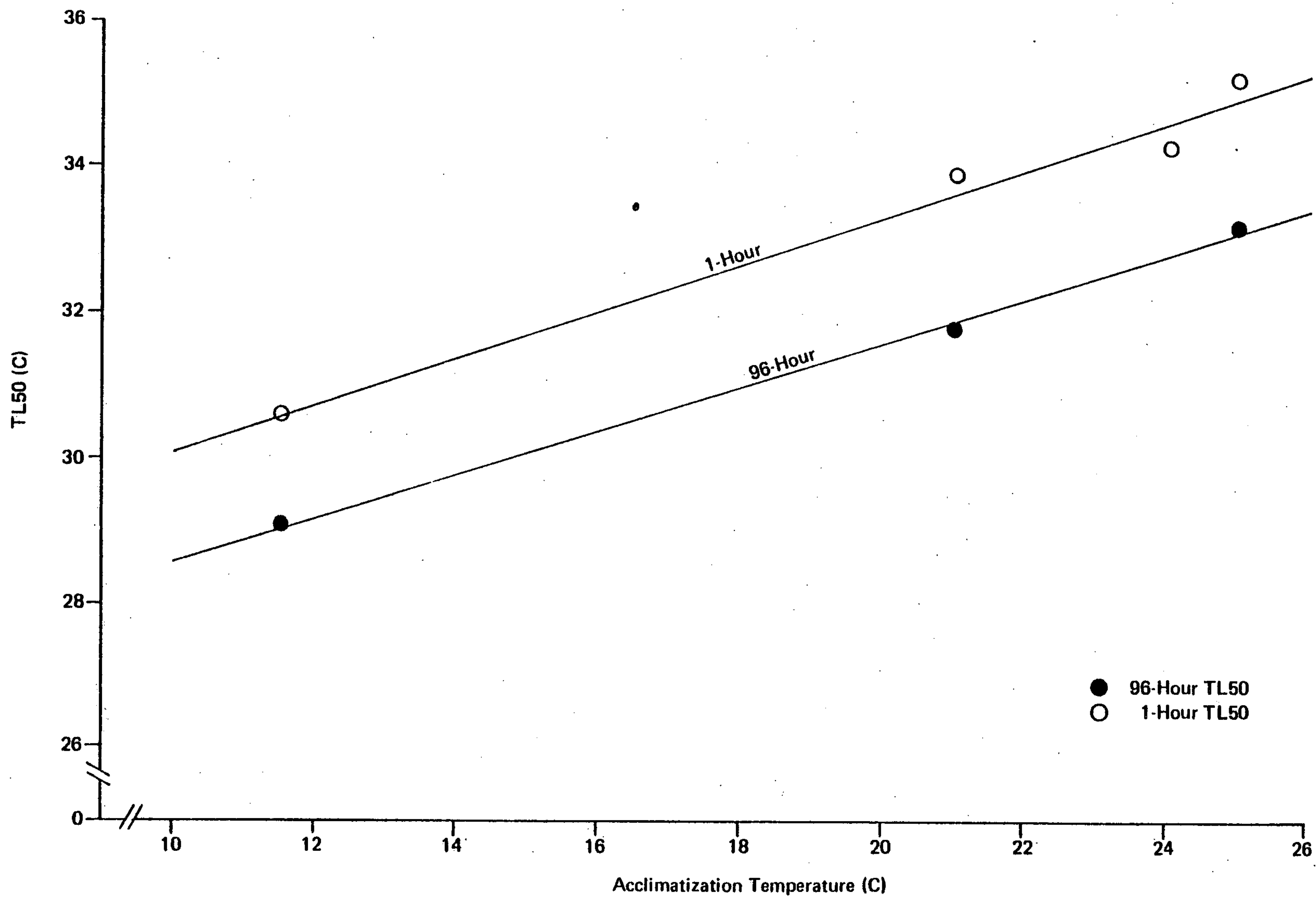


Figure 6.2-2. Relationship of 1-hour thermal tolerance limits to incipient lethal temperatures for striped bass juveniles.

1-hour TL50 = 27.50 + 0.272(acclimatization temperature [C]).

Incipient lethal temperature

= 25.61 + 0.300(acclimatization temperature [C]).

6.2.2 White Perch

White perch thermal tolerance tests were conducted with yolk-sac larvae, juveniles, and adults (Table 6.2-2) (see also Tables and Figures B-46 through B-75, B-7, B-12, and B-15 in Appendix B). Incipient lethal temperatures (96-hour TL50s) for adults and juveniles acclimatized to 25.0-26.0 C ranged from 32.4 to 34.7 C, and were slightly higher for the young-of-the-year fish. The tolerance limits of white perch yolk-sac larvae to extended thermal exposures (24-hour TL50s) ranged from 30.2 to 31.8 C. White perch juveniles and adults were found to be quite sensitive to handling, and many tests did not extend beyond 24 hours because of high mortality resulting from stresses other than temperature, which was reflected by high control mortality.

A comparison of 24-hour TL50s generally reveals little variation among life stages of white perch (Figure 6.2-3). The tolerance limits of yolk-sac larvae remained fairly constant over the 15.0-22.0 C range of acclimation temperatures tested; those for juveniles and adults were strongly influenced by acclimatization temperature. Although the 24-hour TL50 for juvenile white perch was lower than tolerance limits predicted for adults at that acclimatization temperature, TI (1976) found that incipient lethal temperatures (96-hr TL50s) for white perch juveniles and adults did not vary significantly according to size. The linear regression of 24-hour TL50s for white perch adults versus acclimatization temperatures ranging from 10 to 26 C is the following:

TABLE 6.2-2 UPPER THERMAL TOLERANCE LIMITS FOR WHITE PERCH

Age Group	Mean Length (mm)	Date	Accl. Temp. (C)	Exposure Duration (hours)	Thermal Tolerance Limits (C) TL95	TL50	TL5	Test Code
Yolk-sac larvae	(1 day old)	19 JUN 76	22.0	24	29.1	31.8	34.4	LS-031
Yolk-sac larvae	(1 day old)	3 JUN 76	21.0	24	26.7	30.2	33.7	LS-011
Yolk-sac larvae	(1 day old)	5 JUN 76	15.0	24	27.8	30.3	32.9	LS-013
Young of the year	31	22 JUL 76	25.5	1	33.9	35.1	36.4	TT-010
				24	33.4	34.5	35.7	
				48	33.3	34.5	35.7	
				96	33.2	34.4	35.6	
Young of the year	35	28 JUL 76	25.0	1	34.5	35.8	37.1	TT-017
				24	32.9	34.7	36.5	
				48	33.0	34.3	35.7	
				96	34.0	34.7	35.3	
Young of the year	58	1 SEP 76	24.0	1	32.5	34.6	36.8	TT-028
				24	--	33.1	34.9	
Yearling	87	17 JUN 76	21.0	1	28.3	31.2	34.0	TT-006
				24	--	28.0	30.5	
Adult	149	19 JUL 77	26.0	1	33.8	35.8	37.8	TT-072
				24	30.7	33.7	36.7	
				48	30.7	32.5	34.2	
				96	30.6	32.4	34.3	
Adult	104	17 AUG 76	24.0	1	33.1	34.4	35.7	TT-024
				24	32.4	33.7	34.9	
				48	29.3	31.9	34.5	
Adult	162	28 JUN 77	23.0	1	31.5	33.3	35.2	TT-027
Adult[(a)]	175	25 MAY 77	18.0	1	28.7	30.8	32.9	TT-067
				24	27.8	29.3	30.9	
				48	25.3	28.0	30.8	
Adult	169	20 APR 77	10.0	1	23.3	25.8	28.2	TT-066
				24	--	25.5	26.8	

(a) Spawning condition.

Note: Dashes indicate that data were insufficient for accurate determinations of tolerance limits.

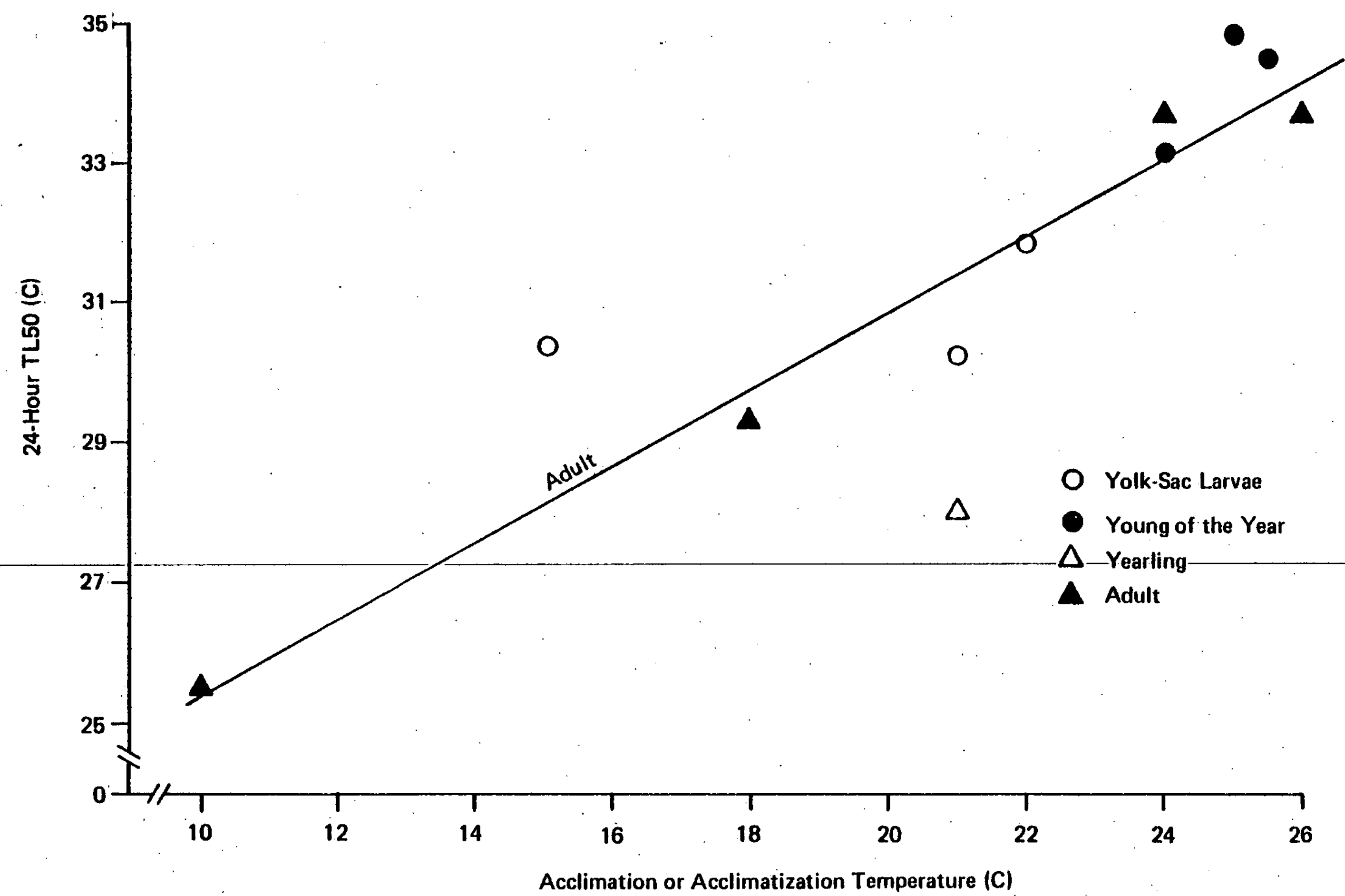


Figure 6.2-3. Relative thermal tolerance of white perch yolk-sac larvae, juveniles, and adults to 24-hour exposures. Regression line shown is for adults only.

24-hour TL50 = 19.92 + 0.545(acclimatization temperature [C]).

6.2.3 Atlantic Tomcod

The thermal tolerances of Atlantic tomcod were determined for yolk-sac larvae, post-yolk-sac larvae, subadults, and adults at ambient river temperatures representative of the seasonal occurence of each life stage (Table 6.2-3) (see also Figures and Tables B-208 through B-232, B-190, and B-201 in Appendix B). Incipient lethal temperatures (96- and 72-hour TL50s) for juveniles and adults ranged from 17.0 C for adults acclimatized to 3.0 C during the winter to 26.8 C for juveniles acclimatized to 24.0 C in the summer. The tolerance limits of Atlantic tomcod larvae to extended exposures (24-hour TL50s) ranged from 16.1 to 17.8 C at acclimation temperatures of 2.5-3.0 C. Figure 6.2-4 illustrates the relative thermal tolerance of Atlantic tomcod to 24-hour exposures. Twenty-four-hour TL50s adults in spawning condition during the winter were 3.0-5.0 C higher than those for other life stages tested at similar acclimation temperatures. The linear regression equation for 24-hour TL50s of subadults and spawning adults is the following:

24-hour TL50 = 19.96 + 0.337(acclimatization temperature [C]).

The mean incipient lethal temperature for Atlantic tomcod juveniles acclimatized to ambient river temperatures of 23.5 and 24.0 C during the summer was 26.6 C, less than 3 C higher than the acclimatization temperatures. Therefore, the ultimate upper incipient lethal temperature for tomcod during the summer is probably equal to this temperature (Figure 6.2-5). All but one of the tests conducted on juvenile tomcod were in fresh water. However, most tomcod are found in the brackish portion of the lower Hudson River estuary during the summer. To determine the thermal tolerance of juvenile tomcod at these

TABLE 6.2-3 UPPER THERMAL TOLERANCE LIMITS FOR ATLANTIC TOMCOD

Age Group	Mean Length (mm)	Date	Accl. Temp. (C)	Exposure Duration (hours)	Thermal Tolerance Limits (C) TL95	TL50	TL5	Test Code
Yolk-sac larvae	(1 day old)	14 FEB 77	2.5	24	15.5	17.8	20.1	LS-037
Post-yolk-sac larvae	(26 days old)	18 FEB 77	3.0	24	12.3	16.1	19.9	LS-042
Subadult	95	26 AUG 76	24.0	1	--	29.5	30.5	TT-025
Subadult[a]	73	26 JUL 77	24.0	1	27.8	28.9	30.1	TT-074
				24	26.2	28.0	29.9	
				48	25.0	27.1	29.2	
				72	26.1	26.8	27.5	
Subadult	94	8 SEP 76	23.5	1	27.9	29.2	30.6	TT-030
				24	26.3	27.6	29.0	
				48	25.1	26.7	28.3	
				96	25.9	26.4	27.0	
Subadult	99	19 OCT 76	15.0	1	26.2	27.6	--	TT-038
				24	23.6	25.5	27.4	
				48	23.9	25.2	26.5	
				96	22.2	24.5	26.7	
Adult	149	13 DEC 76	3.0	1	21.4	23.2	25.0	TT-054
				24	19.0	21.6	24.3	
				48	17.4	20.9	24.4	
				96	--	19.9	23.3	
Adult[b]	160	28 FEB 77	3.0	1	17.8	19.8	21.8	TT-057
				24	15.0	18.0	21.0	
				48	15.0	18.0	20.9	
				96	13.3	17.0	20.8	
Adult	142	18 JAN 77	1.5	1	--	>19.5	--	TT-055
				24	14.4	19.7	--	
				48	--	19.6	--	
				96	--	19.2	--	

(a) Test performed at 2 ppt salinity.
(b) Postspawners.

Note: Dashes indicate that data were insufficient for accurate determinations of tolerance limits.

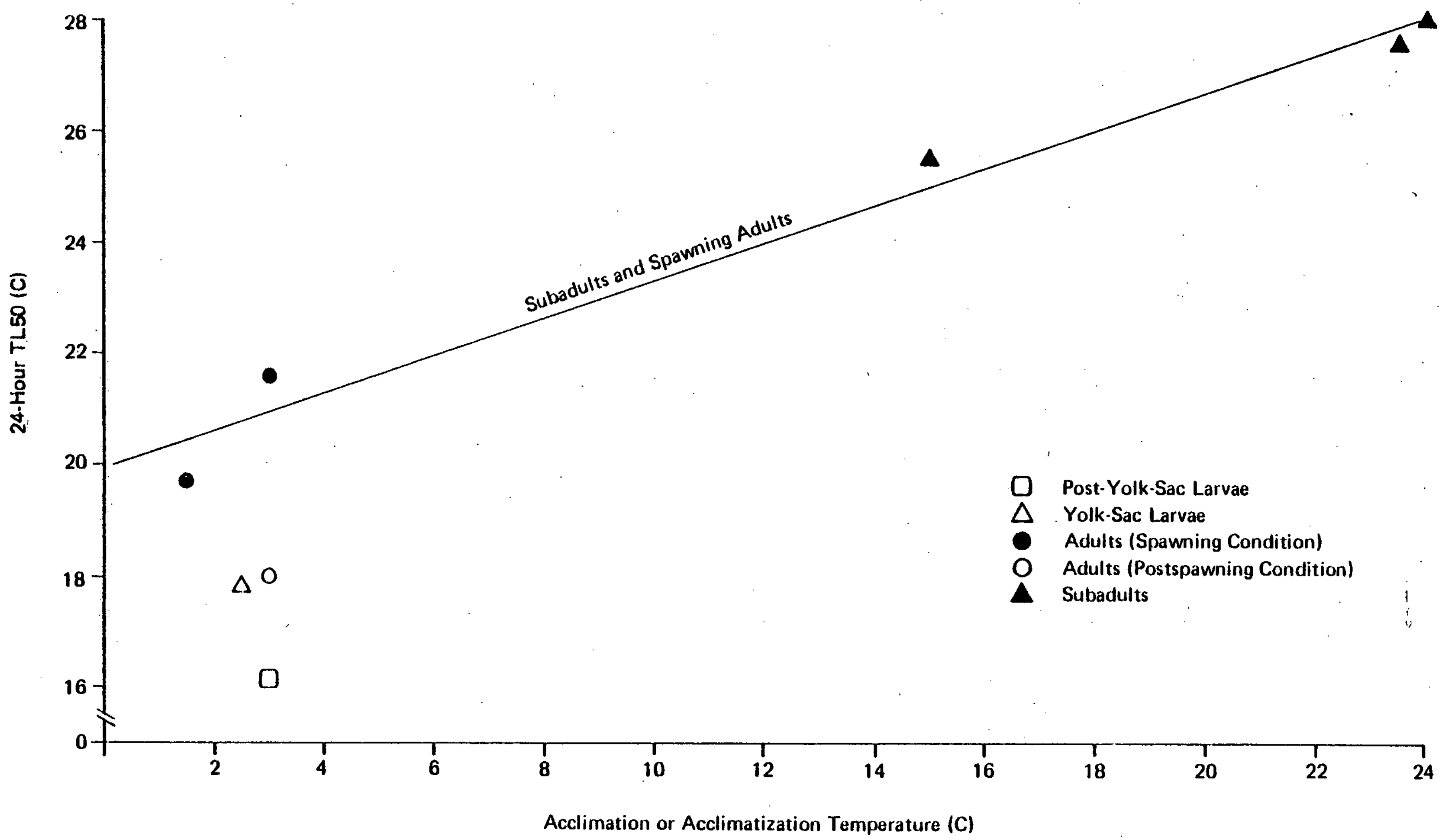


Figure 6.2-4. Relative thermal tolerance of Atlantic tomcod yolk-sac larvae, post-yolk-sac larvae, subadults, spawning adults, and postspawning adults to 24-hour exposures. Regression line shown is for subadults and spawning adults only.

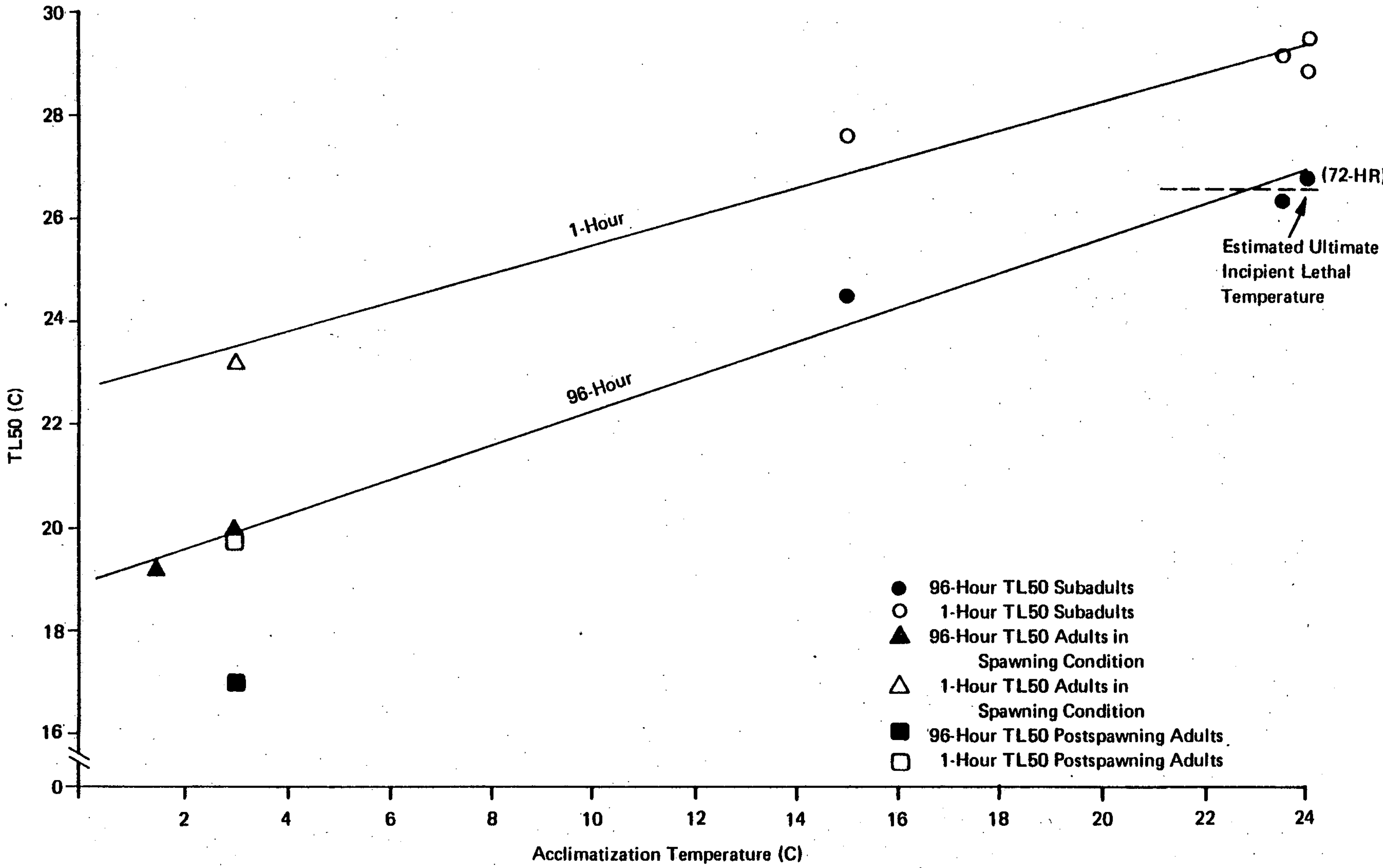


Figure 6.2-5. Relationship of 1-hour thermal tolerance limits to incipient lethal temperatures for Atlantic tomcod. Results for postspawning adults are not included in the regression.

higher salinities, a test was performed under static conditions at 2 ppt salinity. The 72-hour TL50 was only 0.4 C higher than the 96-hour TL50 resulting from a test performed the previous year at a similar acclimatization temperature, indicating that salinities up to 2 ppt did not enhance the tolerance of Atlantic tomcod to elevated temperatures.

The mean incipient lethal temperatures for adults acclimatized to ambient river temperatures during the winter were 19.6 C for adults in spawning condition and 17.0 C for postspawning adults. However, high mortalities occurred during attempts to acclimate and hold spawning adults in the laboratory at 10 and 15 C. Atlantic tomcod acclimated from river temperatures of 1.0-2.0 C to 15 C at a rate of 0.9 C per day all died within a 26-day holding period (Figure 6.2-6). Fifty percent mortality occurred after 20 days for spawning adults that were acclimated from ambient river temperatures to 10 C at a rate of 1.3 C per day. Ripe females were observed to die sooner than males, and many females discharged their eggs into the holding tanks as temperatures increased. In contrast, spawning adults held at ambient river temperatures (1-2 C) for up to 24 days survived with less than 1 percent mortality. All fish were fed frozen brine shrimp throughout the holding period. These results may indicate that the ultimate upper incipient lethal temperature for adults during the winter is much lower than the ultimate upper incipient lethal temperatures observed for subadult tomcod during late summer.

One-hour TL50s for tomcod subadults tested at acclimation temperatures of 23.5 and 24.0 C were approximately 2 C higher than 96-hour TL50s (Figure 6.2-5). Linear regressions for 1-hour TL50s and incipient lethal temperatures (96- and 72-hour TL50s) for subadults and adults are given in the following equations:

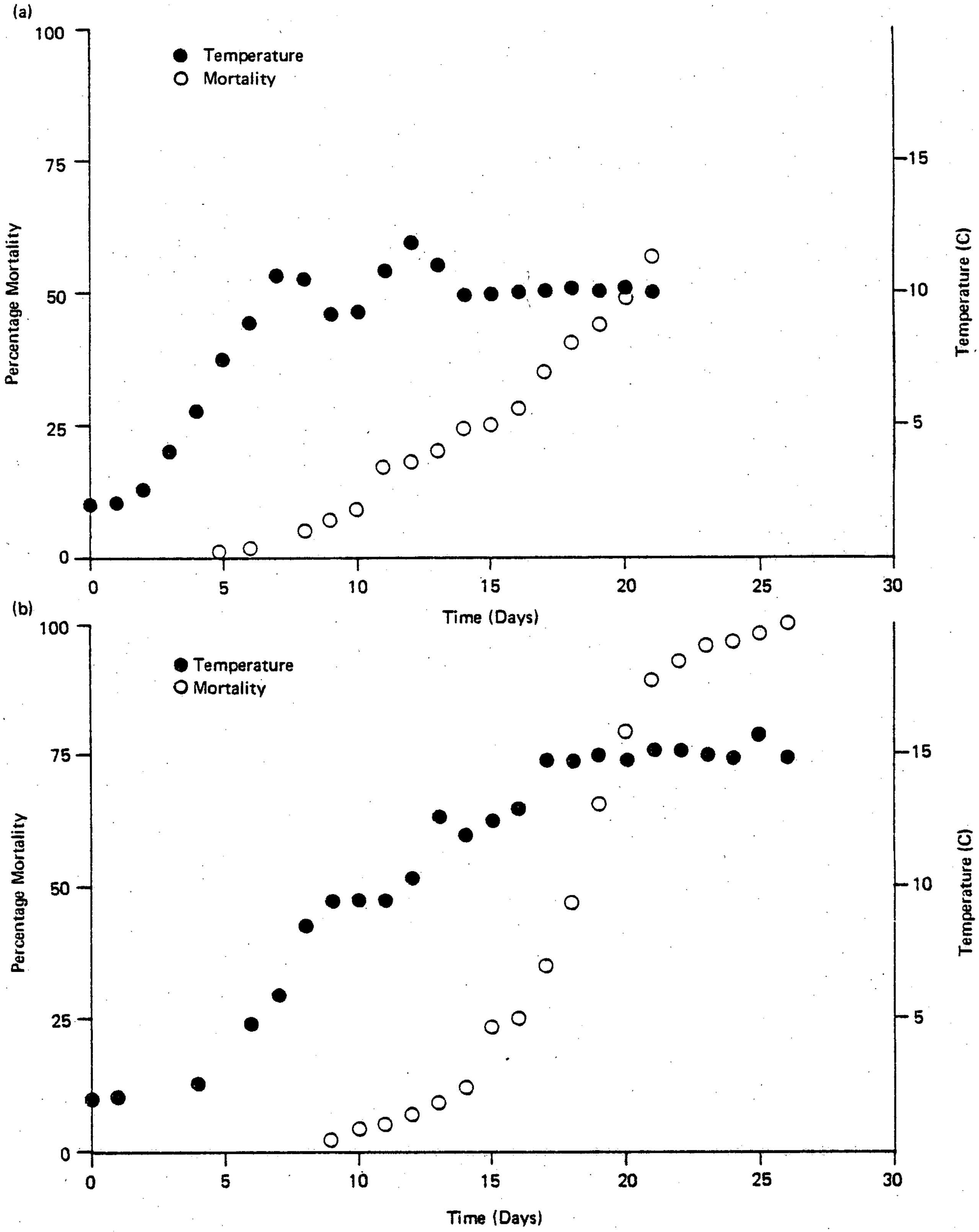


Figure 6.2-6. Mortality of Atlantic tomcod spawning adults during acclimation to above-ambient temperatures in January; (a) acclimation to 10 C at a rate of approximately 1.3 C per day, (b) acclimation to 15 C at a rate of approximately 0.9 C per day.

1-hour TL50 = 22.67 + 0.280(acclimatization temperature [C]).

Incipient lethal temperature

= 18.92 + 0.331(acclimatization temperature [C]).

Because of the apparent decrease in thermal tolerance after spawning, thermal tolerance limits for postspawning adults were omitted from the regression equation. Because the Atlantic tomcod population in the Hudson River is predominantly composed of a single year class (McFadden 1977) the above linear regressions represent thermal tolerance of Atlantic tomcod from late summer through midwinter.

6.2.4 Alewife

Alewife thermal tolerance tests were conducted on yolk-sac larvae, young of the year, and adults (Table 6.2-4) (see also Tables and Figures B-346 through B-362 and B-284 through B-334 in Appendix B). Incipient lethal temperatures (96-hour TL50s) for adults acclimatized to 14.5 C and 20.5 C were 25.5 and 28.4 C, respectively. For young-of-the-year alewife acclimatized to 23.0 and 25.0 C, incipient lethal temperatures were 31.7 and 32.6 C, respectively. The tolerance limits of alewife yolk-sac larvae to extended exposures (24-hour TL50s) ranged from 30.7 to 33.5 C at acclimation temperatures of 14.0 to 24.0 C. With the exception of alewife yolk-sac larvae acclimated to 24.0 C, tests were conducted at acclimatization temperatures representative of the seasonal occurrence of each life stage in the Hudson River.

Figure 6.2-7 illustrates the relative thermal tolerance of alewife to 24-hour exposures. The 24-hour TL50s for yolk-sac larvae varied little over the 10 C range of acclimation temperatures. The mean 24-hour TL50 for yolk-sac larvae was 31.4 C ± 0.8 (± standard deviation). In contrast, acclimatization

TABLE 6.2-4 UPPER THERMAL TOLERANCE LIMITS FOR ALEWIFE

Age Group	Mean Length (mm)	Date	Accl. Temp. (C)	Exposure Duration (hours)	Thermal Tolerance Limits (C) TL95	TL50	TL5	Test Code
Yolk-sac larvae	(1 day old)	17 MAY 76	24.0	24	28.0	30.8	33.6	LS-009
Yolk-sac larvae	(1 day old)	24 MAY 76	24.0	24	--	33.5	--	LS-008
Yolk-sac larvae	(1 day old)	18 MAY 76	20.0	24	27.9	31.1	34.3	LS-007
Yolk-sac larvae	(1 day old)	19 MAY 76	18.0	24	30.0	31.5	33.0	LS-003
Yolk-sac larvae	(1 day old)	25 MAY 76	18.0	24	27.9	31.1	34.2	LS-004
Yolk-sac larvae	(1 day old)	19 MAY 76	18.0	24	30.0	31.5	33.0	LS-003
Yolk-sac larvae	(1 day old)	20 MAY 76	15.0	24	30.4	31.6	32.8	LS-001
Yolk-sac larvae	(1 day old)	21 MAY 76	15.0	24	30.7	32.0	33.3	LS-002
Yolk-sac larvae	(1 day old)	11 MAY 77	14.0	24	29.8	30.7	31.6	LS-069
Yolk-sac larvae	(1 day old)	11 MAY 77	14.0	24	29.7	30.8	31.9	LS-068
Yolk-sac larvae	(1 day old)	11 MAY 77	14.0	24	30.2	31.1	31.9	LS-070
Young of the year	71	3 AUG 76	25.0	1	32.2	33.3	34.5	TT-019
				24	31.5	32.7	33.8	
				48	31.5	32.6	33.8	
				96	31.4	32.6	33.8	
Young of the year	80	15 SEP 76	23.0	1	31.1	32.4	33.7	TT-032
				24	29.3	31.5	33.6	
				48	30.3	31.6	33.0	
				96	30.5	31.7	32.8	
Adult(a)	288	8 JUN 77	20.5	1	27.7	29.6	31.4	TT-062
				24	26.7	28.3	30.0	
				48	26.0	28.0	29.9	
				96(b)	--	28.4	29.8	
Adult(c)	295	16 MAY 77	14.5	1	25.2	27.5	--	TT-061
				24	23.1	25.2	27.2	
				48	23.2	25.2	27.1	
				96(d)	23.6	25.5	27.5	

(a) Postspawners.
(b) Control mortality = 42 percent.
(c) Spawning condition.
(d) Control mortality = 25 percent.

Note: Dashes indicate that data were insufficient for accurate determinations of tolerance limits.

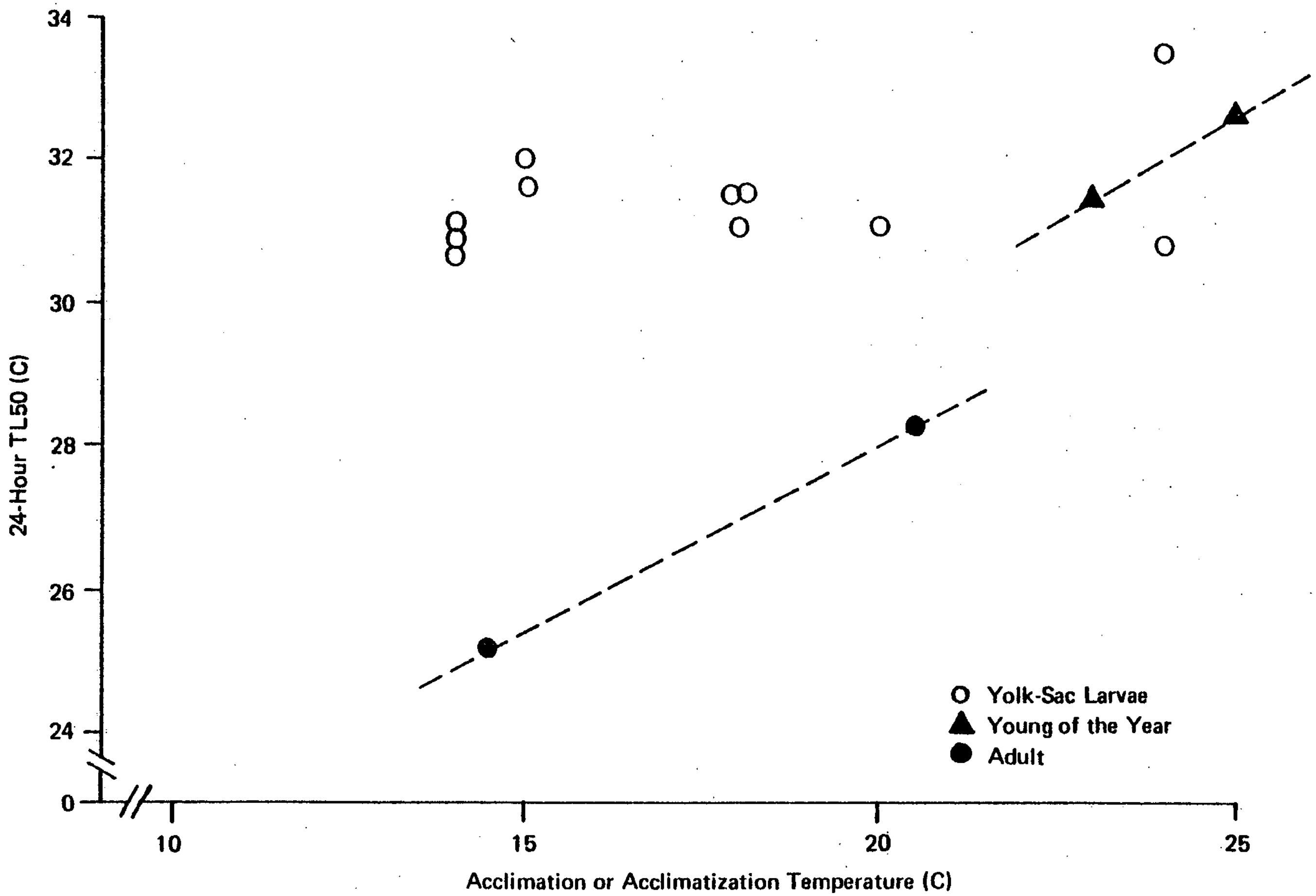


Figure 6.2-7. Relative thermal tolerance of alewife yolk-sac larvae, young of the year, and adults to 24-hour exposures.

temperature was an important factor in determining young-of-the-year and adult thermal tolerance. Whereas young of the year and yolk-sac larvae appeared to have similar thermal tolerances, alewife adults exhibited 24-hour TL50s that were 2.5-6 C lower than those for yolk-sac larvae when acclimated to similar temperatures. As young of the year and adults are usually not found in abundance in the Hudson River at the same time, thermal tolerance limits for the two size groups at similar acclimatization temperatures were not obtained.

Juvenile alewife appear to have a somewhat narrower zone of thermal resistance than adults. Differences between 1-hour TL50s and 96-hour TL50s were 0.7 C for both tests performed on young-of-the-year alewife, but ranged from 1.2 to 2.0 C for adults (Figure 6.2-8). Very little additional mortality was observed beyond 24 hours of exposure to elevated temperatures for both size classes.

6.2.5 White Catfish

The majority of thermal tolerance tests on white catfish were conducted with adults. Thermal tolerance limits were also determined to a lesser extent on post-yolk-sac larvae, early juveniles, and young of the year (Table 6.2-5) (see also Figures and Tables B-372 through B-402, B-368, and B-371 in Appendix B). Incipient lethal temperatures (72- and 96-hour TL50s) for white catfish adults ranged from 27.9 to 34.7 C at acclimatization temperatures of 12.5-26.0 C.

The tolerances of white catfish to extended thermal exposure does not appear to vary according to life stage. The 24-hour TL50s for post-yolk-sac larvae, early juveniles, and young of the year corresponded closely to 24-hour TL50s for adults (Figure 6.2-9). This was particularly evident at the higher

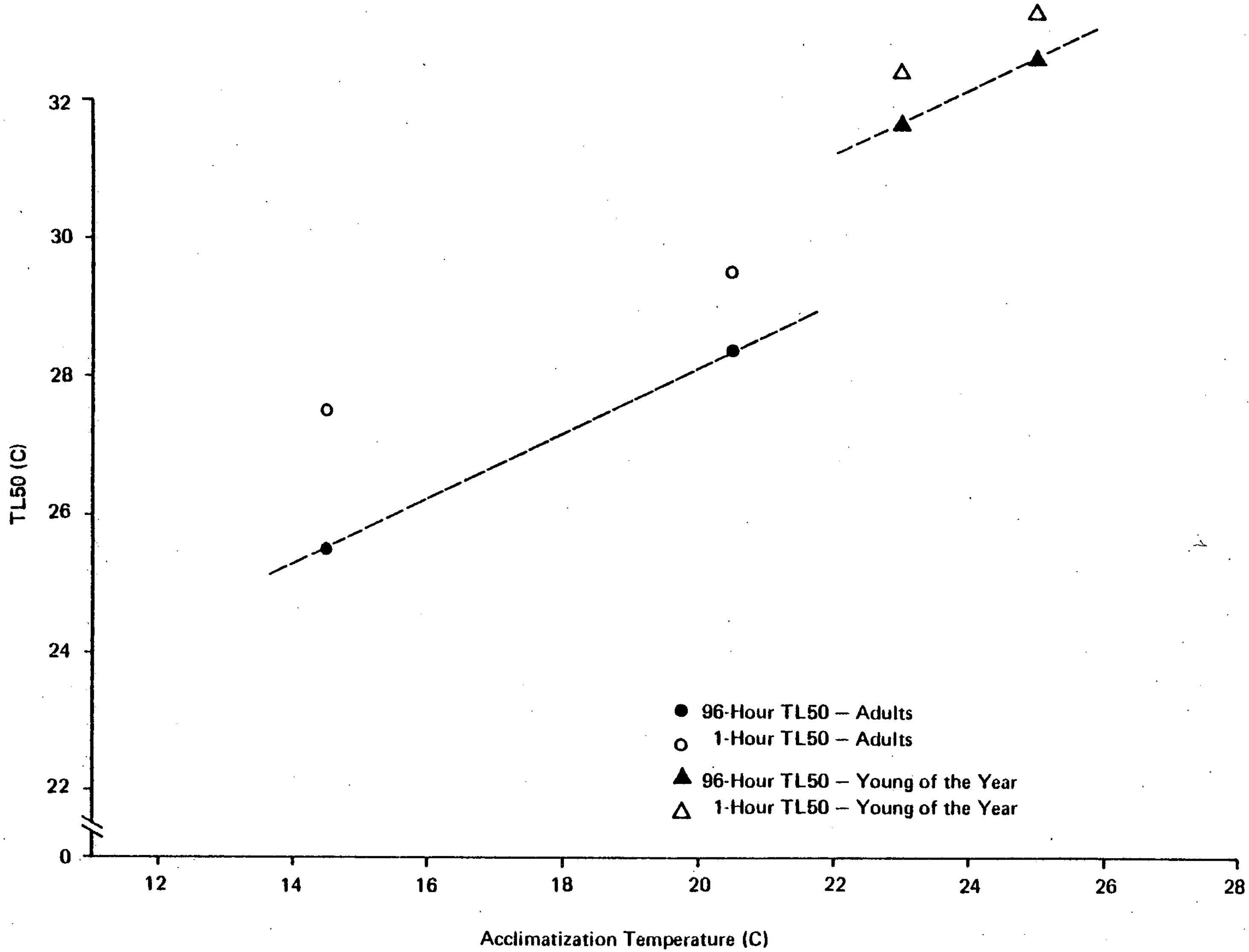


Figure 6.2-8. Relationship of 1-hour thermal tolerance limits to incipient lethal temperatures for alewife.

TABLE 6.2-5 UPPER THERMAL TOLERANCE LIMITS FOR WHITE CATFISH

Age Group	Mean Length (mm)	Date	Accl. Temp. (C)	Exposure Duration (hours)	Thermal Tolerance Limits (C) TL95	TL50	TL5	Test Code
Post-yolk-sac larvae	(10 days old)	22 JUL 76	25.0	24	33.8	35.4	37.1	LS-035
Early juveniles	(15 days old)	12 JUL 77	24.5	24	33.7	34.6	35.6	LS-113
Young of the year	77	29 NOV 76	16.5(a)	1	29.3	31.1	32.9	TT-052
				24	26.7	30.0	33.4	
				48	25.6	29.4	33.1	
				96	--	27.9	31.1	
Young of the year	73	16 NOV 76	7.5	1	--	--	--	TT-049
				24	26.3	26.8	27.3	
				48	24.7	26.3	28.0	
				96	--	25.6	28.1	
Adult(b)	260	8 JUL 76	26.0	1	35.4	36.5	--	TT-012
				24	34.3	35.6	36.9	
				48	34.0	34.7	35.3	
				96	34.0	34.7	35.3	
Adult(b)	268	11 JUL 77	25.0	1	35.0	35.9	36.8	TT-073
				24	32.9	35.0	37.1	
				48	32.3	34.3	36.3	
				96	31.3	33.7	36.1	
Adult(b)	304	20 JUN 77	22.0	1	34.4	35.1	35.9	TT-070
				24	33.8	34.8	35.9	
				48	33.7	34.8	35.9	
				96	31.8	33.9	36.0	
Adult	286	1 JUN 77	19.0	1	--	>35.0	--	TT-069
				24	30.1	32.9	35.7	
				48	30.0	32.9	35.8	
				96	30.0	32.8	35.6	
Adult	263	25 MAY 76	15.0	1	29.8	31.0	--	TT-009
				24	28.5	30.9	--	
				48	28.5	31.0	--	
				72	28.5	30.9	--	
Adult	272	25 APR 77	12.5	1	--	>30.0	--	TT-068
				24	25.4	28.1	30.7	
				48	25.1	27.8	30.5	
				96	25.1	27.9	30.6	

(a) Acclimated from 8.0 to 16.5 C.
(b) Adults in spawning condition.

Note: Dashes indicate that data were insufficient for accurate determinations of tolerance limits.

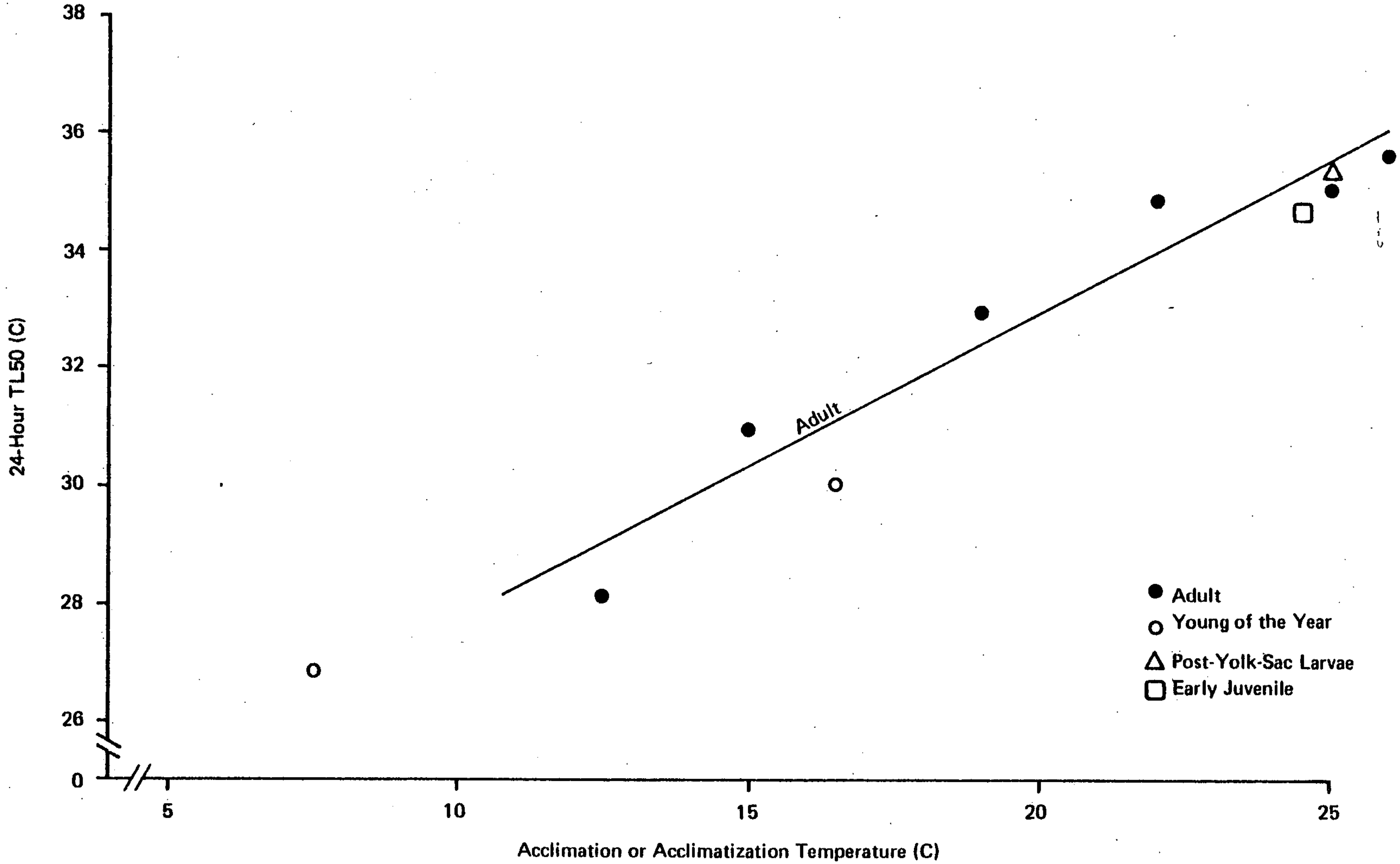


Figure 6.2-9. Relative thermal tolerance of white catfish post-yolk-sac larvae, juveniles, and adults to 24-hour exposures. Regression line shown is for adults only.

acclimatization/acclimation temperatures (24.5-26.0 C), where 24-hour TL50s varied by only 2.0 C among tests on post-yolk-sac larvae, early juveniles, and adults.

Incipient lethal temperatures for white catfish adults appeared to level off at acclimatization temperatures greater than 22 C (Figure 6.2-10). The ultimate upper incipient lethal temperature for white catfish adults appeared to be 34.2 C, as estimated by the mean 96-hour TL50 at acclimatization temperatures of 25.0-26.0 C. Most of the adults tested at these high ambient river temperatures were in spawning condition (i.e., gravid). One-hour TL50s for adults acclimatized to 25.0 and 26.0 C were 35.9 C and 36.5 C, respectively, and exceeded the estimated ultimate upper incipient lethal temperature by 1.7-2.3 C. Linear regressions of both 1-hour and 96-hour TL50s versus acclimatization temperatures for white catfish adults are the following:

1-hour TL50 = 23.71 + 0.496(acclimatization temperature [C]).

Incipient lethal temperature

= 22.74 + 0.472(acclimatization temperature [C]).

6.2.6 Spottail Shiner

Young-of-the-year and adult spottail shiner were tested at acclimatization temperatures ranging from 5 to 26 C (Table 6.2-6) (see also Tables and Figures B-416 through B-477 in Appendix B). Incipient lethal temperatures for both young of the year and adults ranged from 22.6 to 34.4 C. Multiple linear regression analysis revealed that both size and acclimatization temperature were statistically significant variables ($p = 0.05$) in determining tolerance limits for 1-, 24-, and 48-hour exposures, as shown in the following multiple linear regression analysis:

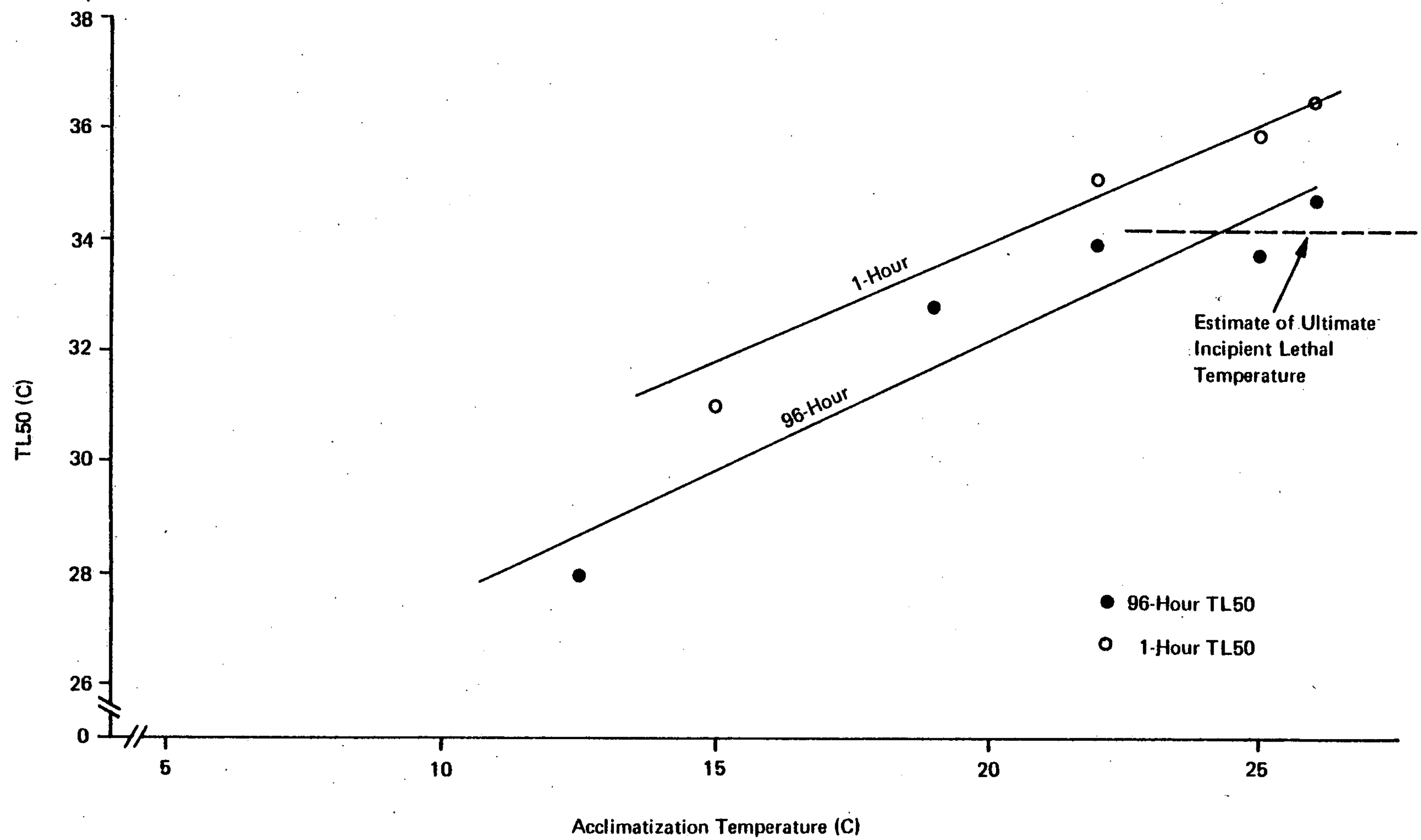


Figure 6.2-10. Relationship of 1-hour thermal tolerance limits to incipient lethal temperatures for white catfish adults.

TABLE 6.2-6 UPPER THERMAL TOLERANCE LIMITS FOR SPOTTAIL SHINERS

Age Group	Mean Length (mm)	Date	Accl. Temp. (C)	Exposure Duration (hours)	Thermal Tolerance Limits (C) TL95	TL50	TL5	Test Code
Young of the year	20	13 JUL 76	26.0	1	35.3	35.8	36.4	TT-014
				24	33.6	35.0	36.4	
				48	33.4	34.7	36.1	
				96	33.0	34.4	35.9	
Young of the year	44	11 AUG 76	24.0	1	33.0	34.5	35.9	TT-022
				24	32.6	33.9	35.2	
				48	31.3	32.9	34.5	
				96	31.3	32.8	34.4	
Young of the year	56	15 SEP 76	23.0	1	33.5	34.2	34.9	TT-033
				24	31.2	33.3	35.3	
				48	31.8	33.2	34.5	
				96	31.7	33.1	34.5	
Young of the year	65	22 NOV 76	16.5(a)	1	30.0	32.4	34.9	TT-047
				24	--	30.2	31.1	
Young of the year	64	2 NOV 76	9.0	1	28.5	30.5	--	TT-041
				24	26.0	28.4	30.8	
				48	25.9	28.3	30.7	
				96	25.4	27.7	30.0	
Adult	87	15 JUL 76	25.0	1	33.7	35.2	36.7	TT-015
				24	32.5	33.7	35.0	
				48(b)	32.1	33.0	33.9	
				96(b)	32.5	33.2	33.9	
Adult	88	21 JUL 76	25.0	1	33.9	35.2	36.4	TT-013
				24	33.6	34.1	34.7	
				48	32.4	33.8	35.2	
				96(c)	32.5	33.8	35.1	
Adult	95	26 AUG 76	24.0	1	34.1	34.8	35.5	TT-026
				24	31.5	33.4	35.3	
				48	31.4	32.7	33.9	
				96	30.6	32.2	33.8	
Adult	103	22 SEP 76	21.5	1	31.7	33.9	36.2	TT-034
				24	30.5	32.3	34.2	
				48	30.1	31.7	33.2	
				96	28.6	30.7	32.8	

(a) Acclimated to 16.5 from 8.0 C (results not included in statistical analyses).
(b) Control Mortality = 30 percent.
(c) Control Mortality = 27 percent.
(d) Spawning condition.

Note: Dashes indicate that data were insufficient for accurate determinations of tolerance limits.

TABLE 6.2-6 (CONT.)

Age Group	Mean Length (mm)	Date	Accl. Temp. (C)	Exposure Duration (hours)	Thermal Tolerance Limits (C) TL95	TL50	TL5	Test Code
Adult(d)	105	13 JUN 77	20.0	1	30.9	32.5	--	TT-065
				24	27.9	30.3	32.7	
				48	27.0	29.7	32.4	
				96	--	27.6	32.4	
Adult	102	22 NOV 76	16.5(a)	1	29.9	32.4	34.8	TT-048
				24	--	29.7	31.1	
Adult(d)	107	23 MAY 77	16.5	1	29.8	30.7	31.7	TT-064
				24	26.9	29.0	31.1	
				48	27.6	28.6	29.7	
				96	27.6	28.6	29.7	
Adult(d)	104	4 JUN 76	16.0	1	28.2	30.9	33.7	TT-001
				24	27.2	29.0	30.7	
				48	25.6	28.3	31.0	
				96	--	27.5	31.3	
Adult	107	3 MAY 77	12.0	1	27.8	29.7	31.6	TT-063
				24	27.9	28.8	29.7	
				48	27.8	28.8	29.7	
				96	28.3	29.4	30.6	
Adult	106	25 OCT 76	11.5	1	--	>30.6	--	TT-040
				24	29.3	29.7	30.1	
				48	29.3	29.7	30.1	
				96	28.3	29.4	30.6	
Adult	106	6 DEC 76	5.0	1	24.7	27.1	--	TT-053
				24	21.4	24.5	27.6	
				48	21.5	24.2	26.9	
				96	21.0	22.6	24.3	

(a) Acclimated to 16.5 from 8.0 C (results not included in statistical analyses).
(b) Control Mortality = 30 percent.
(c) Control Mortality = 27 percent.
(d) Spawning condition.

Note: Dashes indicate that data were insufficient for accurate determinations of tolerance limits.

$$TL50 = a + b_1 \text{ (acclimatization temperature)} + b_2 \text{ (mean length)}$$

Exposure duration (hours)	Mean TL50 (C)	F statistic	Computed t_1 value (acclimatization temperature) (C)	Computed t_2 value (mean length) (mm)
1	32.7	115.8**	12.82**	-2.03*
24	31.1	79.0**	10.06**	-2.12*
48	30.7	49.7**	7.78**	-1.99*
96	30.2	28.7**	5.78**	-1.71

* Significant at $p = 0.05$
** Significant at $p = 0.005$

However, young-of-the-year 24-hour TL50s were only 1.0 C higher than 24-hour TL50s for adults at acclimatization temperatures ranging from 23 to 26 C (Figure 6.2-11). Linear regression equations for each size group are the following:

Young of the year 24-hour TL50 = 25.0 + 0.375(acclimatization temperature [C]).

Adult 24-hour TL50 = 23.0 + 0.421(acclimatization temperature [C]).

Analysis of covariance indicated that the variance and slopes were similar for the two regressions, whereas the elevation of the line for young-of-the-year spottail shiners was significantly greater than that for adults at $p = 0.08$. As indicated by the multiple regression analysis, incipient lethal temperatures (96-hour TL50s) did not vary significantly according to size.

Adult spottail shiners tested from late May through mid-June, just prior to the spawning season, appeared to have somewhat lower thermal tolerances than adults during other seasons, although varying acclimatization temperatures

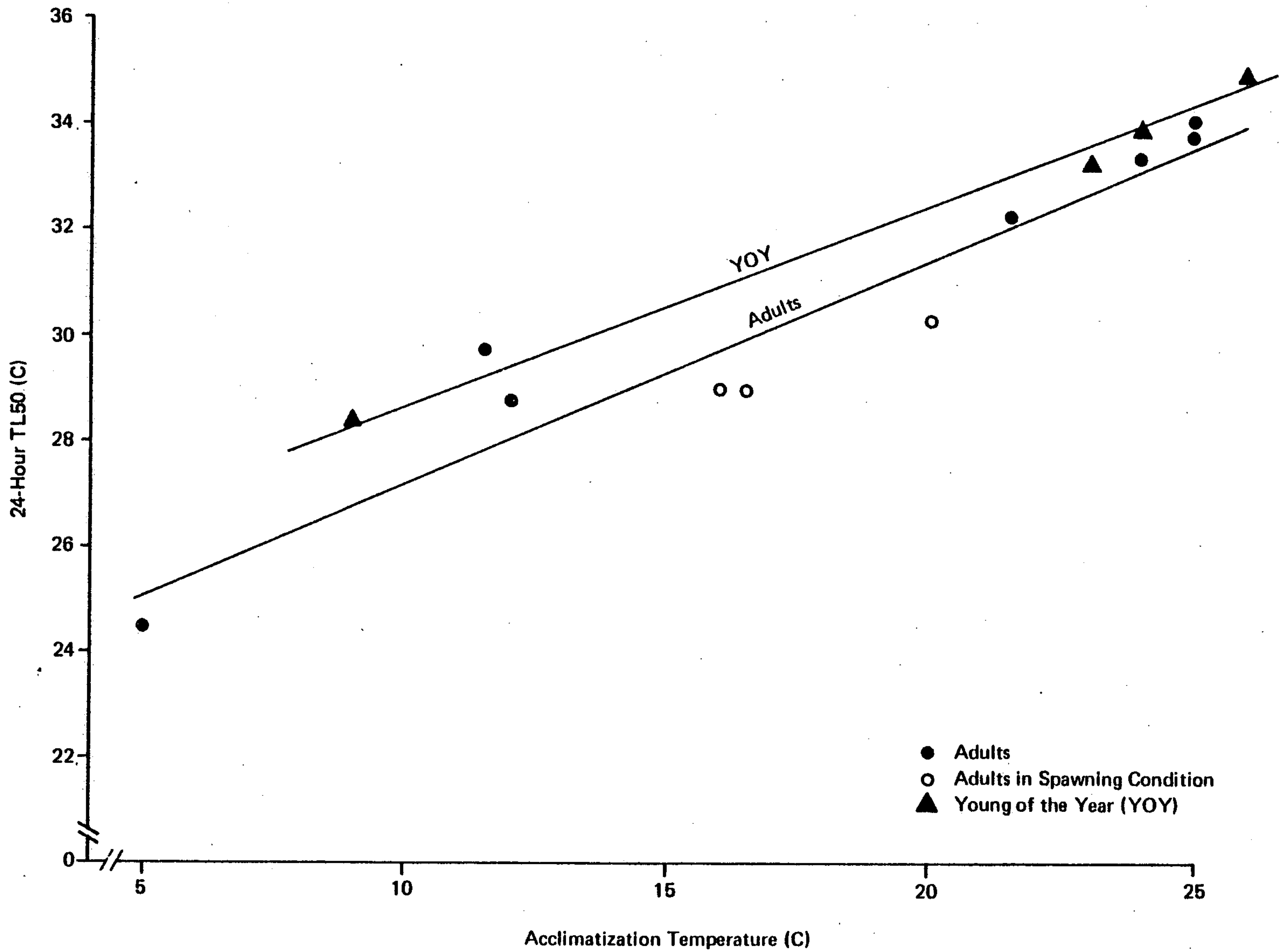


Figure 6.2-11. Relative thermal tolerance of spottail shiner young of the year and adults to 24-hour exposures.

make direct comparisons difficult. This difference was most pronounced for the 96-hour exposures (Figure 6.2-12). Adults tested during the fall at acclimatization temperatures of 11.5 and 12.0 C exhibited incipient lethal temperatures higher than spawning adults tested at acclimatization temperatures of 16-20 C.

The zone of thermal resistance for spottail shiners was most pronounced at the lower acclimatization temperatures (Figure 6.2-12). One-hour TL50s for spottail shiners were generally 2.0 C higher than the incipient lethal temperatures. Linear regressions of both 1-hour and 96-hour TL50s versus acclimatization temperature for young of the year and adults combined are the following:

1-hour TL50 = 25.47 + 0.385(acclimatization temperature [C]).

96-hour TL50 = 22.16 + 0.433(acclimatization temperature [C]).

6.2.7 Other Hudson River Fishes

Six thermal tolerance tests were conducted on five additional Hudson River fishes: pumpkinseed sunfish (*Lepomis gibbosus*), brown bullhead (*Ictalurus nebulosus*), blueback herring (*Alosa aestivalis*), American shad (*Alosa sapidissima*), and bay anchovy (*Anchoa mitchilli*) (Table 6.2-7) (see also Tables and Figures B-491 through B-516 in Appendix B). Incipient lethal temperatures for young-of-the-year blueback herring and American shad acclimatized to 25.0 and 24.0 C, respectively, were similar to incipient lethal tem-

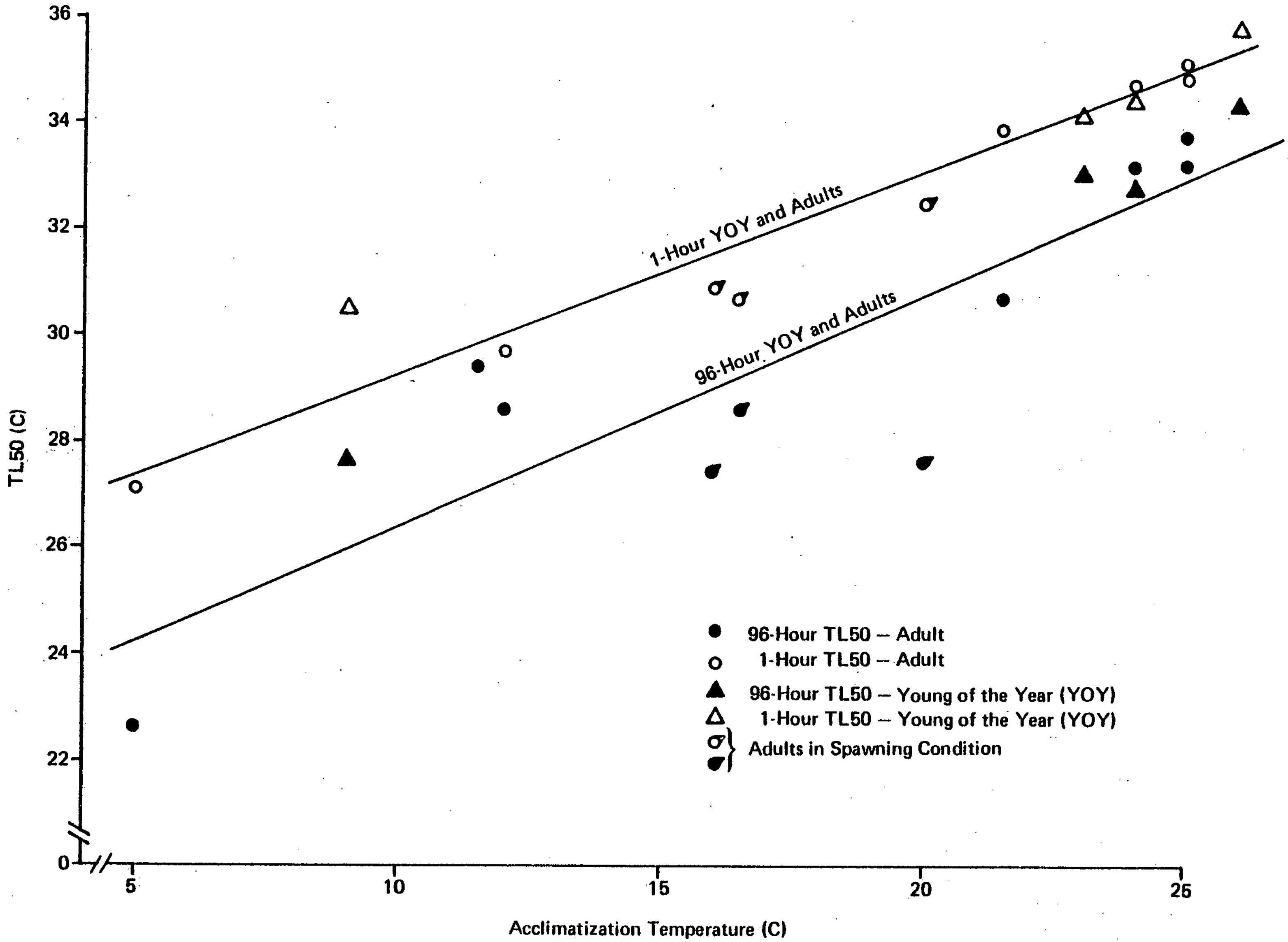


Figure 6.2-12. Relationship of 1-hour thermal tolerance limits to incipient lethal temperatures for spottail shiner.

TABLE 6.2-7 UPPER THERMAL TOLERANCE LIMITS FOR OTHER HUDSON RIVER FISHES

Species	Age Group	Mean Length (mm)	Date	Accl. Temp. (C)	Exposure Duration (hours)	Thermal Tolerance Limits (C) TL95	TL50	TL5	Test Code
Pumpkinseed sunfish (*Lepomis gibbosus*)	Adult	144	21 APR 76	12.5	1	26.0	28.2	--	TT-003
Brown bullhead (*Ictalurus nebulosus*)	Adult	230	3 MAY 76	14.0	1	27.9	30.0	32.1	TT-002
					24	27.1	29.7	32.3	
					44	27.0	29.3	31.6	
	Young of the year	44	8 SEP 76	24.0	1	34.8	35.9	36.9	TT-031
					24	35.0	35.6	36.2	
					48	35.0	35.6	36.2	
					96	35.1	35.7	36.2	
Blueback herring (*Alosa aestivalis*)	Young of the year	34	28 JUL 76	25.0	1	31.6	33.5	35.4	TT-018
					24	31.9	33.0	34.1	
					48	32.0	33.0	34.1	
					96	32.0	33.1	34.1	
American shad (*Alosa sapidissma*)	Young of the year	66	12 AUG 76	24.0	1	32.3	33.1	33.8	TT-021
					24	--	31.7	33.9	
					48	--	31.6	33.9	
					96	--	31.5	34.0	
Bay anchovy(b) (*Anchoa mitchilli*)	Juvenile	45	26 AUG 76	24.0	1	31.8	33.4	35.0	TT-027
					24	30.3	32.4	34.5	
					48(b)	32.1	33.0	33.9	
					93(c)	32.1	33.0	33.9	

(a) Test conducted at 8.0 ppt salinity in closed system aquaria.
(b) Control mortality = 30 percent.
(c) Control mortality = 47 percent.

Note: Dashes indicate that data were insufficient for accurate determinations of tolerance limits.

peratures (96-hour TL50s) exhibited by young-of-the-year alewife acclimatized to ambient river temperatures during summer months, as shown in the following.

Species	Acclimatization temperature (C)	Incipient lethal temperature (C)
Blueback herring	25.0	33.1
American shad	24.0	31.5
Alewife	25.0	32.6
Alewife	23.0	31.7

Bay anchovy juveniles exhibited an incipient lethal temperature (93-hour TL50 = 33.0 C) similar to that of young-of-the-year *Alosa* spp. at an acclimatization temperature of 24.0 C and 8 ppt salinity (Table 6.2-7).

6.2.8 Invertebrates

Five species of Hudson River invertebrates were tested for thermal tolerance to extended exposures at high acclimatization temperatures of 24.0-26.0 C (Table 6.2-8). The most tolerant species was *Chaoborus* spp., with 24-hour TL50s varying from 36.1 to 37.5 C. *Daphnia* spp. and *Gammarus* spp. had similar tolerances; 24-hour TL50s were 33.3 C and 33.8 C, respectively. The least tolerant invertebrate to extended thermal exposures was *Neomysis americana*. The 24-hour TL50 for *N. americana* was 29.4 C, representing a temperature increase of 5.4 C above the acclimatization temperature.

TABLE 6.2-8 UPPER THERMAL TOLERANCE LIMITS FOR HUDSON RIVER INVERTEBRATE SPECIES

Species	Date	Accl. Temp. (C)	Salinity (ppt)	Exposure Duration (hours)	Thermal Tolerance Limits (C) TL95	TL50	TL5	Test Code
Gammarus spp.	4 AUG 76	25.0	0.0	24	32.8	33.8	34.9	IS007
Neomysis americana	20 AUG 76	24.0	3.0	24	27.6	29.4	31.3	IS016
Chaoborus spp.	30 JUN 76	26.0	0.0	24	--	36.1	--	IS004
	16 JUL 76	26.0	0.0	24	34.7	37.5	--	IS001
Daphnia spp.	19 JUL 76	25.0	0.0	24	32.1	33.3	34.5	IS009

Note: Dashes indicate that data were insufficient for accurate determinations of tolerance limits.

CHAPTER 7: LOWER THERMAL TOLERANCE STUDIES

Fish residing in areas influenced by heated discharges may become metabolically acclimated to the warmer temperatures. In the event that the artificial heating should suddenly cease (i.e., total plant shutdown), these fish may become "cold shocked" upon return to the cooler ambient temperatures. The potential for cold shock depends on the extent to which fish are attracted to the warmer discharge waters (especially during the colder months), the magnitude of the temperature decrease between ambient river temperatures and the discharge temperatures within the habitable portions of the thermal plume, the probability of a total plant shutdown, and the lower thermal tolerance limits of the affected organisms. To evaluate the cold shock potential for thermal discharges from Hudson River power plants, lower thermal tolerance limits were determined for several representative important species (RIS). The actual assessments of cold shock potential at each power plant are presented and discussed in 316(a) demonstrations for the Indian Point, Bowline Point, and Roseton and Danskammer Generating Stations.

7.1 METHODS AND MATERIALS

Cold shock tests were usually conducted on fish collected during late fall and winter and acclimated to above-ambient temperatures, according to procedures discussed in Section 4.2. In two instances, fish acclimatized to ambient river temperatures were tested.

Cold shock tests were conducted by abruptly exposing organisms to a series of temperatures cooler than the acclimation temperature. Experimental procedures were similar to those employed for the upper thermal tolerance studies (Subsection 6.7.1), except that all tests were conducted using the direct-transfer method. Lower thermal tolerance limits were determined for 96-hour exposures according to procedures presented in Subsections 6.1.2 and 5.1.2.

7.2 RESULTS AND DISCUSSION

Lower thermal tolerance limits were determined for five species of Hudson River fish at several acclimation temperatures (Table 7.2-1) (see also Tables and Figures B-76 through B-89, B-167 through B-170, B-233 through B-236, B-478 through B-490, and B-403 through B-406). The 96-hour TL50s for all species tested ranged from 9.8 to 17.0 C below the acclimation temperatures. Atlantic tomcod and spottail shiner acclimated to 10 C tolerated cold shocks to 0 C.

The cold shock tolerances of white perch, striped bass, white catfish, and spottail shiner were remarkably similar. The 96-hour TL50s for these species acclimated to 16.5-17.0 C varied by only 2.0 C and ranged from 13.4 to 14.9 C below the acclimation temperatures, as shown in the following.

Species	Acclimation Temperature (C)	96-hr TL50 (C)	Acclimation temperature minus 96-hr TL50 (C)
White perch	17.0	3.0-3.6	13.4-14.0
Striped bass	17.0	2.2	14.8
White catfish	16.5	1.6	14.9
Spottail shiner	17.0	2.1-2.3	14.7-14.9

TABLE 7.2-1 LOWER THERMAL TOLERANCE LIMITS FOR FIVE HUDSON RIVER FISHES

Species	Age Group	Mean Length (mm)	Date Yr - Mo - Dy	Acclimation Temperatures (C)	96-Hr Thermal Tolerance Limits (C)			Test Code
					TL95	TL50	TL5	
White Perch	Young of the year	62	76 - 09 - 29	22.5(a)	7.6	5.5	3.5	TT-037
White Perch	Adult	141	76 - 11 - 02	17.0	4.4	3.0	1.6	TT=042
White Perch	Young of the year	79	76 - 11 - 02	17.0	5.0	3.6	2.2	TT-043
Striped bass	Young of the year	88	76 - 11 - 08	17.0	3.1	2.2	1.2	T-045
Atlantic tomcod	Adult	151	77 - 01 - 26	10.0(b)	--	<0.2	--	TT-056
White catfish	Young of the year	79	76 - 11 - 22	16.5	2.8	1.6	0.4	TT-046
Spottail shiner	Young of the year	65	76 - 09 - 22	22.0(a)	9.5	6.7	--	TT-035
Spottail shiner	Adult	102	76 - 11 - 16	17.0	2.8	2.3	1.8	TT-050
Spottail shiner	Young of the year	67	76 - 11 - 16	17.0	2.8	2.1	1.5	TT-051
Spottail shiner	Adult	107	77 - 03 - 23	10.0	--	<0.0	--	TT-058

(a) Acclimated to ambient river temperatures.
(b) Control mortality = 38 percent.

Note: Dashes indicate that data were insufficient for accurate determinations of tolerance limits.

CHAPTER 8: STUDIES ON THE EFFECTS OF CONTINUOUS EXPOSURE TO ELEVATED TEMPERATURES ON HATCHING SUCCESS OF FISH EGGS

The discharge of heated effluents into areas frequently utilized by fish for spawning can impair or prevent the normal development of eggs in areas of the thermal plume exceeding temperature requirements. Eggs that are basically planktonic (e.g., striped bass eggs) would not be expected to remain in areas influenced by the thermal plume for extended periods. However, eggs with demersal and/or adhesive properties that may be spawned in areas influenced by the thermal plume might be exposed to the elevated temperatures throughout the incubation period. To evaluate the extent to which the thermal plumes from Hudson River power plants might exceed temperature requirements for the normal development of fish eggs, hatching success studies were conducted at several elevated temperatures for selected representative important species (RIS). Where applicable, the areas and volumes of thermal plumes from the Indian Point Generating Station, the Bowline Point Generating Station, and the combined plume from the Danskammer Point and Roseton Generating Stations that exceed these temperature requirements are presented and discussed in 316(a) demonstrations for the respective power plants.

8.1 METHODS AND MATERIALS

8.1.1 Experimental Procedures

Eggs of four Hudson River fishes were tested to determine the upper temperature limits for normal embryonic development and hatch. Atlantic tomcod, alewife, and white perch eggs were obtained by artificially spawning adults collected from the Hudson River. Striped bass eggs were obtained from a hatchery operated by Texas Instruments personnel at Verplanck, New York, and transported to the laboratory under controlled temperature conditions and aeration.

Eggs were incubated for 2-12 hours at ambient temperatures prior to experimentation to ensure selection of live eggs for testing.

One hundred fertilized eggs were counted into polyvinyl chloride (PVC) incubation containers 7.6 cm in diamater and 9.4 cm deep with screened bottoms and sides. Screening used for alewife, Atlantic tomcod, and striped bass eggs was 0.5 mm; 0.25-mm screening was necessary for white perch eggs to prevent the newly hatched larvae from escaping. Five to seven containers per female were prepared and transferred directly to flow-through water baths adjusted to the desired test temperatures until hatch (Figure 4.1-1[a]). Containers were supported off the bottom by runners along the sides of the incubation tank to allow water to flow under the eggs, preventing stagnation within the incubation containers. For the incubation of Atlantic tomcod eggs, special siphoning devices were attached to the standpipe, which caused the water level in the bath to rise and fall approximately one-half inch every 15 minutes. This additional "flushing" was necessitated by the long incubation time required for tomcod eggs. Atlantic tomcod and alewife eggs were treated once a week for 15 seconds with 500 parts per million (ppm) malachite green solution during the studies to prevent mortality due to fungus infestation.

The effects of temperature on hatching success were examined at several constant above-ambient temperatures. Thermister probes placed in each water bath monitored temperatures hourly. Dead eggs were counted and removed daily. Containers were checked for hatch every 2-15 hours for white perch, alewife, and striped bass, and once daily for Atlantic tomcod. Percentage total hatch, percentage normal hatch, and time to median hatch were recorded for each container. Larvae were preserved in 5 percent buffered formalin after hatch.

To quantify the observation made in this study that striped bass larvae appeared to hatch in premature stages of development at higher elevated temperatures, individual total lengths were determined on a subsample of 15 preserved striped bass larvae from each incubation temperature. The weight of striped bass larvae hatched at each temperature was determined by drying a group of preserved specimens in an oven for 24 hours at 68 C and weighing to the nearest 0.01 mg. Mean dry weights were calculated for each incubation temperature from the pooled weight and the number of larvae weighed.

8.1.2 Analytical Procedures

Where applicable, four end points were used to describe the response of eggs to incubation temperature (after Hokanson et al. 1973). The "optimum temperature" is defined as the temperature that produces the highest percentage hatch. The "hatching range" is the temperature range that produces hatch, regardless of condition or success. The "optimum range" is the range of temperatures tested over which the response was not significantly different from the highest value ($p = 0.05$, Tukey's multiple range test). The "upper lethal temperature (TL50)" is the interpolated temperature at which embryo survival to hatch was 50 percent of the highest normal hatch. The data were normalized prior to interpolation by calculating the percentage of the highest value for each female at each temperature to adjust for differences in hatching success due to variation in the spawning condition of the females. The TL50 was determined by plotting these normalized percentage values against an arithmetic scale of temperature, and interpolating between the points bracketing the 50 percent level. Where appropriate, a regression line depicting the response at the three highest temperatures was calculated and used to predict the TL50.

Although this TL50 determination estimates an endpoint similar to TL50s determined for other life stages, the application of this term for egg thermal tolerance departs from the standard application because the exposure time is essentially the entire incubation period, which varies according to species and temperature.

8.2 RESULTS AND DISCUSSION

8.2.1 Striped Bass

The optimum temperature for normal hatch of striped bass eggs was 22.2 C, whereas the hatching range extended to 27.2 C (Table 8.2-1). The TL50 was 26.3 C (Figure 8.2-1). The mean length of newly hatched larvae incubated at temperatures over 23.7 C decreased with increasing temperature, while the average weight steadily increased. This indicates that larvae incubated at temperatures higher than 23.7 C may have hatched in a premature stage of development. Striped bass larvae that hatched at 27.2 C were obviously premature ("stunted") and were categorized as abnormal. Times to median hatch ranged from 42 hours (1.8 days) at 18.8 C to 20 hours (0.8 day) at 27.2 C.

8.2.2 White Perch

The optimum temperature for mean normal hatch of white perch eggs was 24.1 C (Table 8.2-2). However, there was no significant difference in percentage hatch among the test temperatures (p = 0.05). The highest test temperature, 27.0 C, resulted in 67.0-97.3 percent of the highest normal hatch response of each female (Figure 8.2-2). Therefore, temperatures up to 27 C appear to have no detrimental effect on white perch egg development. Successful hatch was obtained at 30.5 C for white perch eggs incubated at the higher temperature for conducting thermal tolerance tests on yolk-sac larvae (Subsection 5.2.2), but the degree of hatching success was not observed. Times to median hatch ranged from 96 hours (4 days) at 15.0 C to 33 hours (1.4 days) at 27.0 C.

TABLE 8.2-1 HATCHING SUCCESS OF EGGS SPAWNED FROM A SINGLE STRIPED BASS FEMALE ON 26 MAY 1977[a]

Incubation Temperature $\bar{x} \pm$ SD (C)	Total Hatch (%)	Normal Hatch (%)	Time to Median Hatch (hours)	Total Length $\bar{x} \pm$ SD (mm)	Dry Weight per Individual (mg)
18.8 ± 0.5	59	59	42	3.9 ± 0.1	0.087
20.0 ± 0.2	53	53	42	4.1 ± 0.1	0.076
22.2 ± 0.1	63	63	32	3.8 ± 0.2	0.118
23.7 ± 0.3	46	46	28	3.9 ± 0.1	0.127
25.8 ± 0.1	47	47	24	3.6 ± 0.2	0.129
27.2 ± 0.2	13	0	20	3.5 ± 0.1	0.144
29.7 ± 0.2	0	0	--	--	--

(a) Eggs were held at 18.0 C for 8 hours prior to incubation at several elevated temperatures. Hatch observations were made every 2-10 hours.

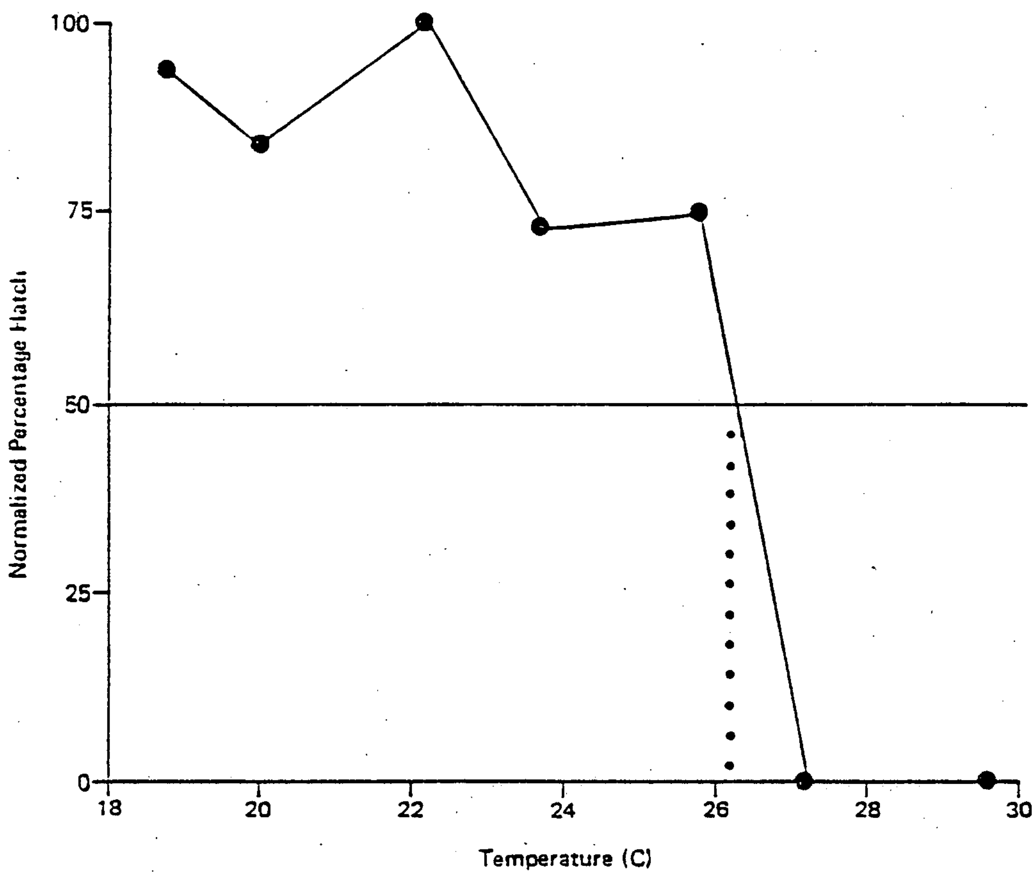


Figure 8.2-1. **Normalized percentage normal hatch of eggs spawned from a single striped bass female (TL50 was 26.3 C).**

TABLE 8.2-2 HATCHING SUCCESS OF EGGS SPAWNED FROM THREE WHITE PERCH ON 1 JUNE 1976[(a)]

Incubation Temperature $\bar{x} \pm$ SD (C)	Female	Total Hatch (%)	Normal Hatch (%)	Time to Median Hatch (hours)
15.0 ± 0.3	1	68.5	68.0	96
	2	82.0	82.0	97
	4	76.0	75.5	97
	Mean	75.5	75.2	96.7
17.9 ± 0.3	1	62.0	62.0	72
	2	81.5	80.0	72
	4	65.0	64.0	73
	Mean	69.5	68.7	72.3
20.8 ± 0.4	1	74.5	74.0	47
	2	80.0	80.0	48
	4	62.5	62.0	48
	Mean	72.3	72.0	47.7
24.1 ± 0.5	1	71.5	71.5	34
	2	89.5	89.5	34
	4	69.5	69.5	35
	Mean	76.8	76.8	34.3
27.0 ± 0.2	1	61.0	60.5	33
	2	60.0	60.0	33
	4	73.5	73.5	33
	Mean	64.8	64.7	33

(a) Eggs were incubated 3-6 hours after fertilization. Spawning temperature was 18.0 C. Observations were made every 10-15 hours.

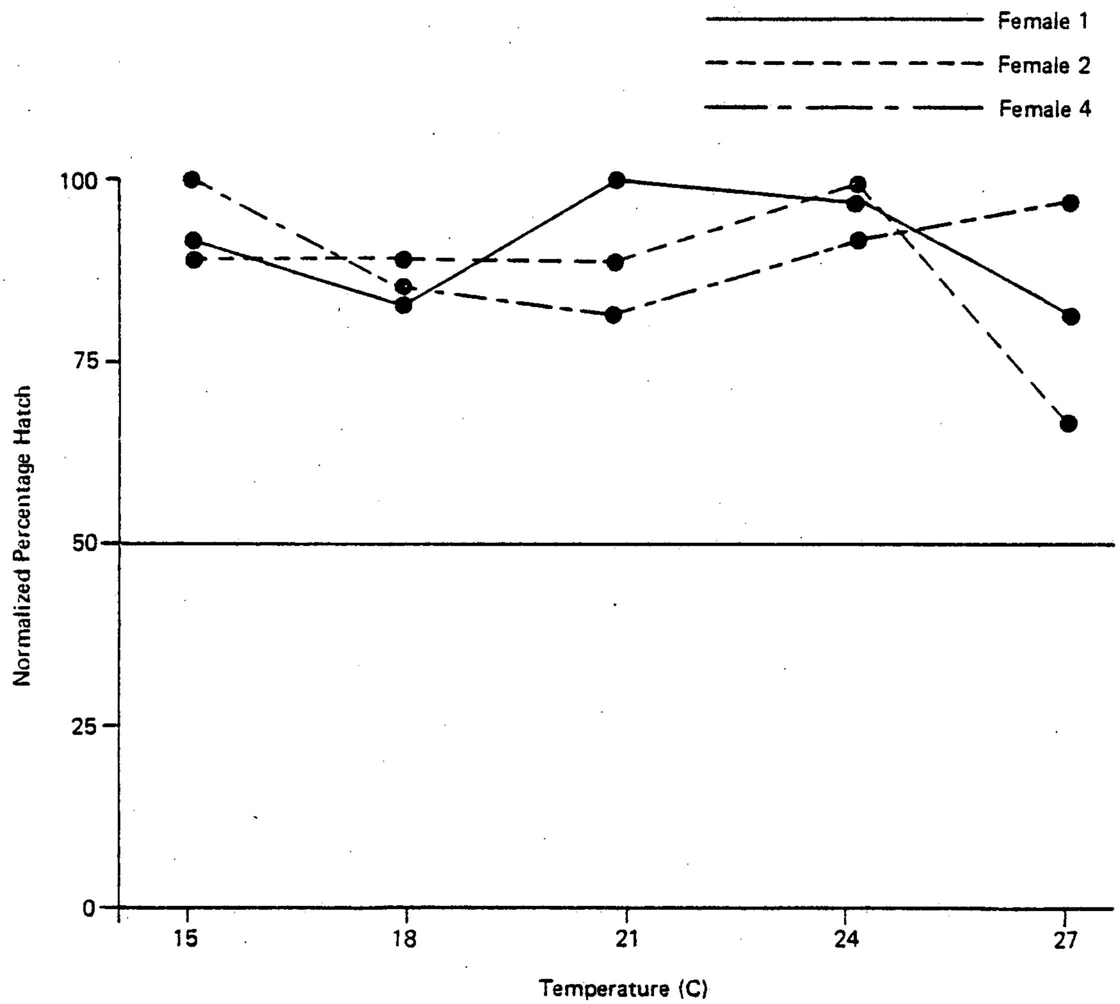


Figure 8.2-2. Normalized percentage normal hatch of eggs spawned from three white perch females.

8.2.3 Atlantic Tomcod

The optimum hatch of Atlantic tomcod eggs occurred at the two lowest temperatures tested, 2.0 and 3.4 C (Table 8.2-3). The hatching range extended to 7.3 C. The optimum range (after normalizing the data to adjust for variation among females) was 2.0-4.9 C (p = 0.05). It is likely that the optimum range extends below 2.0 C, as Atlantic tomcod commonly spawn under the ice at temperatures below 1 C. Although the hatching success of each female was fairly consistent at temperatures up to 4.9 C, there was considerable variation among females (Table 8.2-3). This variability may have been due to differences in the degree of ripeness of the eggs at fertilization. Slightly overripe or underripe eggs, although fertilized, would have died during later stages of development. Upper lethal temperatures (TL50) varied little among eggs from separate females, ranging from 6.0 to 6.9 C (Figure 8.2-3). Forty-five percent of the total hatch at 7.3 C were abnormal. Figure 8.2-4 depicts two extreme conditions of deformity resulting from incubation at high temperatures. Times to median hatch ranged from 39 days at 2.0 C to 24 days at 7.3 C.

8.2.4 Alewife

The optimum temperature for mean normal hatch of alewife eggs was 20.8 C, whereas the hatching range extended to 26.7 C (Table 8.2-4). The optimum hatching range extended from the lowest test temperature to 23.9 C (p = 0.05). Inspection of hatching success results of eggs from each female indicates the possibility for genetic-based variability in thermal tolerance of alewife eggs. Upper lethal temperatures (TL50s) were 25.5, 28.2, 26.3, and 25.4 C for females 1, 2, 4, and 6, respectively (Figure 8.2-5). The TL50 for eggs from female 2 was 1.9-2.8 C higher than upper lethal temperatures for eggs from the other three females. In addition, the optimum hatching temperature for eggs

TABLE 8.2-3 HATCHING SUCCESS OF EGGS SPAWNED FROM THREE ATLANTIC TOMCOD FEMALES ON 5 JANUARY 1977[a]

Incubation Temperature $\bar{x} \pm SD$ (C)	Female	Total Hatch (%)	Normal Hatch (%)	Time to Median Hatch (days)
2.0 ± 0.5	1	10	9	41
	2	25	22	39
	3	40	38	37
	Mean	25	23	39
3.4 ± 0.4	1	10	8	33
	2	27	25	33
	3	36	35	33
	Mean	24	23	33
4.9 ± 0.5	1	10	10	27
	2	23	19	28
	3	33	32	28
	Mean	22	20	28
7.3 ± 0.4	1	7	4	22
	2	14	2	27
	3	21	17	23
	Mean	14	8	24
8.8 ± 0.4	1	0	0	--
	2	0	0	--
	3	0	0	--

(a) Eggs from females 1, 2, and 3 were incubated at elevated temperatures 2, 6, and 7 hours after fertilization, respectively. Spawning temperature was 2.0 C. Hatch observations were made daily.

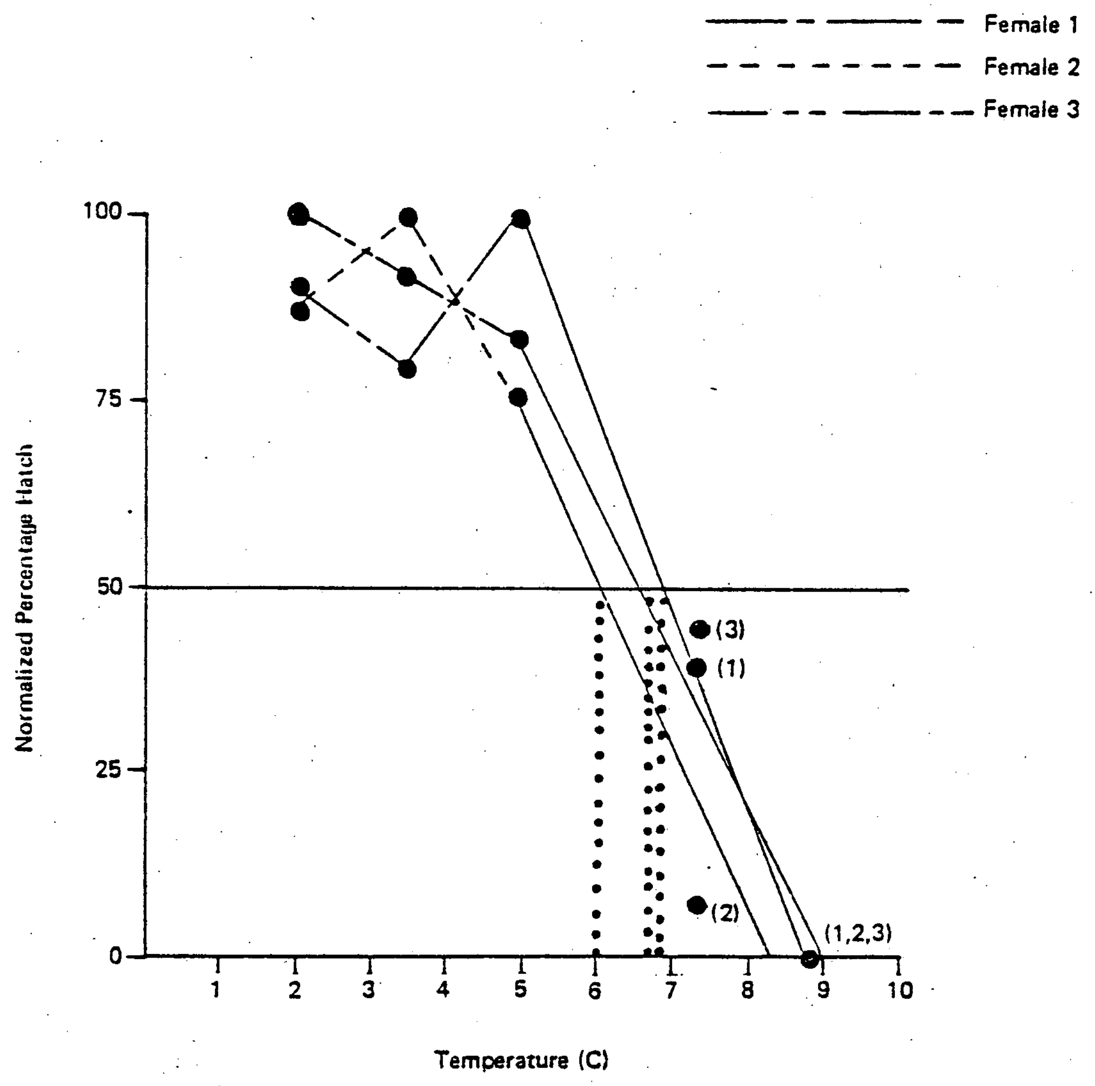


Figure 8.2-3. Normalized percentage normal hatch of eggs spawned from three Atlantic tomcod females. The solid lines represent the regression through the responses at the three highest temperatures for eggs from each female (TL50s ranged from 6.0 to 6.9 C).

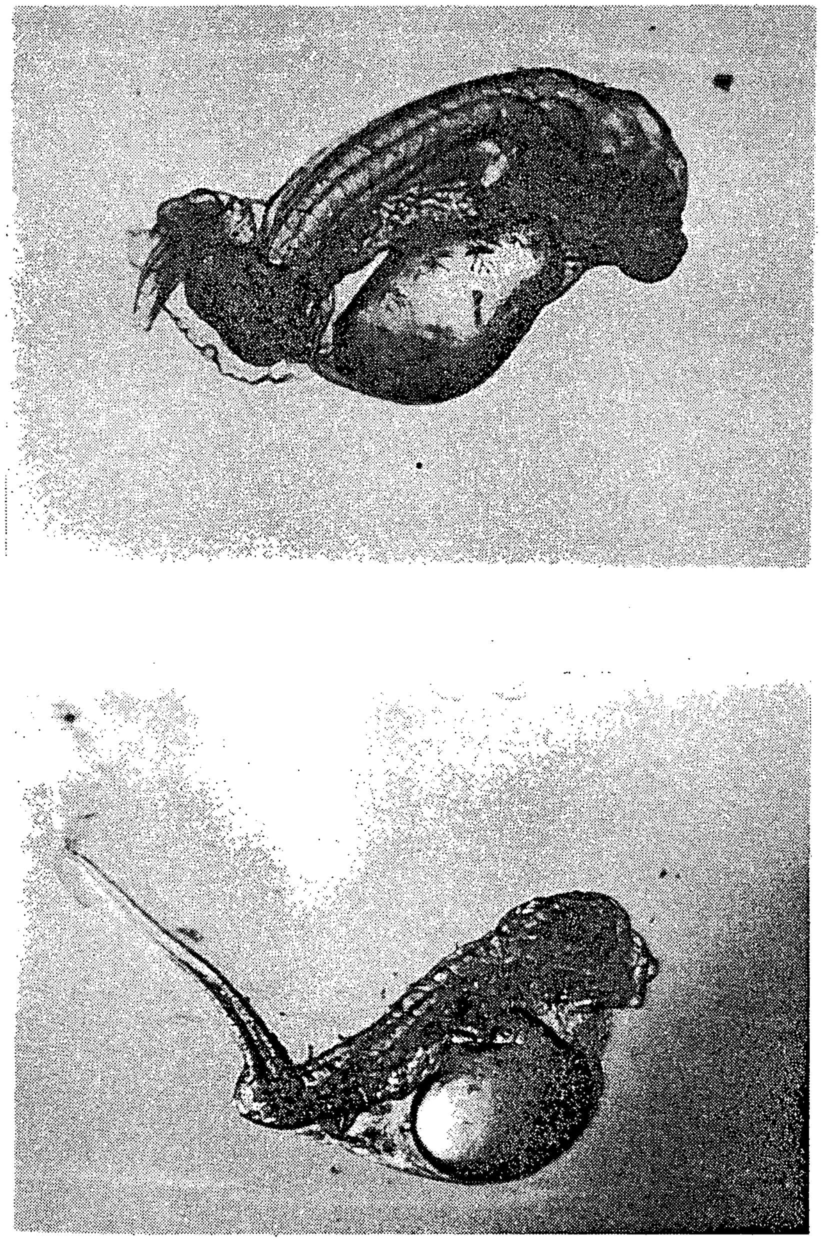


Figure 8.2-4. Deformed Atlantic tomcod larvae hatched from eggs ______ maintained at a constant temperature of 7.3 C throughout incubation (5.3 C above spawning temperature). The magnification factor is 20X.

TABLE 8.2-4 HATCHING SUCCESS OF EGGS SPAWNED FROM FOUR ALEWIFE ON 4 MAY 1977[(a)]

Incubation Temperature $\bar{X} \pm SD$ (C)	Female	Total Hatch (%)	Normal Hatch (%)	Time to Median Hatch (hours)
12.7 ± 0.5	1	80	77	177
	2	64	56	175
	4	65	61	176
	6	63	60	182
	Mean	68	64	178
18.1 ± 0.2	1	67	58	109
	2	63	57	109
	4	78	60	109
	6	63	63	108
	Mean	68	60	109
20.8 ± 0.3	1	82	74	99
	2	75	68	100
	4	80	72	100
	6	71	70	100
	Mean	77	71	100
23.9 ± 0.1	1	77	58	73
	2	72	68	73
	4	79	66	72
	6	61	48	72
	Mean	72	60	72
26.7 ± 0.2	1	29	16	70
	2	81	73	72
	4	53	25	70
	6	41	21	71
	Mean	51	34	71
29.7 ± 0.0	1	0	0	--
	2	0	0	--
	4	0	0	--
	6	0	0	--

(a) Eggs from females 1, 2, 4, and 6 were incubated at elevated temperatures 12, 10, 9, and 8 hours after fertilization, respectively. Spawning temperature was 13-14 C. Hatch observations were made every 2-8 hours.

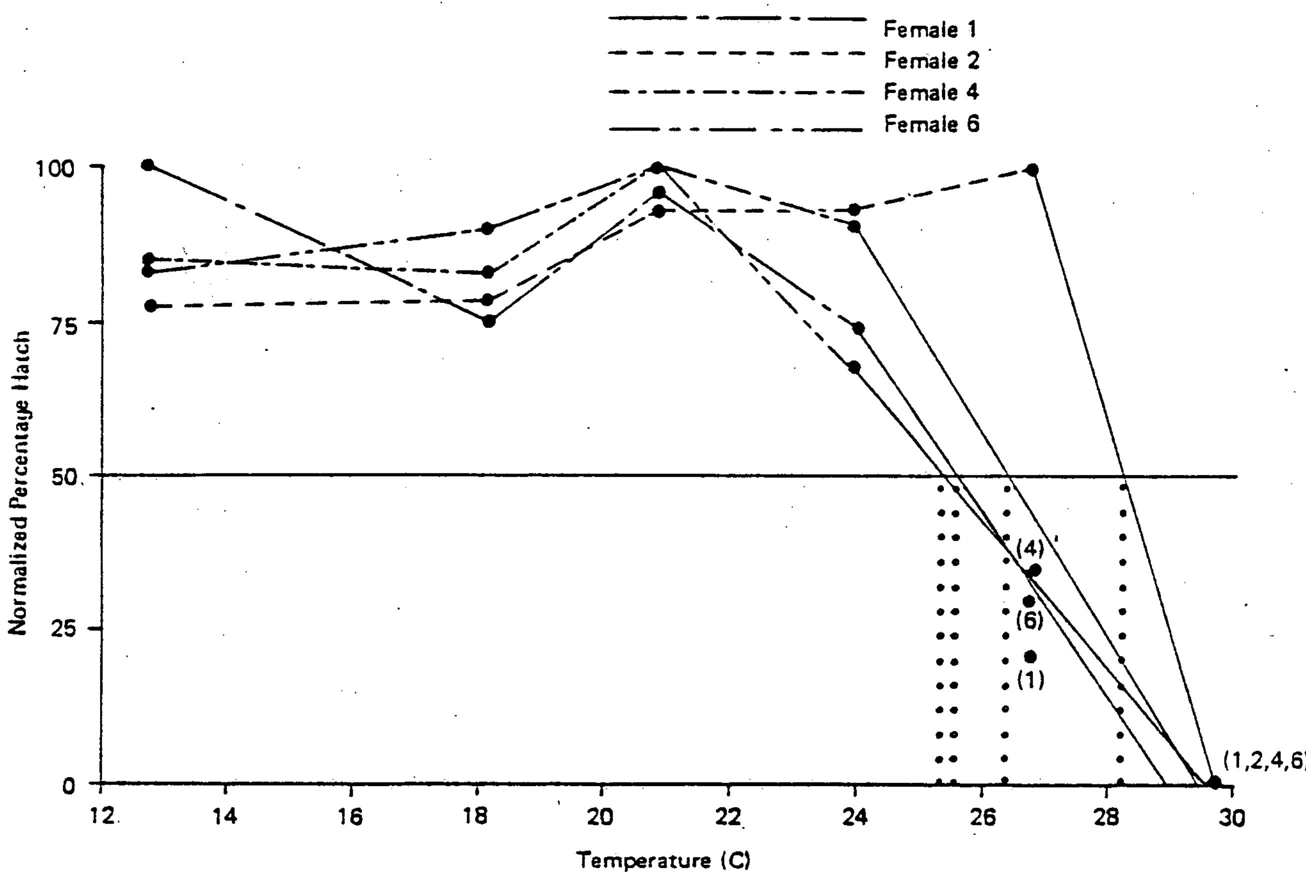


Figure 8.2-5. **Normalized percentage normal hatch of eggs spawned from four alewife females. The solid lines represent the regression through the responses at the three highest temperatures for eggs from each female (TL50s ranged from 25.4 to 28.2 C).**

from female 2 exceeded the TL50s of the other eggs tested. It is unlikely that this difference in tolerance was due to the degree of ripeness of the eggs at fertilization, since percentage hatch at lower test temperatures was comparable. Forty-nine percent of the total hatch at 26.7 C for eggs from alewife females 1, 4, and 6 were abnormal, but few larvae from eggs of female 2 were deformed. Figure 8.2-6 depicts some of the common deformities observed after incubation at high temperatures. Times to median hatch ranged from 178 hours (7.4 days) at 12.7 C to 71 hours (3 days) at 26.7 C.

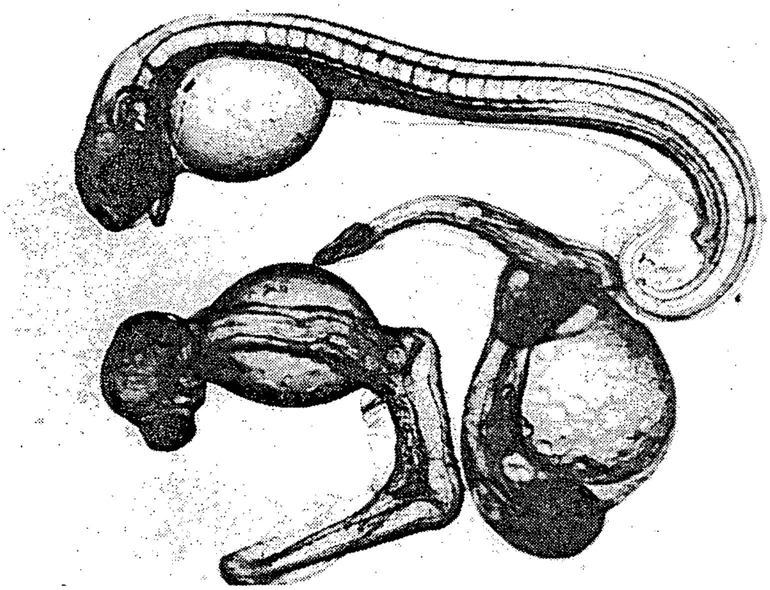


Figure 8.2-6. Deformed alewife larvae from eggs of female 6 incubated at a constant temperature of 26.7 C (13.0 C above spawning temperature). The magnification factor is 20X.

CHAPTER 9: STUDIES ON THE EFFECTS OF ELEVATED TEMPERATURES ON GROWTH OF YOUNG FISH

Temperature requirements for early development of aquatic organisms are necessary to define areas of thermal plumes that, but for their high temperatures, would be suitable for successful spawning and early development. The natural occurrence of most aquatic organisms is limited within the thermal tolerance zone (delimited by incipient lethal temperatures) 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 limit of the optimum temperature range for physiological activities can be used to estimate the maximum temperatures within thermal plumes that will permit optimum performance. To evaluate the extent to which areas influenced by thermal discharges from Hudson River power plants may be unsuitable for early development of fish because of high temperatures, the optimum temperatures for growth and normal development of larvae and early juveniles were determined in the laboratory. The areas and volumes of thermal plumes from the Indian Point and Bowline Generating Stations and the combined plume from the Danskammer Point and Roseton Generating Stations in which these upper limits for optimum growth are exceeded are presented and discussed in 316(a) demonstrations for the respective power plants.

9.1 METHODS AND MATERIALS

9.1.1 Experimental Procedures

Tests were conducted to determine optimum temperatures for growth and normal development of larvae and juveniles of six Hudson River fishes. The general experimental and analytical procedures used were adapted from Hokanson et al. (1973). Growth and survival were monitored for each species at six or seven constant temperatures, including ambient, for 12-28 days. Test fish were obtained by collecting and artificially spawning adults from the river or by collecting early juveniles from nearby nursery areas. An equal number of fish were counted into each rearing tank and acclimated to the test temperatures at rates of 1.0-2.5 C per hour. Fish were fed appropriate food items in excess of demand throughout the test period. The tanks were cleaned, and dead fish were removed and counted daily. Thermister probes placed in each water bath monitored temperatures hourly. Dissolved oxygen was monitored two to three times a week for each rearing tank.

A sample of the initial stock was weighed and total lengths were obtained. Small samples of fish were removed from each test tank at regular intervals during the test for weight and total length determinations. At the end of the test period the remaining fish were counted and weighed, and total length determinations were made on a subsample. Specific experimental designs varied somewhat for each species because of the source and availability of test fish and differences in rearing requirements. Specific procedures used for each species are discussed in the following subsections.

9.1.1.1 Specific Procedures for Striped Bass

Striped bass post-yolk-sac larvae were reared for 16 days at seven constant temperatures ranging from 19.7 to 34.8 C. Sixteen-day-old larvae were obtained from a hatchery operated by Texas Instruments personnel at Verplanck, New York, on 13 June and transported to the laboratory under controlled temperature conditions. Larvae were held for 2 days at 22 C (ambient) prior to initiation of the test. Larvae were fed brine shrimp nauplii during this holding period.

Two hundred larvae were counted into 8-liter aquaria for acclimation to rearing temperatures at a rate of 2.5 C per hour. Following acclimation, the larvae were transferred to a 30-liter water bath at each temperature for rearing (Figure 4.1-1[c]). Each water bath was supplied with a flow of approximately 5 liters per minute (1.25 gpm). Thermister probes in each water bath monitored temperatures hourly. Feeding was initiated within hours after the fish were released into the water baths. Brine shrimp nauplii were cultured and fed to fish every 8 hours. Wild zooplankton collected with a 0.2-mm-mesh plankton net, primarily consisting of copepods, ostracods, and cladocerans, were fed to each tank daily. Some Gammarus spp. and Chaoborus spp. were collected from entrainment samples and fed to fish when available. Live Tubifex worms, frozen brine shrimp, and dehydrated brine shrimp were fed to fish during the last 7 days of the test to supplement the above food items.

Samples of larvae from the initial larval stock, samples of larvae taken from each tank on the fifth and tenth days, and fish remaining at the end of the experiment were weighed (wet) to the nearest 0.01 g. Mean wet weights were calculated for each sample. Lengths were determined to the nearest 0.1 mm. Samples were not removed during the test from the 34.8 C rearing tank because of the high mortality rate.

Of the larvae introduced into each tank initially, 75-98 percent were recovered. The number of larvae unaccounted for was greatest at test temperatures ranging from 27.0 to 34.8 C. Cannibalism may account for these higher loss values. Cannibalism of dead larvae was observed occasionally, but cannibalism of live larvae was not observed.

9.1.1.2 Specific Procedures for White Perch

White perch early juveniles were reared for 14 days at six constant temperatures ranging from 22.5 to 34.8 C. Fish were collected from nearby nursery areas with a 30-ft, 1/8-in.-mesh seine. The fish were held for 1 week at 23-25 C (ambient) prior to the test. Frozen brine shrimp were fed to the fish daily during this holding period. At the initiation of the test, 35 fish per test temperature were acclimated to the rearing temperatures at a rate of 2.5 C per hour. Other experimental details were similar to those for striped bass. Fish were fed frozen brine shrimp two to three times daily as a primary food item, supplemented regularly with food items listed in Subsection 9.1.1.1. Samples were not taken from the tanks for length determinations during the test because of the small initial sample size. Eighty-six to one hundred percent of the initial sample size was recovered. Cannibalism was never observed.

9.1.1.3 Specific Procedures for Atlantic Tomcod

Atlantic tomcod yolk-sac larvae were reared for 28 days at six constant temperatures ranging from 3.2 to 10.9 C (Table 9.1-1). Larvae were obtained by artificially spawning tomcod adults collected from the river. Eggs were treated once per week with a 15-second dip in a malachite green solution (500 parts per million [ppm]) to prevent fungus infestation. Larvae used for rearing at temperatures up to 5.0 C were obtained from eggs incubated at temperatures within 1 C of the rearing temperature; larvae used for rearing at temperatures greater than 5.0 C were obtained from eggs incubated at 3.9 C and acclimated to the rearing temperatures at a rate of 1 C per hour. Growth experiments were conducted with ambient-salinity water (fresh) and at salinities adjusted to 1.2 $\pm$ 0.3 parts per thousand (ppt). The number of replicates at

TABLE 9.1-1 SUMMARY OF GROWTH EXPERIMENTS WITH ATLANTIC TOMCOD LARVAE

Rearing Conditions			Source of Larvae		
Temperature (C)	Salinity (ppt)	Number of Successful Replicates	Spawning Date[a]	Egg Incubation Temperature (C)	Hatching Date
3.3	(fresh)	3	5 JAN 77	2.0	14 FEB 77
3.2	1.2	3			
3.8	(fresh)	1	5 JAN 77	3.4	7 FEB 77
4.1	1.2	3			
5.2	(fresh)	1	14 JAN 77	4.9	8 FEB 77
5.4	1.2	1			
7.1	(fresh)	1	14 JAN 77	3.9	13 FEB 77
7.3	1.2	1			
9.1	(fresh)	1	14 JAN 77	3.9	13 FEB 77
9.1	1.2	1			
10.8	(fresh)	1	14 JAN 77	3.9	13 FEB 77
10.9	1.3	2			

(a) 8-10 females spawned each date. Larvae used were a mixture from each spawn.

each rearing temperature varied according to availability of tomcod larvae and rearing success.

Tomcod larvae were reared in 8-liter aquaria immersed in water baths, as shown in Figure 4.1-1(b). A screen (0.25-mm mesh) at one end of the tank prevented the larvae from escaping through the standpipe. Each aquarium was supplied with a 25-50 ml/minute flow of river water (freshwater replicates) or water from a 4,000-liter reservoir adjusted to approximately 1.2 ppt salinity. Temperatures in each rearing aquarium were recorded every 6 hours. Tanks were supplied with light aeration throughout the test. Feeding was initiated 2-3 days after hatch. Live fish food was collected by pumping unfiltered river water through a 0.070-mm-mesh plankton net for several hours. This "extract," primarily containing rotifers and copepods, was introduced into each rearing tank daily. In addition, live brine shrimp nauplii (Artemia) cultured in the laboratory were fed to the fish daily.

Four hundred newly hatched tomcod larvae were counted into each rearing aquarium at the initiation of the test. Samples of larvae from the initial larval stocks, weekly samples taken from each tank, and those specimens remaining at the end of the experiment were preserved in 5 percent buffered formalin. Photographs were taken of larvae from each sample prior to preservation. Lengths were determined to the nearest 0.01 mm using an ocular micrometer. The dry weight of initial and final samples was determined by drying preserved specimens in an oven for 24 hours at 68 C and weighing to the nearest 0.01 mg. Mean dry weights were calculated from the pooled dry weight and the number of larvae weighed. Of the larvae initially introduced into each tank, 66-97.5 percent were recovered. The larvae unaccounted for were most likely overlooked during the daily removal of dead specimens and probably decomposed in the rearing tanks. Cannibalism was never observed.

9.1.1.4 Specific Procedures for Alewife

Alewife yolk-sac larvae were reared for 12 days at seven constant temperatures ranging from 12.9 to 29.1 C. Larvae were obtained by artificially spawning eight alewife adults collected from Black Creek on 20 April 1977 and incubating mixtures of the eggs at temperatures ranging from 13 to 21 C. Eggs were treated 2 days after fertilization with a 15-second dip in a 500 ppm malachite green solution. Larvae reared at temperatures of 12.9-20.8 C were obtained from eggs incubated at the rearing temperatures; larvae used for rearing at temperatures greater than 21 C were obtained from eggs incubated at 21 C and acclimated to the higher rearing temperatures at a rate of 1.0-1.5 C per hour.

Alewife growth experiments were conducted in 8-liter aquaria immersed in water baths, as shown in Figure 4.1-1(b). The exterior of each aquarium was lined with black plastic. Two replicates at each temperature were conducted at 1.0-1.3 ppt salinity. One replicate at each temperature was conducted with fresh water. All tests were performed under static conditions without flow to prevent live food items (smaller than 0.25 mm) from being flushed from the aquaria. Approximately 25 percent of the water in each tank was changed daily and light aeration was supplied to each tank to prevent stagnation. Dissolved oxygen levels remained near 100 percent saturation in all tanks throughout the test. Rearing temperatures were recorded every 8 hours. Feeding was initiated one day after hatch. Rotifers, copepod adults and nauplii, cladocerans, and algae were collected from the river using a 0.070-mm mesh plankton net and introduced into each tank daily. A culture of Paramecium multimicronucleatum was kept in the laboratory, and portions were introduced into each receiving tank daily. Brine shrimp nauplii were fed to fish twice per day starting on the eighth day of the experiment.

Five hundred newly hatched alewife larvae were counted into each rearing aquarium at the initiation of the test. Samples of the initial larval stocks, samples taken from each tank on the third and sixth days, and those specimens remaining at the end of the experiment were preserved in 5 percent buffered formalin. Photographs were taken of larvae from each sample prior to preservation. Lengths and dry weights were determined according to procedures outlined for Atlantic tomcod.

9.1.1.5 Specific Procedures for White Catfish

White catfish post-yolk-sac larvae were reared for 21 days at seven constant temperatures ranging from 20.0 to 34.7 C. Larvae were obtained from eggs spawned by a pair of adults in a holding tank on 21 June and hatched on 27-28 June. The larvae were held at 23.0-24.0 C (ambient) for 8 days prior to the test. At the initiation of the test, one hundred larvae were acclimated to each rearing temperature at a rate of 2.5 C per hour. Other experimental details were similar to those for striped bass. Fish were fed several times daily. Frozen brine shrimp and Tubifex worms were the most important food items for white catfish. Ninety to one hundred percent of the initial sample size was recovered from each test tank. Cannibalism of dead larvae was occasionally observed.

9.1.1.6 Specific Procedures for Spottail Shiner

Spottail shiner early juveniles were reared for 21 days at seven constant temperatures ranging from 20.0 to 34.7 C. Fish were collected from nearby nursery areas with a 30-ft, 1/8-in.-mesh seine. The fish were held for 5 days at

24.0-25.0 C (ambient) prior to the test. Frozen brine shrimp were fed daily during this holding period. At the initiation of the test, 200 fish were acclimated to each rearing temperature at a rate of 2.5 C per hour. Other experimental details were similar to those for striped bass. Fish were fed frozen brine shrimp two to three times daily as a primary food item, supplemented regularly with food items listed in Subsection 9.1.1.1. Samples for length determinations were not removed during the test from the 34.7 C rearing tank because of the high mortality rate. Of the fish introduced into the test tanks initially, 85-92.5 percent were recovered. Cannibalism was never observed.

9.1.2 Analytical Procedures

Instantaneous rates of growth, mortality, and net biomass change were calculated according to the following equations (Ricker 1968):

$$G = \frac{\ln Wt_2 - \ln Wt_1}{\Delta t} \qquad (9.1\text{-}1)$$

where

G = instantaneous growth rate

Wt_2 = average weight of fish at end of test

Wt_1 = average weight of fish at beginning of test

Δt = the length of the test in days.

$$Z = -\frac{\ln N_2 - \ln N_1}{\Delta t} \qquad (9.1\text{-}2)$$

where

Z = instantaneous mortality rate

N_2 = number of live fish at end of test

N_1 = number of live fish at beginning of test

Δt = the length of the test in days.

$$\text{Rate of Net Biomass Change} = G - Z . \qquad (9.1\text{-}3)$$

Net biomass change was calculated to quantify the effects of temperature on growth and survival simultaneously.

The number of fish remaining in each tank at the end of the test (N_2) was adjusted to include the probable survival of fish that were removed from each tank throughout the test for length determinations. This adjustment was accomplished by predicting the survival of these fish on the basis of survival ratios calculated for each interval between samples. Survival ratios were determined from the daily mortality rate in each tank. This adjustment increased N_2 by 6-37 percent, depending on the sample sizes removed and the mortality rate in each rearing tank. This adjustment was not necessary for test temperatures in which samples were not taken during the experiment.

Daily mortality was not monitored because partially decayed alewife larvae could not be readily distinguished from dead dipteran larvae introduced into the rearing tanks with the wild zooplankton. The number of fish remaining (N_2) was therefore not adjusted to account for the removal of samples during the test. However, since only 3 percent of the initial sample was removed during the test and mortality rates were high in all tanks, it is unlikely that the mortality and net biomass change rates were significantly affected.

Four basic end points similar to those used for the hatching success studies were used to describe the response of fish to rearing temperatures. The "optimum temperature" is defined as the temperature producing the highest response. Optimum temperatures are determined for the growth rate and the rate of net biomass gain. The "optimum temperature range" for growth is estimated to be those temperatures producing a growth rate at least 90 percent of the highest growth rate observed. The "growth range" is the temperature range that produces a positive growth rate. The "upper lethal temperature (TL50)" is the interpolated temperature at which survival is 50 percent of the highest value. The TL50 is determined by normalizing survival data at each temperature as a percentage of the highest survival value, plotting these normalized values against an arithmetic scale of temperature, and interpolating between the points bracketing the 50 percent level.

9.2 RESULTS AND DISCUSSION

9.2.1 Striped Bass

Striped bass post-yolk-sac larvae were obtained from a hatchery operated by Texas Instruments at Verplanck, New York. Larvae were 18 days old when the test was initiated and had a mean total length of 8.7 mm and a mean weight of 6 mg (Table 9.2-1). Significant growth did not occur until after the fifth day (Figure 9.2-1). Maximum total length at the end of the test was observed at 29.6 C. Fish in all tanks developed from post-yolk-sac larvae to juveniles during the test.

The optimum temperatures for growth were 27.3 and 29.6 C; the optimum range (within 10 percent of the optimum rate) included 25.1 C. The growth rates at 27.3 and 29.6 C varied by less than 0.1 percent per day (Table 9.2-2). Growth rates at 25.1-29.6 C exceeded 21 percent weight gain per day. Although growth at 32.2 C was not within the optimum range (defined as those temperatures resulting in growth rates at least 90 percent of the optimum), growth of larvae reared at this temperature exceeded growth rates for larvae reared at ambient temperatures (22.5 C) by over 3 percent per day. The optimum temperature for net biomass gain was 27.3 C. Positive net biomass change rates resulted at all temperatures except 34.8 C, ranging from 10.5 to 19.0 percent per day (Figure 9.2-2). Survival at 34.8 C over the 16-day test was 1 percent. The two fish remaining at 34.8 C had increased 2.6 mm in length, but weighed less than the larval stock; this resulted in a negative growth rate at this rearing temperature. The TL50 for the 16-day exposure was 33.5 C (Figure 9.2-3).

TABLE 9.2-1 RESULTS OF STRIPED BASS GROWTH STUDY CONDUCTED AT SEVEN CONSTANT TEMPERATURES. INITIAL SAMPLE SIZE WAS 200 POST-YOLK-SAC LARVAE

Rearing Temperature $\bar{x}$ ± SD (C)	Dissolved Oxygen (mg/l)	Age (Days) = 18 (a) (Initial) Length $\bar{x}$ ± SD (mm)	Age (Days) = 18 (a) (Initial) Wet Weight per Individual (g)	Age (Days) = 23[b] Length $\bar{x}$ ± SD (mm)	Age (Days) = 23[b] Wet Weight per Individual (g)	Age (Days) = 28[b] Length $\bar{x}$ ± SD (mm)	Age (Days) = 28[b] Wet Weight per Individual (grams)	Age (Days) = 34[c] (Final) Length $\bar{x}$ ± SD (mm)	Age (Days) = 34[c] (Final) Wet Weight per Individual (grams)	Number of Fish Remaining
19.7 ± 0.4	8.7	8.69 ± 0.4	0.006	7.98 ± 0.3	0.010	14.64 ± 0.6	0.030	17.97 ± 0.6	0.052	109
22.5 ± 0.2	8.6	8.69 ± 0.4	0.006	8.70 ± 0.3	0.011	16.45 ± 1.5	0.051	21.71 ± 2.0	0.109	98
25.1 ± 0.2	8.3	8.69 ± 0.4	0.006	8.87 ± 0.4	0.016	18.82 ± 0.7	0.092	27.59 ± 1.7	0.199	81
27.3 ± 0.2	8.1	8.69 ± 0.4	0.006	8.86 ± 0.3	0.020	20.02 ± 1.0	0.109	28.92 ± 1.5	0.268	83
29.6 ± 0.6	7.7	8.69 ± 0.4	0.006	8.90 ± 0.3	0.021	20.04 ± 1.0	0.121	29.68 ± 1.4	0.271	72
32.2 ± 0.4	7.6	8.69 ± 0.4	0.006	8.14 ± 0.3	0.012	17.13 ± 1.2	0.092	24.69 ± 1.7	0.176	107
34.8 ± 0.3	7.4	8.69 ± 0.42	0.006	--(d)	--	--	--	11.30 ± 1.3	0.005	2

(a) Based on a sample of 100 fish from the initial stock. Length determinations were made on a subsample of 30 larvae.
(b) Based on a sample of 10 fish for each sampling period.
(c) All survivors were weighed. Lengths were determined on a subsample of 20 fish.
(d) Dashes indicate no data available. Samples were not removed from the 34.8 C rearing tank during the test because of high mortality.

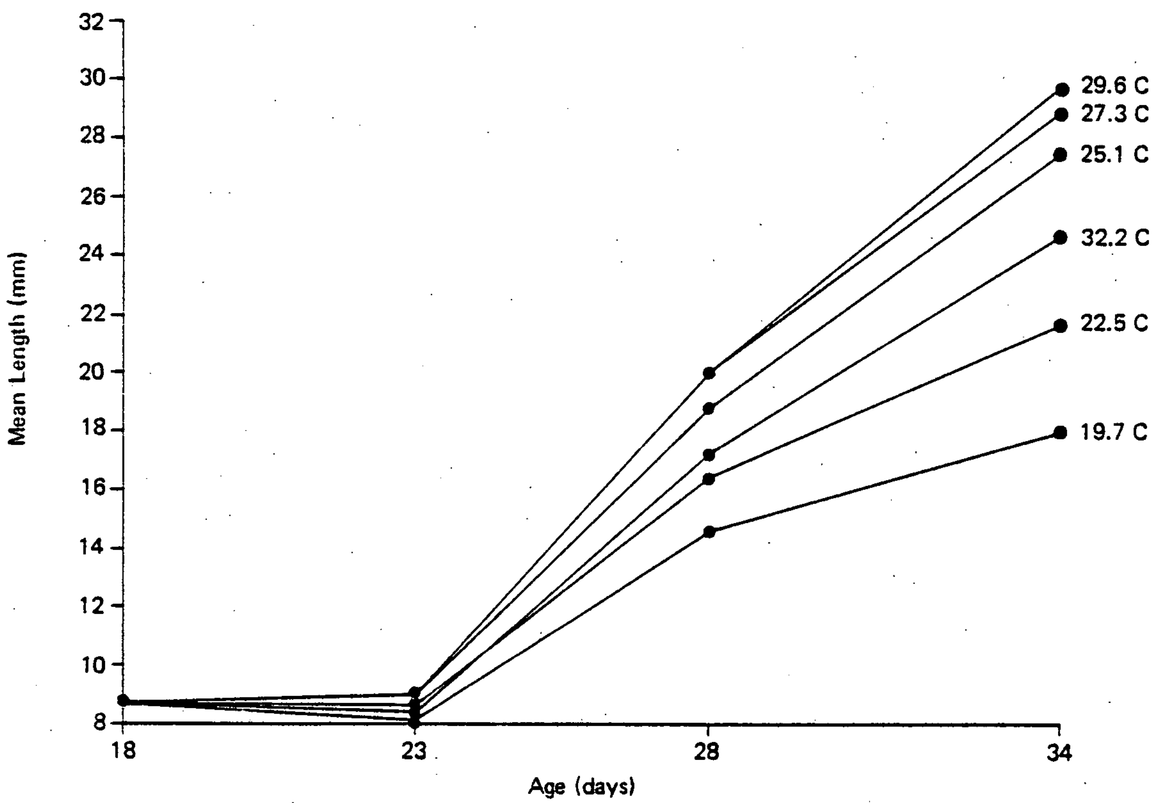


Figure 9.2-1. Growth in length of striped bass post-yolk-sac larvae at six constant temperatures.

TABLE 9.2-2 INSTANTANEOUS RATES OF GROWTH, MORTALITY, AND NET BIOMASS CHANGE FOR STRIPED BASS POST-YOLK-SAC LARVAE REARED AT SEVEN CONSTANT TEMPERATURES FOR 16 DAYS

Rearing Temperature $\bar{x} \pm SD$ (C)	Instantaneous Growth Rate (wet weight) (%/day)	Instantaneous Mortality Rate (%/day)	Instantaneous Net Biomass Change (%/day)
19.7 ± 0.4	13.304	2.777	10.527
22.5 ± 0.2	17.906	3.495	14.411
25.1 ± 0.2	21.667	4.737	16.93
27.3 ± 0.2	23.547	4.527	19.02
29.6 ± 0.6	23.601	5.267	18.334
32.2 ± 0.4	20.916	3.000	17.916
34.8 ± 0.3	-1.344	28.782	-30.126

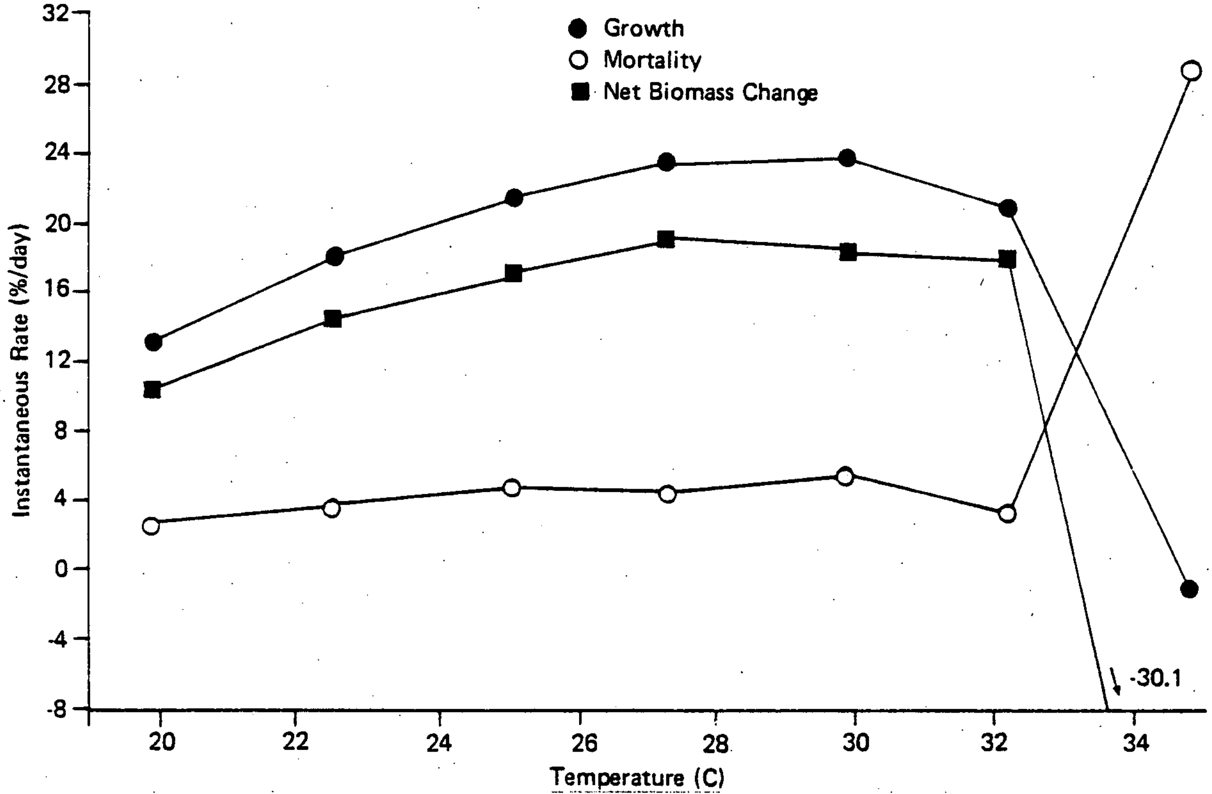


Figure 9.2-2. Instantaneous rates of growth, mortality, and net biomass change for striped bass post-yolk-sac larvae.

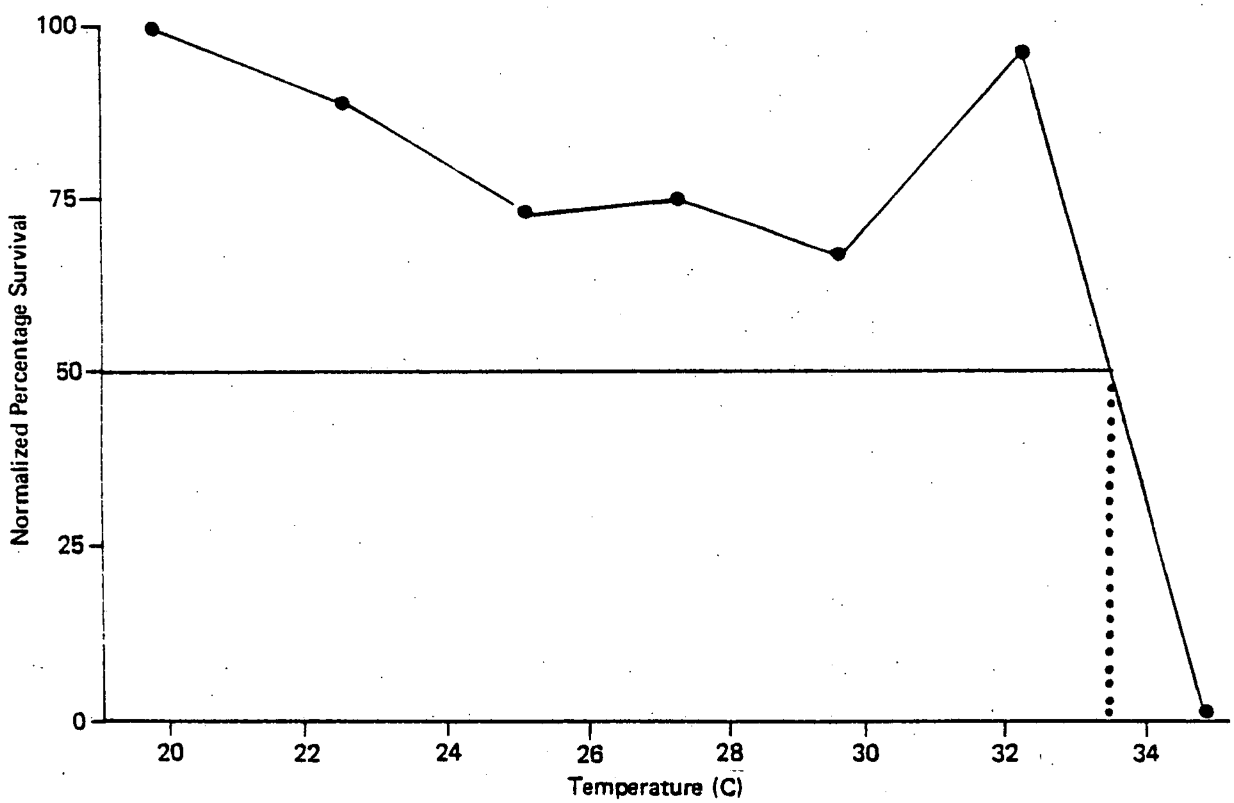


Figure 9.2-3. Normalized percentage survival of striped bass post-yolk-sac larvae reared at seven constant temperatures for 16 days (TL50 was 33.5 C).

9.2.2 White Perch

White perch were obtained from the Hudson River at the earliest possible stage permitting speciation of living specimens. The mean initial length of test organisms was 27.5 ± 2.8 mm (Table 9.2-3). The growth range (positive growth rates) extended from the lowest test temperature to 32.2 C. The optimum temperature for growth and net biomass gain of these early juvenile white perch was 27.3 C (Table 9.2-4). The optimum range for growth was 27.3-29.7 C. Growth rates at these temperatures exceeded 6 percent weight gain per day. Although growth at 32.2 C was less than 90 percent of the highest growth rate (the criteria used here to define optimum range for growth), the growth rate for white perch reared at this temperature was still quite high (4.9% per day). The highest percentage survival occurred at the optimum temperature for growth, 27.3 C (Figure 9.2-4). The TL50 for the 14-day test was 33.8 C (Figure 9.2-5). Normalized percentage survival for white perch reared at 34.8 C was less than 30 percent. Survivors reared at this temperature actually exhibited a weight loss.

9.2.3 Atlantic Tomcod

Atlantic tomcod yolk-sac larvae were obtained by artificially spawning adults collected from the river, and were reared at six constant temperatures and two salinity conditions. Rearing beyond the yolk-sac stage at all temperatures using fresh river water was unsuccessful (Table 9.2-5). Total length of larvae reared at all temperatures in fresh water increased less than 10 percent. Complete mortality occurred sooner for larvae reared at the higher temperatures, probably because of an accelerated rate of development. Differences in growth due to temperature were apparent after the fourteenth day for larvae reared in tanks adjusted to 1.2 ppt salinity (Figure 9.2-6). Most fish reared

TABLE 9.2-3 RESULTS OF WHITE PERCH GROWTH STUDY CONDUCTED AT SIX CONSTANT TEMPERATURES. INITIAL SAMPLE SIZE WAS 35 JUVENILES PER TANK

		Day 0 (Initial)[a]		Day 14 (Final)[b]		
Rearing Temperature $\bar{x} \pm SD$ (°C)	Dissolved Oxygen (mg/l)	Length $\bar{x} \pm SD$ (mm)	Wet Weight per Individual (g)	Length $\bar{x} \pm SD$ (mm)	Wet Weight per Individual (g)	Number of Fish Remaining
22.5 ± 0.2	8.1	27.5 ± 2.8	0.24	31.2 ± 2.0	0.39	12
25.0 ± 0.2	8.0	27.5 ± 2.8	0.24	30.9 ± 2.6	0.40	20
27.3 ± 0.3	8.0	27.5 ± 2.8	0.24	34.9 ± 2.4	0.60	26
29.7 ± 0.2	7.9	27.5 ± 2.8	0.24	35.0 ± 2.4	0.59	22
32.2 ± 0.3	7.9	27.5 ± 2.8	0.24	33.9 ± 2.2	0.50	22
34.8 ± 0.2	7.8	27.5 ± 2.8	0.24	27.7 ± 4.3	0.24	7

(a) Based on a sample of 20 fish from the initial stock.
(b) Lengths and weights taken on all survivors.

TABLE 9.2-4 INSTANTANEOUS RATES OF GROWTH, MORTALITY, AND NET BIOMASS CHANGE FOR WHITE PERCH JUVENILES REARED AT SIX CONSTANT TEMPERATURES FOR 14 DAYS

Rearing Temperature $\bar{x} \pm SD$ (°C)	Instantaneous Growth Rate (wet weight) (%/day)	Instantaneous Mortality Rate (%/day)	Instantaneous Net Biomass Change (%/day)
22.5 ± 0.2	3.307	7.646	-4.339
25.0 ± 0.2	3.415	3.79	-0.375
27.3 ± 0.3	6.311	2.123	4.188
29.7 ± 0.2	6.142	3.316	2.826
32.2 ± 0.3	4.937	3.316	1.621
34.8 ± 0.2	-0.145	11.496	-11.641

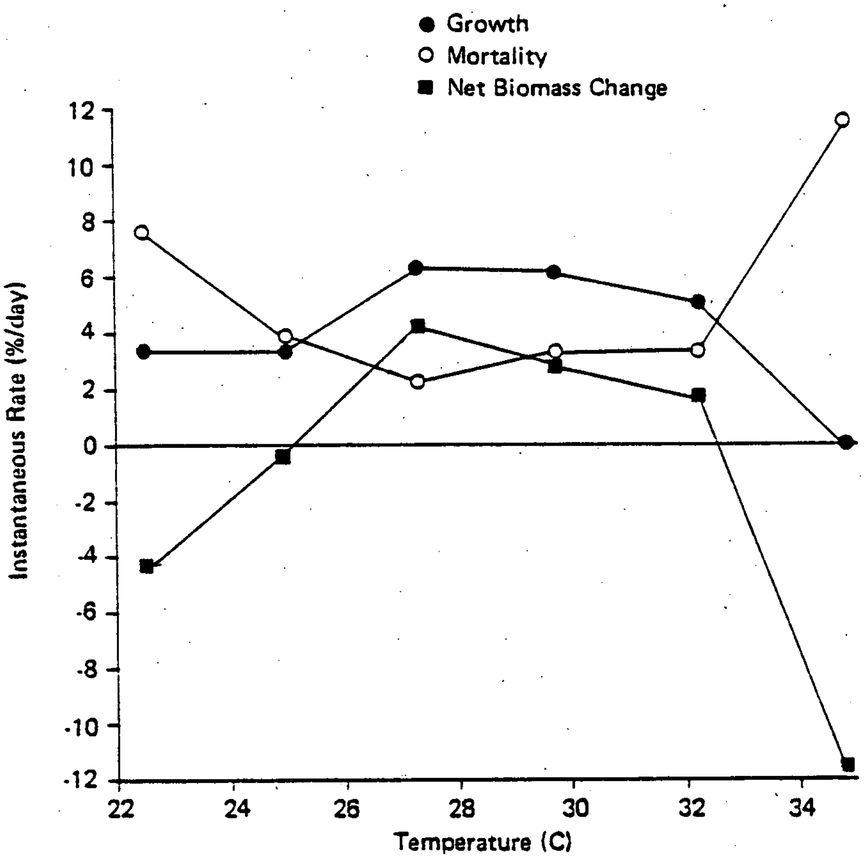


Figure 9.2-4. **Instantaneous rates of growth, mortality, and net biomass change for white perch juveniles.**

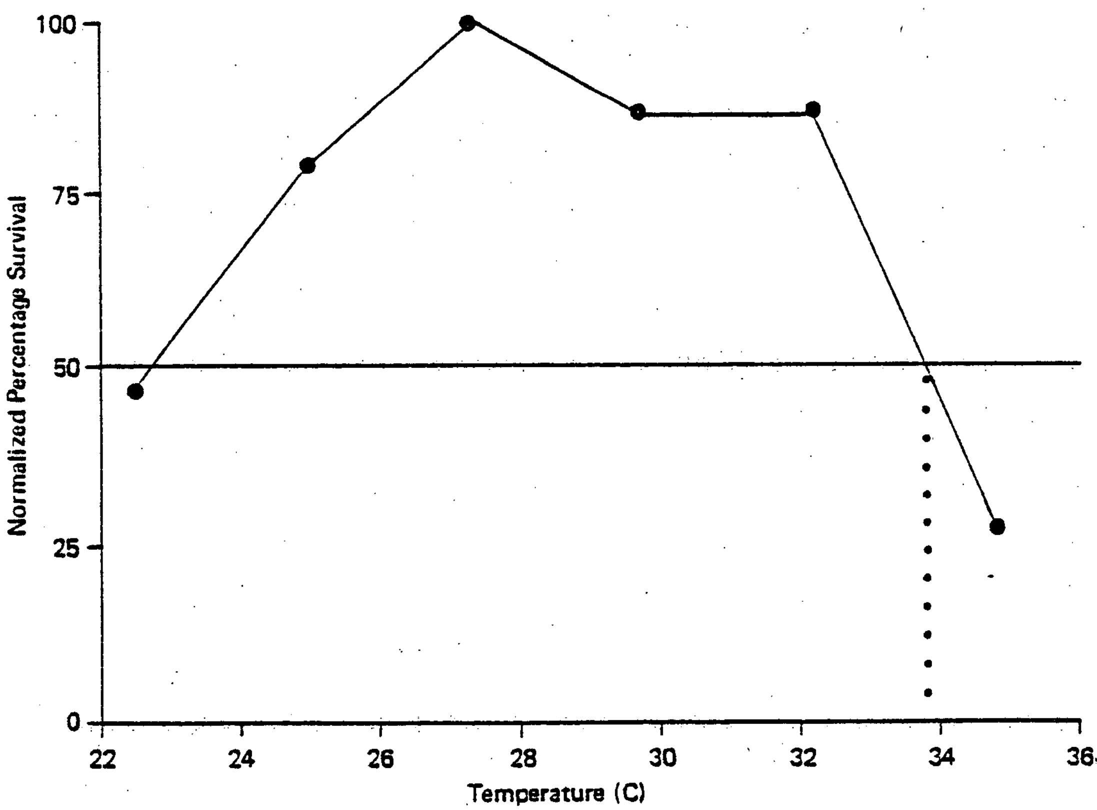


Figure 9.2-5. **Normalized percentage survival of white perch juveniles reared at six constant temperatures for 14 days (TL50 was 33.8 C).**

TABLE 9.2-5 RESULTS OF ATLANTIC TOMCOD GROWTH STUDY CONDUCTED AT SIX CONSTANT TEMPERATURES. INITIAL SAMPLE SIZE WAS 400 YOLK-SAC LARVAE PER TANK. THE NUMBER OF REPLICATES VARIED FROM 1 TO 3 FOR EACH TEMPERATURE-SALINITY COMBINATION(a)

Rearing Temperature $\bar{x} \pm$ SD (C)	Dissolved Oxygen (mg/l)	Age (Days) = 0(b) (Initial) Length $\bar{x} \pm$ SD (mm)	Age (Days) = 0(b) (Initial) Dry Weight per Individual (mg)	Age (Days) = 7(c) Length $\bar{x} \pm$ SD (mm)	Age (Days) = 14(c) Length $\bar{x} \pm$ SD (mm)	Age (Days) = 21(c) Length $\bar{x} \pm$ SD (mm)	Age (Days) = 28(d) Final Length $\bar{x} \pm$ SD (mm)	Age (Days) = 28(d) Final Dry Weight per Individual (mg)	Age (Days) = 28(d) Final Number of Fish Remaining
Fresh									
3.3 ± 0.5	10.6	6.37 ± 0.3	0.08	6.76 ± 0.2	6.84 ± 0.2	6.72 ± 0.5	--	--	0
3.8 ± 0.4	10.2	6.07 ± 0.3	0.09	6.63 ± 0.3	6.59 ± 0.3	--	--	--	0
5.2 ± 0.6	10.7	5.48 ± 0.3	0.08	6.52 ± 0.2	6.32 ± 0.3(e)	--	--	--	0
7.1 ± 0.4	9.7	6.04 ± 0.1	0.08	6.35 ± 0.2(f)	--	--	--	--	0
9.1 ± 0.4	9.7	6.04 ± 0.1	0.08	6.32 ± 0.1(g)	--	--	--	--	0
10.8 ± 0.4	9.5	6.04 ± 0.1	0.08	6.23 ± 0.2(g)	--	--	--	--	0
1.2 ± 0.3 ppt Salinity									
3.2 ± 0.4	10.8	6.37 ± 0.3	0.08	6.75 ± 0.2	6.92 ± 0.3	7.18 ± 0.3	7.55 ± 0.3	0.18	141
4.1 ± 0.4	10.7	6.07 ± 0.3	0.09	6.54 ± 0.1	6.80 ± 0.3	7.21 ± 0.4	7.54 ± 0.6	0.22	158
5.4 ± 0.5	10.6	5.48 ± 0.3	0.08	6.31 ± 0.4	6.59 ± 0.2	6.41 ± 0.3	6.47 ± 0.5	0.17	12
7.3 ± 0.4	10.3	6.04 ± 0.1	0.08	6.58 ± 0.2	6.89 ± 0.2	7.72 ± 0.4	8.28 ± 0.9	0.38	7
9.1 ± 0.4	10.0	6.04 ± 0.1	0.08	6.41 ± 0.2	6.80 ± 0.4	8.33 ± 0.5	9.02 ± 0.5	0.46	8
10.9 ± 0.4	10.0	6.04 ± 0.1	0.08	6.50 ± 0.2	7.49 ± 0.5	8.35 ± 1.4	10.65 ± 1.1	1.07	40

(a) All results are reported as means where more than one successful replicate was performed (see Table 9.1-1).
(b) Based on samples of 30-40 yolk-sac larvae.
(c) Based on samples of 3-30 larvae.
(d) Based on samples of 8-30 larvae.
(e) Fish did not survive past the twelfth day.
(f) Fish did not survive past the tenth day.
(g) Fish did not survive past the ninth day.

Note: Dashes indicate no data available.

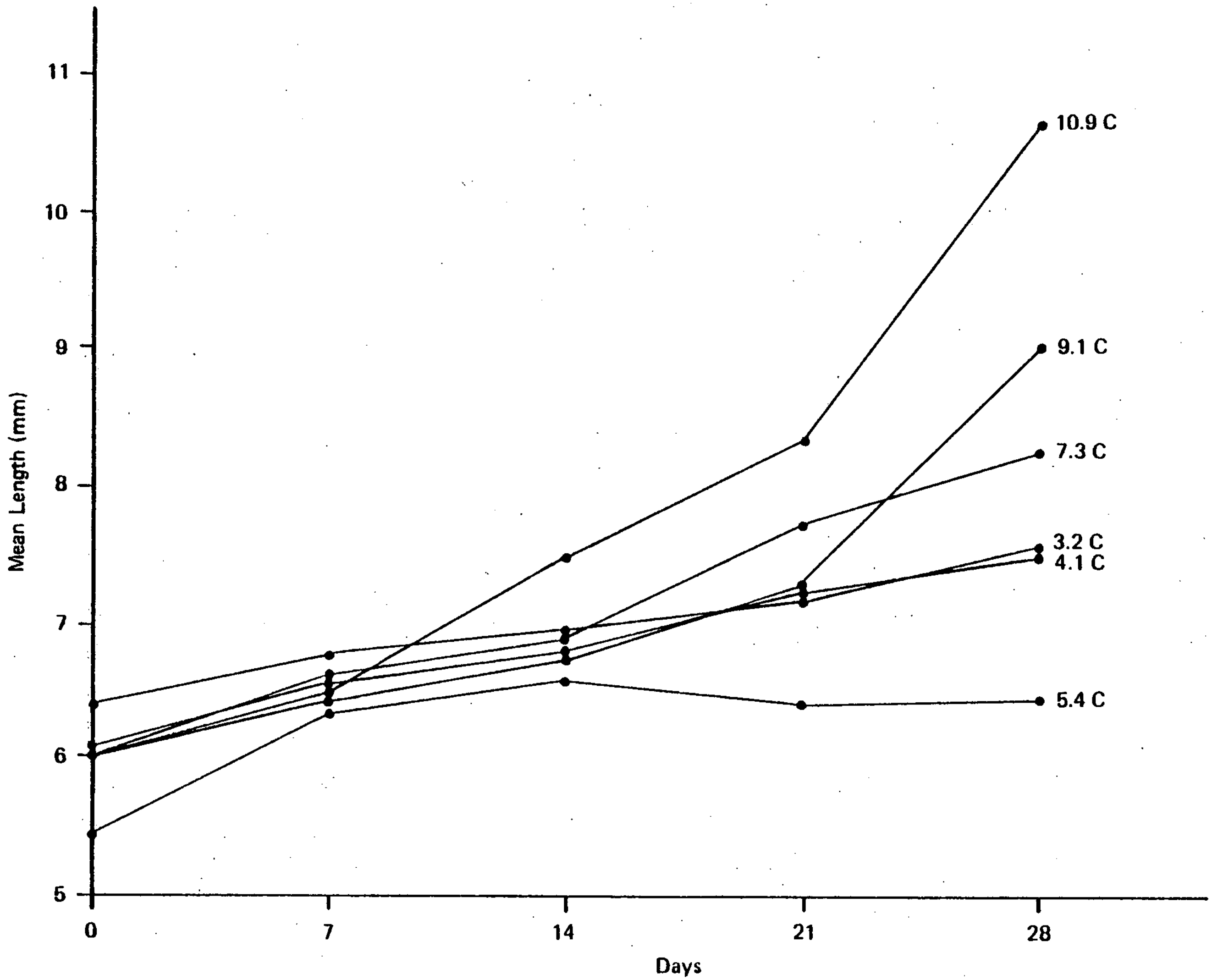


Figure 9.2-6. Growth in length of Atlantic tomcod larvae at six constant temperatures and 1.2 ppt salinity.

at 9.1 and 10.9 C had developed into the juvenile stage at the end of the test. Figure 9.2-7 illustrates developmental progress of Atlantic tomcod larvae at three rearing temperatures.

The optimum temperature for Atlantic tomcod growth and net biomass gain at 1.2 ppt salinity was 10.9 C, the highest rearing temperature tested. Weight gain at 10.9 C exceeded 9 percent per day (Table 9.2-6). Growth rates at 3.3-5.4 C were quite low and differed by less than 0.5 percent per day. Mortality rates at 5.4-9.1 C were high, resulting in negative rates of net biomass change (Figure 9.2-8). Because of the difficulties encountered in rearing tomcod larvae and the moderate mortality resulting at the highest test temperature, it is questionable that the observed mortality at the intermediate test temperatures was entirely due to temperature. Tomcod survival and growth at 10.9 C were higher than at the lower temperatures, but effects of chronic exposures to temperatures greater than 10.9 C cannot be evaluated.

9.2.4 Alewife

Alewife yolk-sac larvae were obtained by artificially spawning adults collected from the river, and were reared at seven constant temperatures and two salinity conditions (Table 9.2-7). Differences in growth as a result of increased temperatures were not evident until the sixth day (Figure 9.2-9). Growth was observed to increase markedly after the initiation of *Artemia* nauplii as a food source on the eighth day, particularly at the higher temperatures. Fish reared at 26.4 and 29.1 C had developed to an advanced post-yolk-sac stage at the end of the test. Figure 9.2-10 illustrates developmental progress of alewife larvae at four rearing temperatures.

Rearing Temperature $\bar{X} \pm SD$ (C)

Age (days)

7 | 14

3.3 ± 0.5

7.3 ± 0.4

10.9 ± 0.4

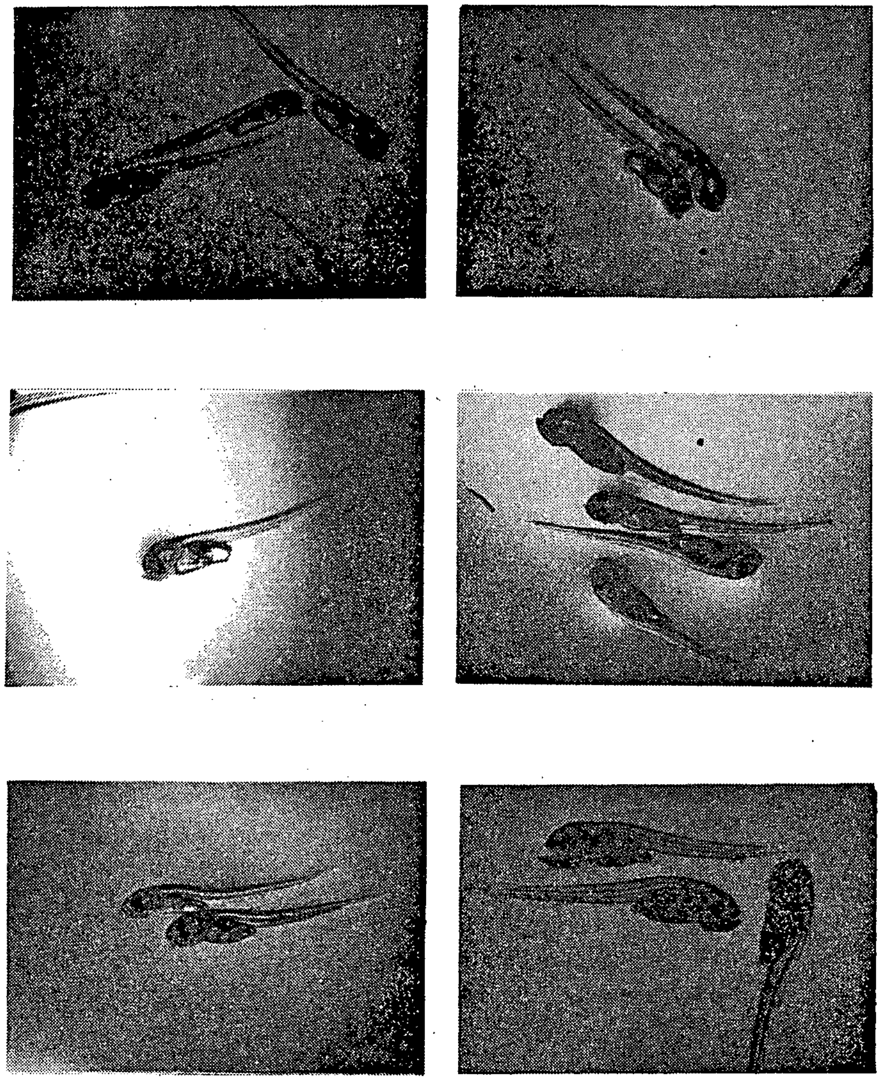


Figure 9.2-7. Development of Atlantic tomcod larvae reared at three constant temperatures for 28 days following hatch (all photographs taken at 7X magnification).

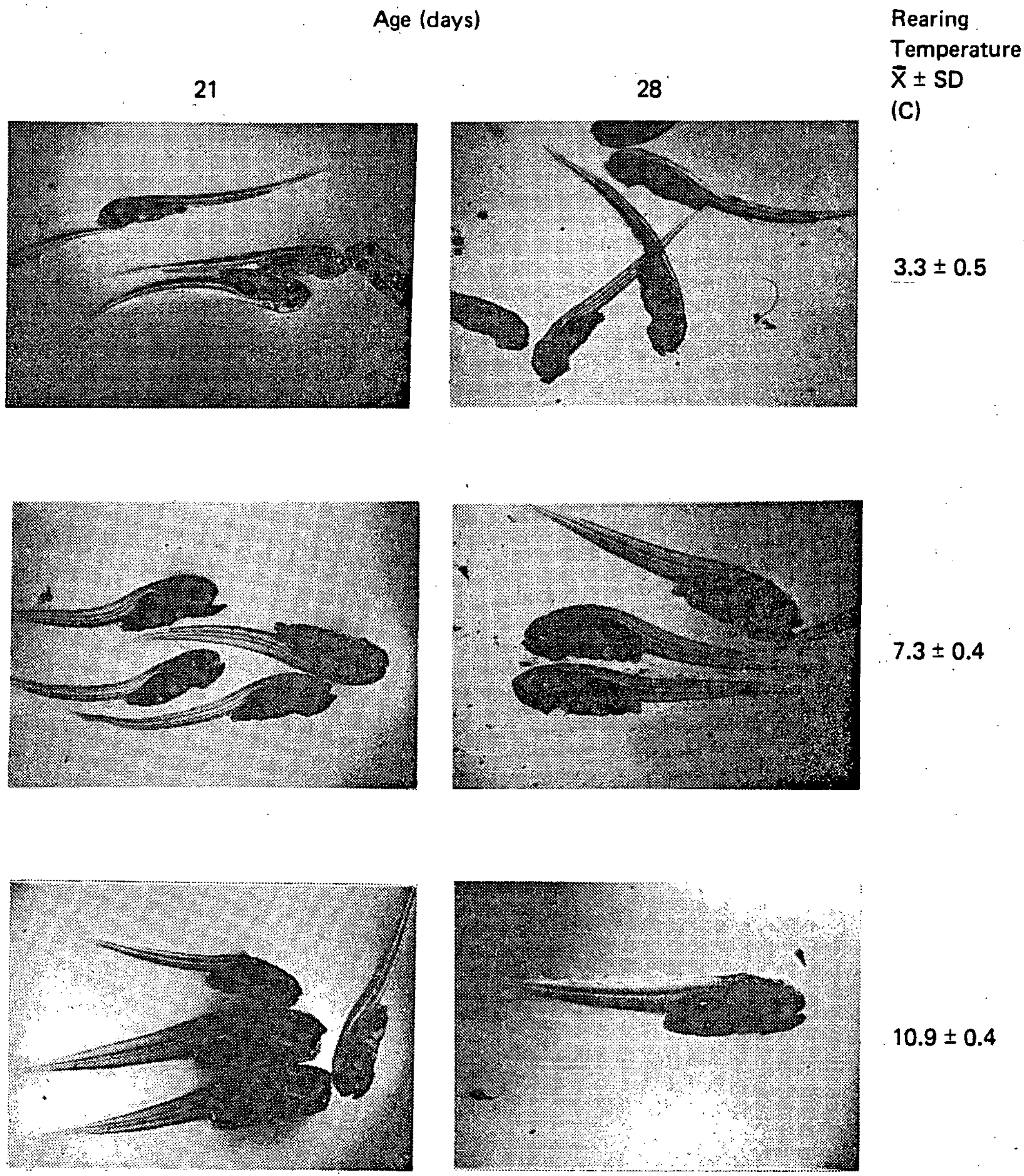


Figure 9.2-7. Continued.

TABLE 9.2-6 INSTANTANEOUS RATE OF GROWTH, MORTALITY, AND NET BIOMASS CHANGE FOR ATLANTIC TOMCOD LARVAE REARED AT SIX CONSTANT TEMPERATURES AND 1.2 PPT SALINITY

Rearing Temperature $\bar{x} \pm$ SD (C)		Instantaneous Growth Rate (dry weight) (%/day)	Instantaneous Mortality Rate (%/day)	Instantaneous Net Biomass Change (%/day)
3.3 ± 0.5		2.90	3.20	-0.30
		2.69	4.53	-1.84
		3.09	2.82	0.27
	Mean	2.89	3.51	-0.62
4.1 ± 0.4		2.67	4.90	-2.23
		3.65	2.07	1.58
		3.35	2.55	0.80
	Mean	3.22	3.17	0.05
5.4 ± 0.4		2.79	12.78	-9.99
7.3 ± 0.4		5.56	13.76	-8.20
9.1 ± 0.4		6.25	13.35	-7.10
10.9 ± 0.4		9.33	7.93	1.40
		9.20	7.23	1.97
	Mean	9.26	7.58	1.68

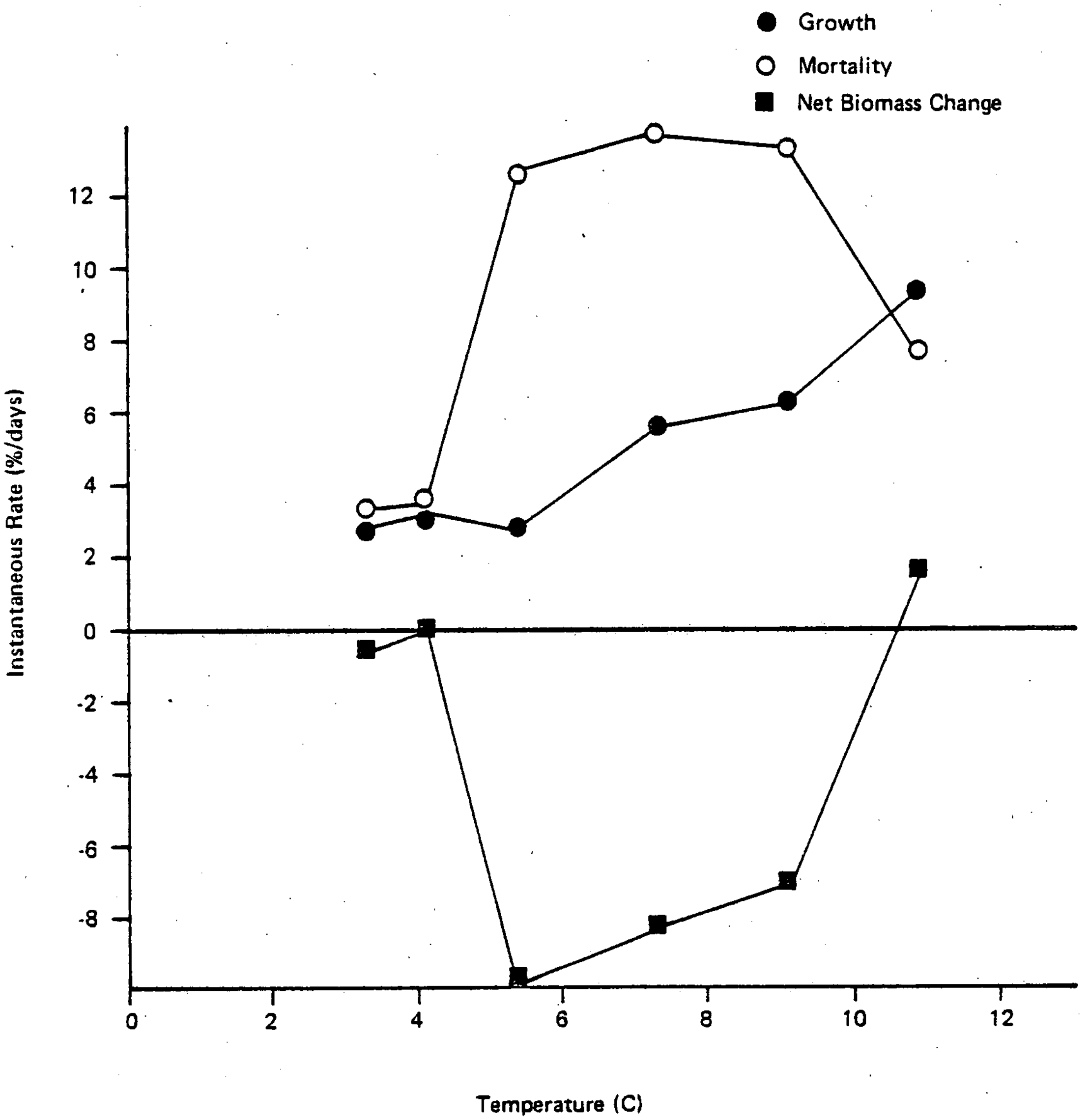


Figure 9.2-8. **Instantaneous rates of growth, mortality, and net biomass change for Atlantic tomcod larvae reared at six constant temperatures and 1.2 ppt salinity.**

TABLE 9.2-7 RESULTS OF ALEWIFE GROWTH STUDY CONDUCTED AT SEVEN CONSTANT TEMPERATURES AND TWO SALINITIES. INITIAL SAMPLE SIZE WAS 500 YOLK-SAC LARVAE PER TANK

Rearing Temperature x̄ ± SD (C)	Dissolved Oxygen (mg/l)	Age (Days) = 0(a) (Initial) Length x̄ ± SD (mm)	Age (Days) = 0(a) (Initial) Dry Weight per Individual (g)	Age (Days) = 3(b) Length x̄ ± SD (mm)	Age (Days) = 6(b) Length x̄ ± SD (mm)	Age (Days) = 12(c) (Final) Length x̄ ± SD (mm)	Age (Days) = 12(c) (Final) Dry Weight per Individual (g)	Number of Fish Remaining
Fresh								
12.9 ± 0.6	9.1	4.63 ± 0.29	0.04	5.35 ± 0.30	5.96 ± 0.21	7.12 ± 0.36	0.05	113
15.2 ± 0.2	8.5	4.63 ± 0.29	0.04	5.80 ± 0.25	6.32 ± 0.36	8.30 ± 0.39	0.09	11
18.2 ± 0.3	8.7	4.85 ± 0.20	0.04	6.13 ± 0.31	6.86 ± 0.44	9.88 ± 0.90	0.14	120
20.8 ± 0.4	8.2	5.32 ± 0.16	0.04	6.09 ± 0.27	7.36 ± 0.94	11.48 ± 0.12	0.28	27
23.7 ± 0.3	7.6	5.32 ± 0.16	0.04	6.19 ± 0.21	7.40 ± 1.64	12.70 ± 1.78	0.53	14
26.4 ± 0.3	7.3	5.32 ± 0.16	0.04	5.93 ± 0.38	7.44 ± 1.39	13.23 ± 1.53	0.56	19
29.1 ± 0.1	7.2	5.32 ± 0.16	0.04	5.87 ± 0.31	8.90 ± 1.20	--(e)	--	0
1.0-1.3 ppt Salinity(e)								
12.9 ± 0.6	9.8	4.63 ± 0.29	0.04	5.36 ± 0.19	6.01 ± 0.19	7.08 ± 0.54	0.06	116
15.2 ± 0.2	9.0	4.63 ± 0.29	0.04	5.92 ± 0.21	6.23 ± 0.28	8.62 ± 0.87	0.10	68
18.2 ± 0.3	8.8	4.85 ± 0.20	0.04	6.40 ± 0.23	6.78 ± 0.47	10.48 ± 1.26	0.18	86
20.8 ± 0.4	8.2	5.32 ± 0.16	0.04	6.23 ± 0.26	6.97 ± 0.66	11.27 ± 1.24	0.25	76
23.7 ± 0.3	7.8	5.32 ± 0.16	0.04	6.19 ± 0.28	6.70 ± 0.41	11.85 ± 2.15	0.37	30
26.4 ± 0.3	7.6	5.32 ± 0.16	0.04	6.13 ± 0.40	7.61 ± 1.22	14.74 ± 2.36	0.86	28
29.1 ± 0.1	7.2	5.32 ± 0.16	0.04	5.90 ± 0.41	8.22 ± 1.22	14.01 ± 2.95	1.04	12

(a) Based on samples of 50-150 larvae from the initial stock. Length determinations made on a subsample of 10 larvae from each stock.
(b) Based on a sample of 10 fish from each replicate.
(c) Based on a sample of 5 fish from each replicate.
(d) All survivors were weighed. Lengths were determined on a subsample of 20 fish for each replicate.
(e) Dashes indicate no data available. All larvae died after the tenth day in this replicate.
(f) Lengths, weights, numbers of fish, and dissolved oxygen determinations are mean values from 2 replicates.

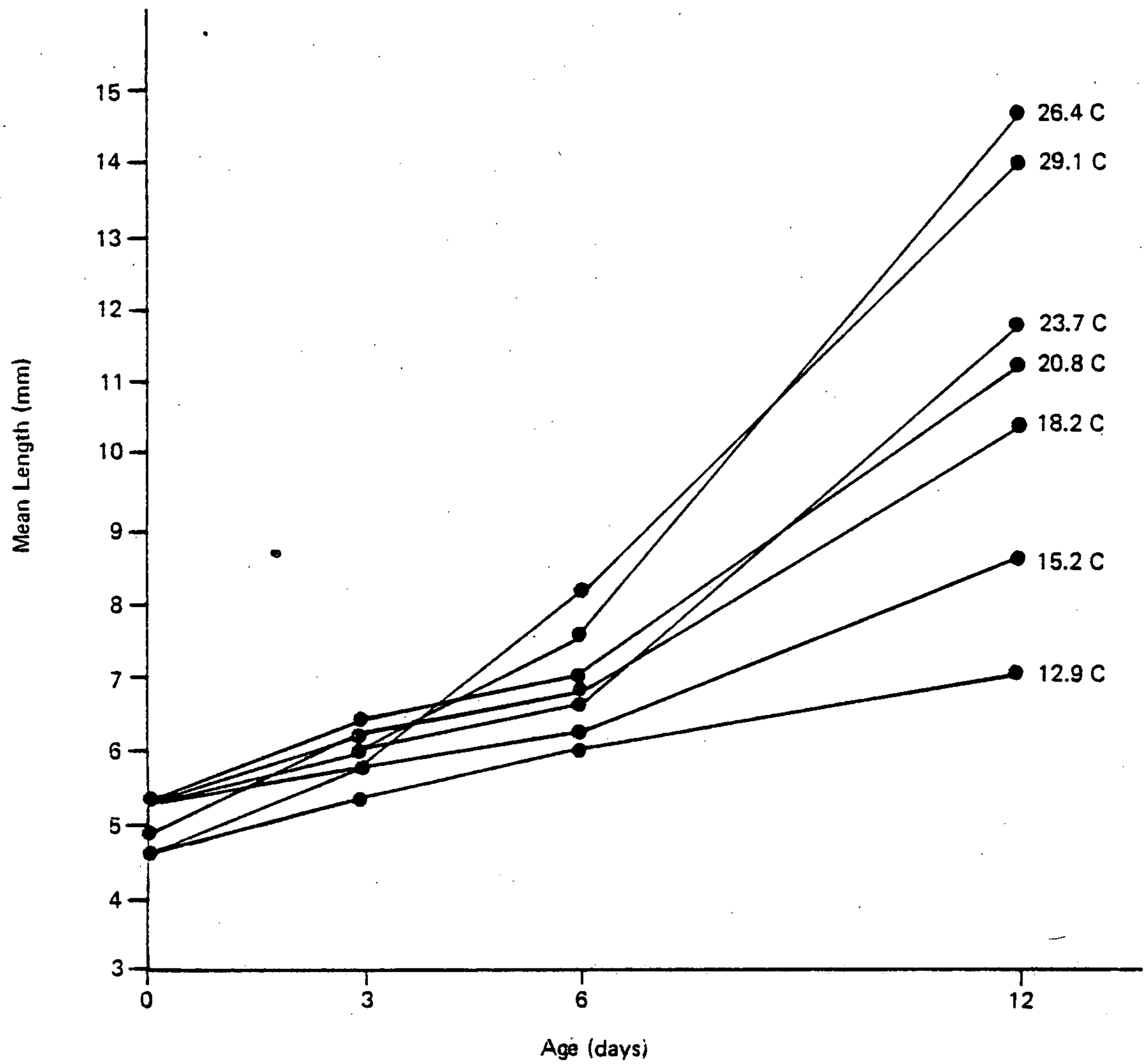


Figure 9.2-9. Growth in length of alewife larvae reared at seven constant temperatures and 1.0-1.3 ppt salinity.

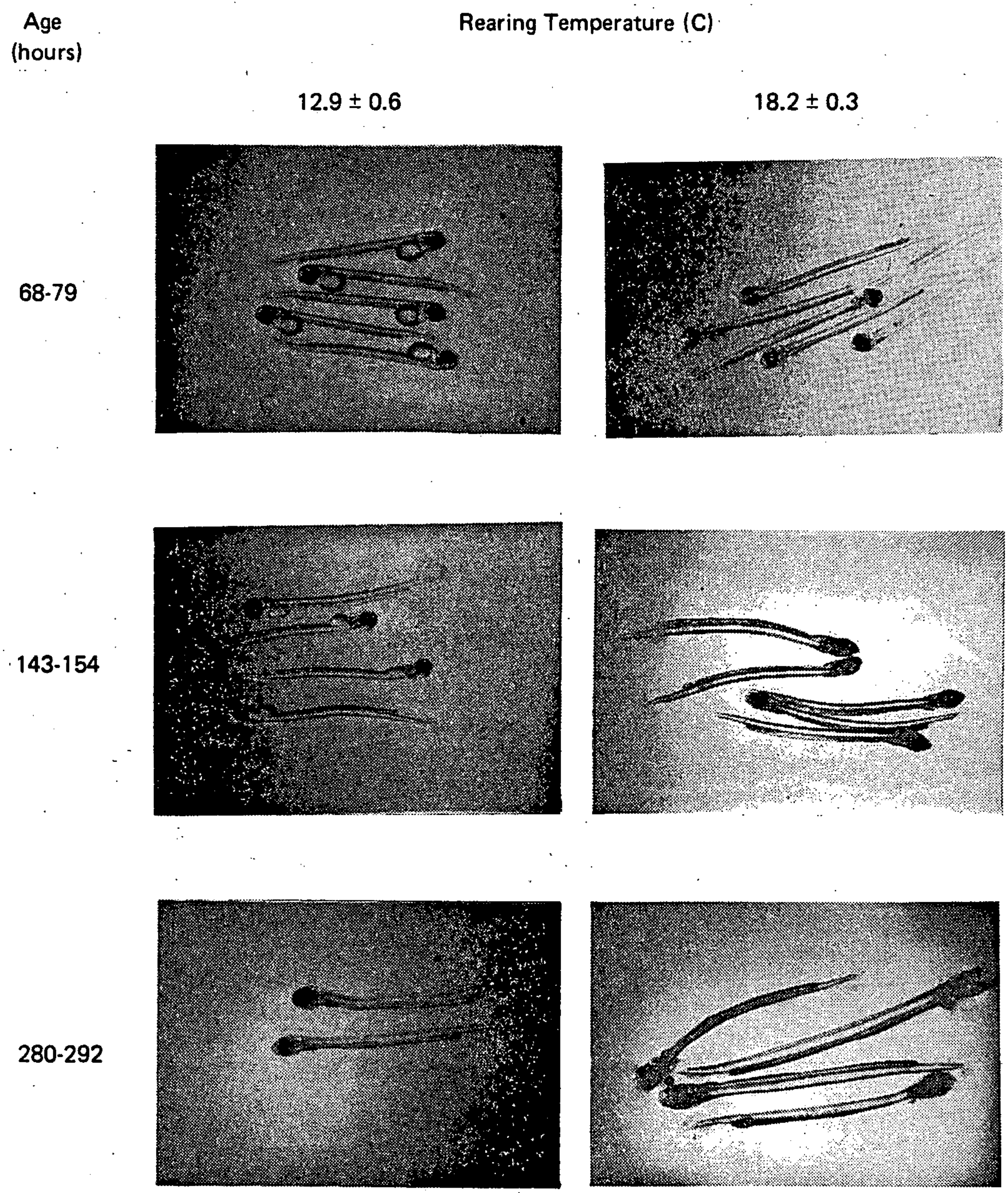


Figure 9.2-10. Development of alewife larvae reared at four constant temperatures for 12 days following hatch (all photographs taken at 7X magnification).

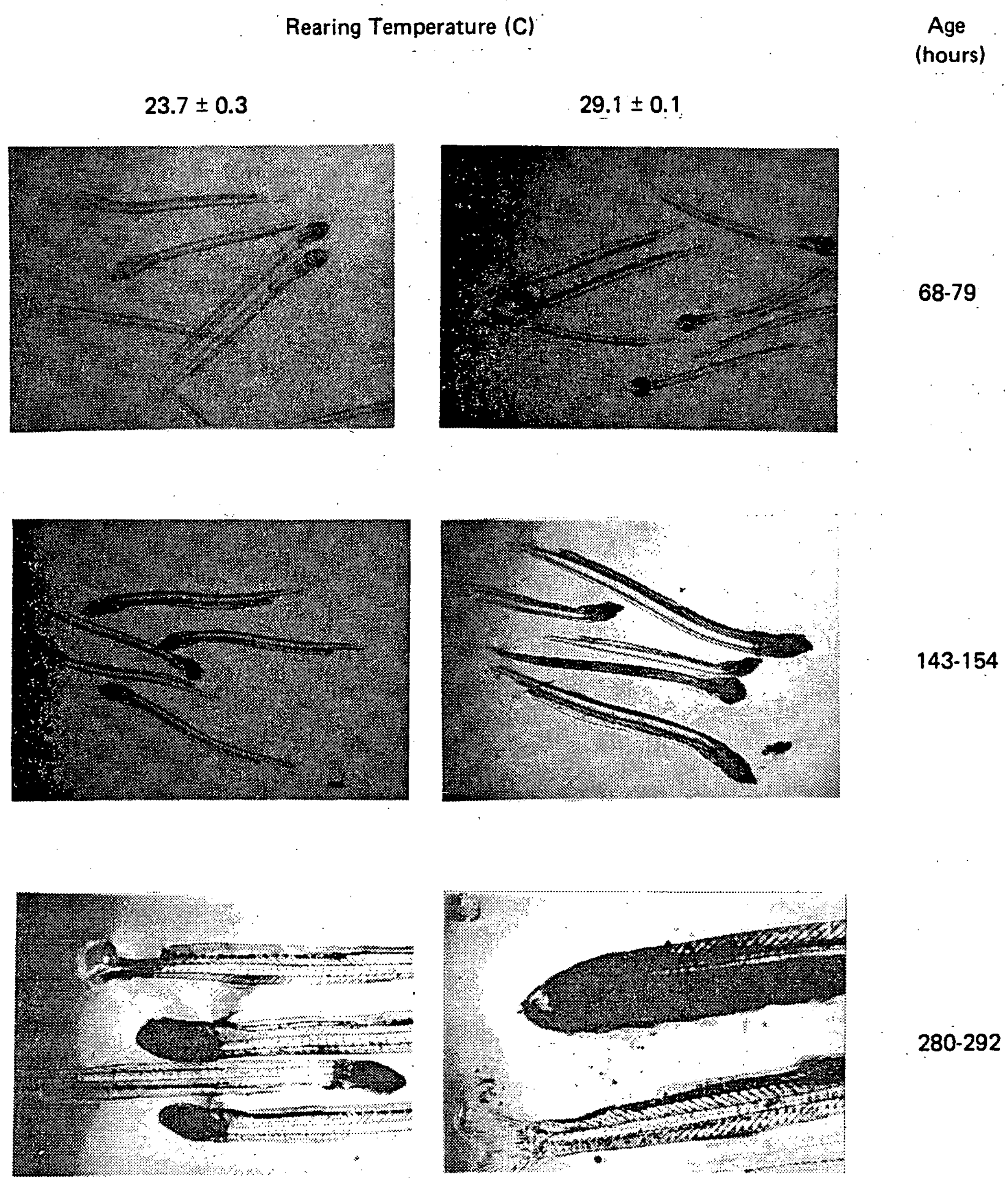


Figure 9.2-10. Continued.

Survival was low for all replicates at all temperatures, which attested to the difficulty of rearing alewife under laboratory conditions. Mortality ranged from 11 to 52 percent per day, and generally increased with temperature (Table 9.2-8). Mortality rates for alewife larvae reared in fresh water were typically higher than for larvae reared at 1.0-1.3 ppt (Figure 9.2-11). There was no survival beyond the tenth day in the freshwater replicate at 29.1 C. Growth rates varied little between freshwater and saltwater replicates at temperatures ranging from 12.9 to 23.7 C (Figure 9.2-12). However, the growth rate for larvae reared at 26.4 C in fresh water was only slightly greater than the response at 23.7 C, whereas growth rates of larvae reared in salt water continued to increase with temperature.

The effects of temperature on development and survival of alewife larvae are best represented by tests performed at 1.0-1.3 ppt salinity, owing to the erratic mortality pattern observed for larvae reared in fresh water under laboratory conditions. Figure 9.2-13 presents instantaneous rates of growth, mortality, and net biomass change for alewife larvae reared at 1.0-1.3 ppt salinity. Positive growth rates occurred at all test temperatures and increased steadily with temperature to an optimum of 27 percent per day weight gain for larvae reared at 29.1 C. The optimum temperature for growth was 29.1 C, but the highest rate of mortality was observed at this temperature as well. Therefore, the best estimate of the optimum response of alewife larvae to long-term temperature exposure in this study appears to be the optimum temperature for net biomass change, which was 26.4 C.

9.2.5 White Catfish

White catfish larvae were obtained from a pair of adults that spawned in the laboratory, and were reared at seven constant temperatures ranging from 20.0

TABLE 9.2-8 INSTANTANEOUS RATES OF GROWTH, MORTALITY, AND NET BIOMASS GAIN FOR ALEWIFE LARVAE REARED AT SEVEN CONSTANT TEMPERATURES AND TWO SALINITY CONDITIONS

Rearing Temperature $\bar{x} \pm SD$ (C)		Instantaneous Growth Rate (dry weight) (%/day)	Instantaneous Mortality Rate (%/day)	Instantaneous Net Biomass Change (%/day)
Fresh				
12.9 ± 0.6		1.86	12.39	-10.53
15.2 ± 0.2		6.76	31.81	-25.05
18.2 ± 0.3		10.44	11.89	-1.45
20.8 ± 0.4		16.22	24.32	-8.11
23.7 ± 0.3		21.53	29.80	-8.26
26.4 ± 0.3		21.99	27.25	-5.26
29.1 ± 0.1(a)		--	51.79	--
1.0-1.3 ppt Salinity				
12.9 ± 0.6		3.38	11.62	-8.24
		1.86	12.77	-10.91
	Mean	2.62	12.19	-9.57
15.2 ± 0.2		6.76	16.27	-9.51
		7.64	17.13	-9.49
	Mean	7.20	16.70	-9.50
18.2 ± 0.3		11.02	11.04	-0.02
		14.21	21.48	-7.27
	Mean	12.61	16.26	-3.64
20.8 ± 0.4		15.60	16.27	-0.67
		14.93	17.53	-2.60
	Mean	15.26	16.90	-1.64

(a) No survival past the tenth day.

TABLE 9.2-8 (CONT.)

Rearing Temperature $\bar{x} \pm SD$ (C)	Instantaneous Growth Rate (dry weight) (%/day)	Instantaneous Mortality Rate (%/day)	Instantaneous Net Biomass Change (%/day)
23.7 ± 0.3	17.83	20.25	-2.42
	19.19	28.68	-9.49
	Mean 18.51	24.47	-5.96
26.4 ± 0.3	25.57	23.17	2.40
	25.57	25.30	0.27
	Mean 25.57	24.24	1.33
29.1 ± 0.1	27.77	29.80	-2.03
	26.40	31.81	-5.41
	Mean 27.08	30.80	-3.72

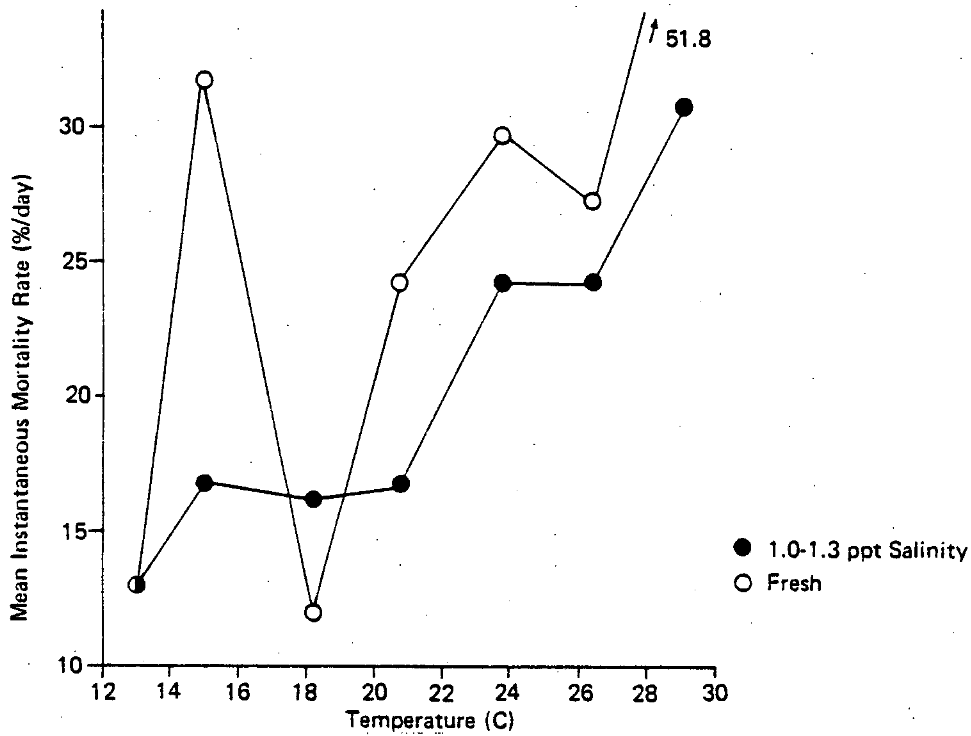


Figure 9.2-11. Instantaneous mortality rates for alewife larvae reared at seven constant temperatures and two salinity levels.

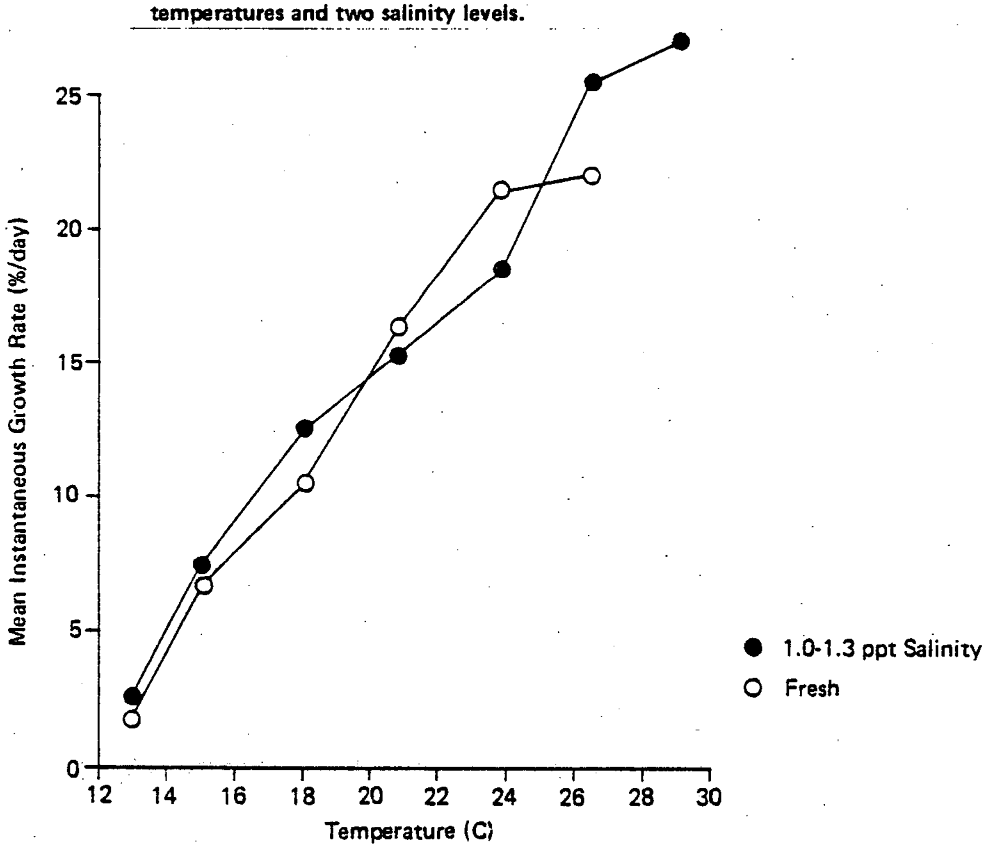


Figure 9.2-12. Instantaneous growth rates for alewife larvae reared at seven constant temperatures and two salinity levels.

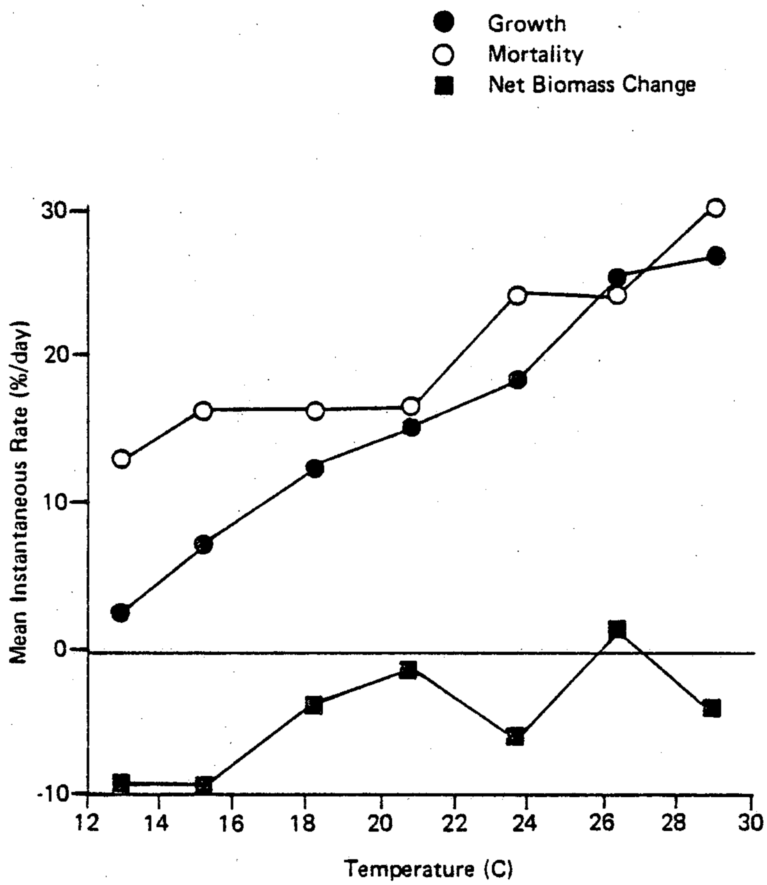


Figure 9.2-13. Instantaneous rates of growth, mortality, and net biomass change for alewife larvae reared at seven constant temperatures and 1.0-1.3 ppt salinity.

to 34.7 C. The test was initiated with 8-day-old post-yolk-sac larvae with a mean total length of 15.8 mm and a mean weight of 0.06 g (Table 9.2-9). All larvae had developed into juveniles soon after the eighth day. The optimum range for growth was 27.3-32.2 C. Growth rates at these temperatures ranged from 9.9 to 10.5 percent per day (Table 9.2-10). Although the highest growth rate occurred at 29.6 C, differences among the growth rates at these temperatures were less than 0.7 percent per day. Mortality rates at all temperatures were low, ranging from 0.28 to 2.1 percent per day. The optimum temperature for net biomass gain was 29.6 C. Net biomass change rates were fairly high at all rearing temperatures (Figure 9.2-14), ranging from 4.9 to 8.8 percent per day.

Growth of fish at 34.7 C tapered off after the fourteenth day (Figure 9.2-15), which resulted in a growth rate only slightly greater than the growth rate for fish reared at 20 C. Although survival for white catfish reared at 34.7 C was high, 90 percent of the survivors were grossly deformed. The TL50 for normal survival (i.e., deformed fish were included as mortality) at the end of the 21-day exposure period was 33.0 C (Figure 9.2-16).

9.2.6 Spottail Shiner

Spottail shiners were obtained from the Hudson River at the earliest possible stage permitting speciation of living specimens. The test was initiated with juveniles measuring 20.2 $\pm$ 2.7 mm total length with a mean weight of 0.11 g (Table 9.2-11). Growth differences due to temperature became apparent after the fifth day (Figure 9.2-17). The optimum temperature range for growth was 25.0-32.2 C (Table 9.2-12). Growth rates at these temperatures ranged from 7.8 to 8.3 percent per day, differing by only 0.5 percent per day over the 7.2 C range (Figure 9.2-18). Mortality rates were fairly constant from 20 to

TABLE 9.2-9 RESULTS OF WHITE CATFISH GROWTH STUDY CONDUCTED AT SEVEN CONSTANT TEMPERATURES. INITIAL SAMPLE SIZE WAS 100 POST-YOLK-SAC LARVAE PER TANK

Rearing Temperature $\bar{x} \pm SD$ (C)	Dissolved Oxygen (mg/l)	Age (Days) = 8(a) (Initial) Length $\bar{x} \pm SD$ (mm)	Wet Weight per Individual (g)	Age (Days) = 16(b) Length $\bar{x} \pm SD$ (mm)	Wet Weight per Individual (g)	Age (Days) = 22(b) Length $\bar{x} \pm SD$ (mm)	Wet Weight per Individual (g)	Age (Days) = 29(c) (Final) Length $\bar{x} \pm SD$ (mm)	Wet Weight per Individual (g)	Number of Fish Remaining
20.0 ± 0.4	8.4	15.8 ± 0.5	0.06	19.6 ± 1.4	0.10	23.2 ± 0.7	0.18	24.4 ± 0.7	0.21	67(d)
22.5 ± 0.2	8.9	15.8 ± 0.5	0.06	21.1 ± 0.7	0.12	26.0 ± 1.3	0.22	30.0 ± 1.4	0.35	75
25.0 ± 0.2	8.1	15.8 ± 0.5	0.06	22.4 ± 0.7	0.15	27.2 ± 0.7	0.26	30.6 ± 1.4	0.39	49
27.3 ± 0.2	8.1	15.8 ± 0.5	0.06	23.2 ± 2.1	0.17	30.0 ± 0.5	0.30	35.0 ± 2.0	0.54	52
29.6 ± 0.3	8.0	15.8 ± 0.5	0.06	24.2 ± 1.2	0.21	32.6 ± 1.2	0.41	35.0 ± 1.7	0.59	53
32.2 ± 0.3	7.9	15.8 ± 0.5	0.06	23.5 ± 1.2	0.18	31.1 ± 1.6	0.34	35.2 ± 2.0	0.52	49
34.7 ± 0.2	7.7	15.8 ± 0.5	0.06	21.7 ± 0.9	0.13	24.1 ± 1.5	0.17	25.0 ± 1.5	0.25	63(e)

(a) Based on samples of 30 larvae.
(b) Based on samples of 10 fish.
(c) Lengths based on samples of 20 fish; all survivors were weighed.
(d) Severe infestation of ichthyophthiriasis.
(e) 90% of survivors were grossly deformed.

TABLE 9.2-10 INSTANTANEOUS RATES OF GROWTH, MORTALITY, AND NET BIOMASS CHANGE FOR WHITE CATFISH JUVENILES REARED AT SEVEN CONSTANT TEMPERATURES FOR 21 DAYS

Rearing Temperature $\bar{x} \pm SD$ (C)	Instantaneous Growth Rate (wet weight) (%/day)	Instantaneous Mortality Rate (%/day)	Instantaneous Net Biomass Change (%/day)
20.0 ± 0.4	5.590	0.736	4.854
22.5 ± 0.2	8.131	0.275	7.856
25.0 ± 0.2	8.557	2.118	6.439
27.3 ± 0.2	10.157	1.797	8.36
29.6 ± 0.3	10.569	1.764	8.805
32.2 ± 0.3	9.930	1.893	8.037
34.7 ± 0.2	6.545	0.963	5.582

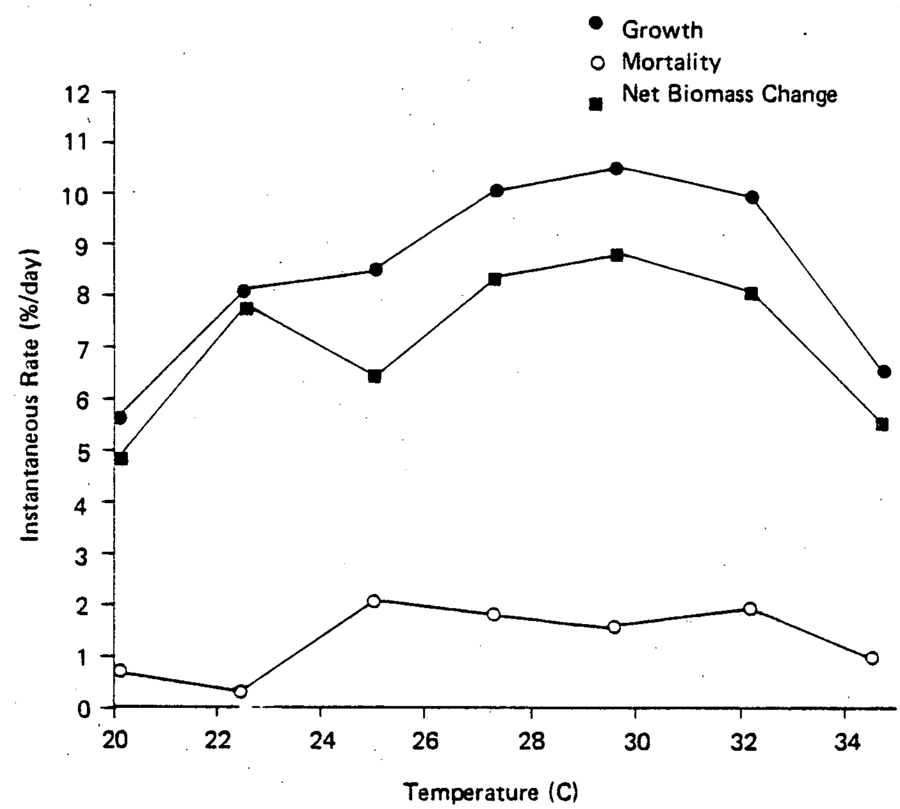


Figure 9.2-14. Instantaneous rates of growth, mortality, and net biomass change for white catfish juveniles reared at seven constant temperatures for 21 days.

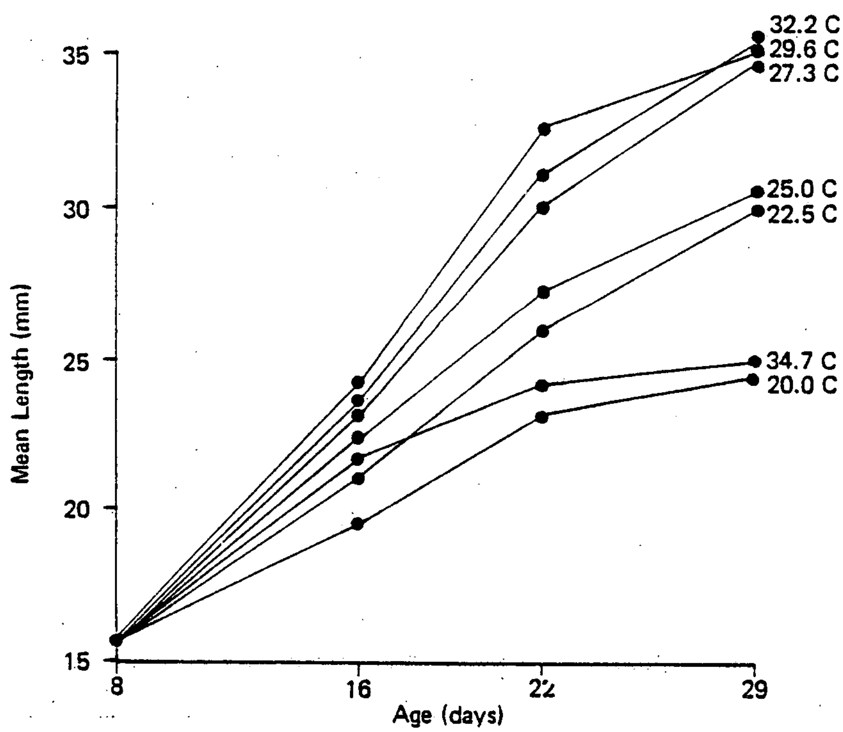


Figure 9.2-15. Growth in length of white catfish juveniles at seven constant temperatures.

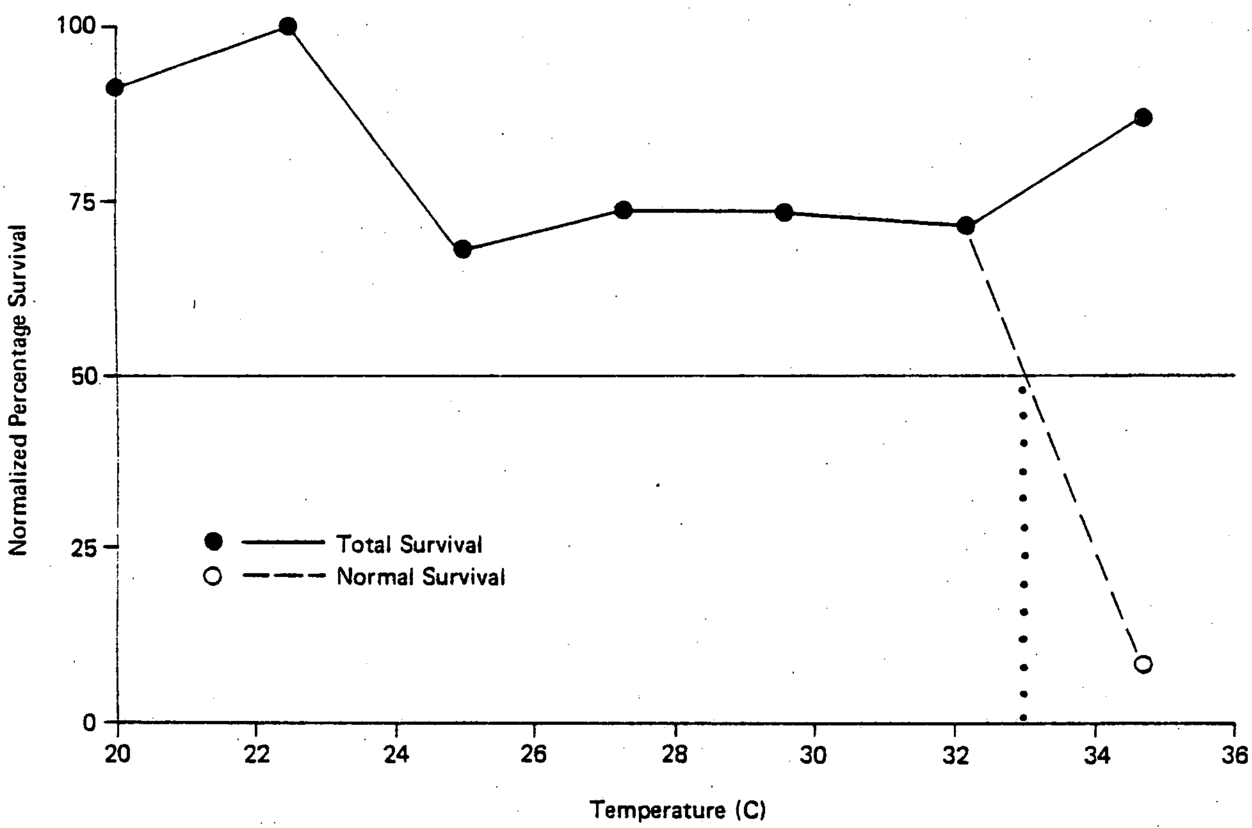


Figure 9.2-16. Normalized percentage survival of white catfish juveniles reared at seven constant temperatures for 21 days (TL50 for normal survival was 33.0 C).

TABLE 9.2-11 RESULTS OF SPOTTAIL SHINER GROWTH STUDY CONDUCTED AT SEVEN CONSTANT TEMPERATURES. INITIAL SAMPLE SIZE WAS 200 JUVENILES PER TANK

Rearing Temperature x̄ ± SD (C)	Dissolved Oxygen (mg/l)	Day 0[a] (Initial) Length x̄ ± SD (mm)	Day 0[a] (Initial) Wet Weight per Individual (g)	Day 5[b] Length x̄ ± SD (mm)	Day 5[b] Wet Weight per Individual (g)	Day 12[b] Length x̄ ± SD (mm)	Day 12[b] Wet Weight per Individual (g)	Day 21[c] (Final) Length x̄ ± SD (mm)	Day 21[c] (Final) Wet Weight per Individual (g)	Number of Fish Remaining
20.0 ± 0.4	8.2	20.2 ± 2.7	0.11	23.9 ± 3.1	0.12	25.3 ± 2.6	0.16	29.8 ± 3.0	0.22	104
22.5 ± 0.2	8.2	20.2 ± 2.7	0.11	23.5 ± 2.1	0.14	28.7 ± 2.3	0.23	34.4 ± 2.5	0.34	138
25.0 ± 0.1	7.9	20.2 ± 2.7	0.11	24.1 ± 2.7	0.14	30.2 ± 3.7	0.29	36.9 ± 2.8	0.39	113
27.3 ± 0.3	8.0	20.2 ± 2.7	0.11	25.3 ± 1.8	0.16	31.2 ± 2.9	0.30	37.5 ± 4.0	0.43	84
29.6 ± 0.3	7.9	20.2 ± 2.7	0.11	24.4 ± 2.7	0.17	32.3 ± 3.7	0.32	37.8 ± 3.5	0.40	110
32.2 ± 0.3	7.7	20.2 ± 2.7	0.11	25.1 ± 2.1	0.16	31.8 ± 3.0	0.32	35.6 ± 2.1	0.41	119
34.7 ± 0.2	7.7	20.2 ± 2.7	0.11	--[d]	--	--	--	20.8 ± 1.7	0.07	12[e]

(a) Based on a sample of 30 juveniles.
(b) Based on samples of 20 juveniles.
(c) Lengths based on samples of 12-20 juveniles; all survivors were weighed.
(d) Dashes indicate no data available. Samples were not removed from the 34.7 C rearing tank during the test because of high mortality.
(e) All survivors were grossly deformed.

TABLE 9.2-12 INSTANTANEOUS RATES OF GROWTH, MORTALITY, AND NET BIOMASS CHANGE FOR SPOTTAIL SHINER JUVENILES REARED AT SEVEN CONSTANT TEMPERATURES

Rearing Temperature $\bar{x} \pm$ SD (°C)	Instantaneous Growth Rate (wet weight) (%/day)	Instantaneous Mortality Rate (%/day)	Instantaneous Net Biomass Change (%/day)
20.0 ± 0.4	5.124	1.917	3.207
22.5 ± 0.2	7.141	0.635	6.506
25.0 ± 0.1	7.814	1.431	6.383
27.3 ± 0.3	8.316	2.654	5.662
29.6 ± 0.3	8.030	1.565	6.465
32.2 ± 0.3	8.042	1.561	6.481
34.7 ± 0.2	-0.064	13.397	-13.461

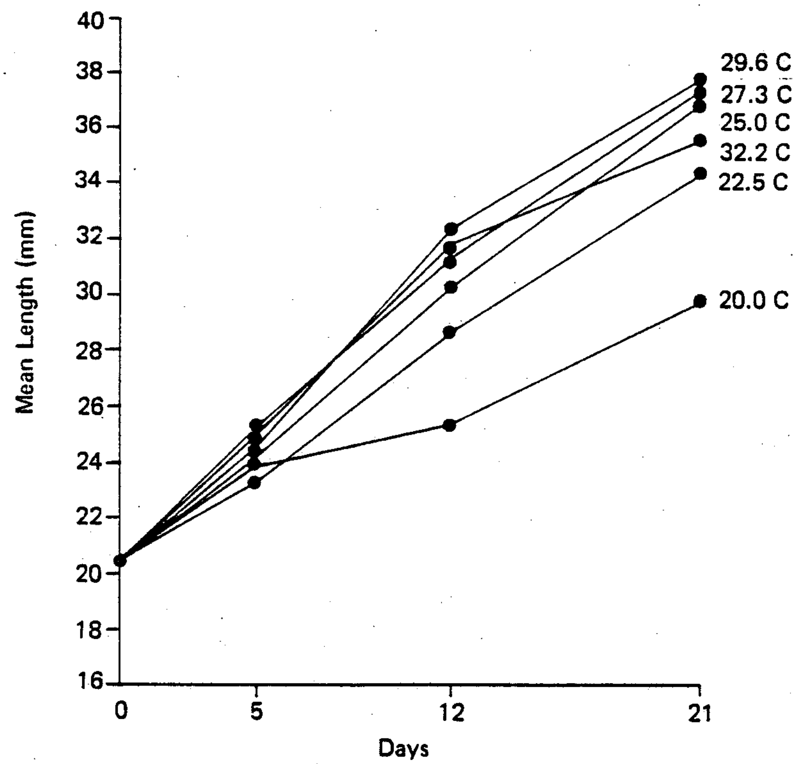


Figure 9.2-17. Growth in length of spottail shiner juveniles at six constant temperatures.

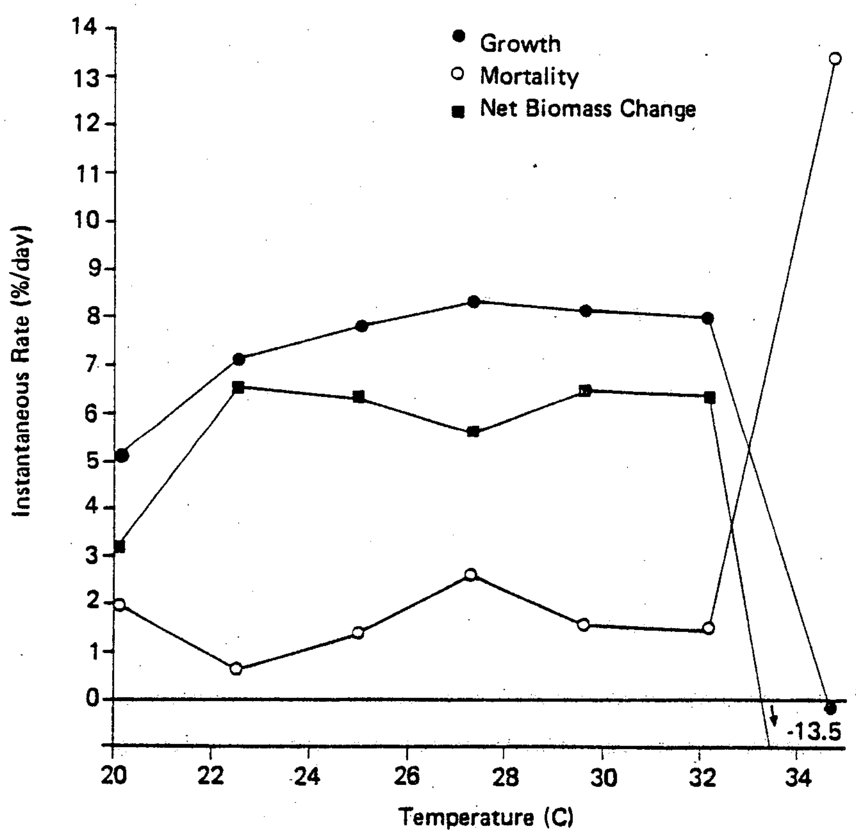


Figure 9.2-18. Instantaneous rates of growth, mortality, and net biomass change for spottail shiner juveniles.

32.2 C, ranging from 0.6 to 2.7 percent per day. However, mortality at 34.7 C exceeded 13 percent per day and all survivors exhibited severe curvature of the spine. Fish reared at this temperature actually exhibited weight loss. The TL50 for the survival of normal spottail shiner juveniles at the end of the 21-day exposure was 33.1 C (Figure 9.2-19).

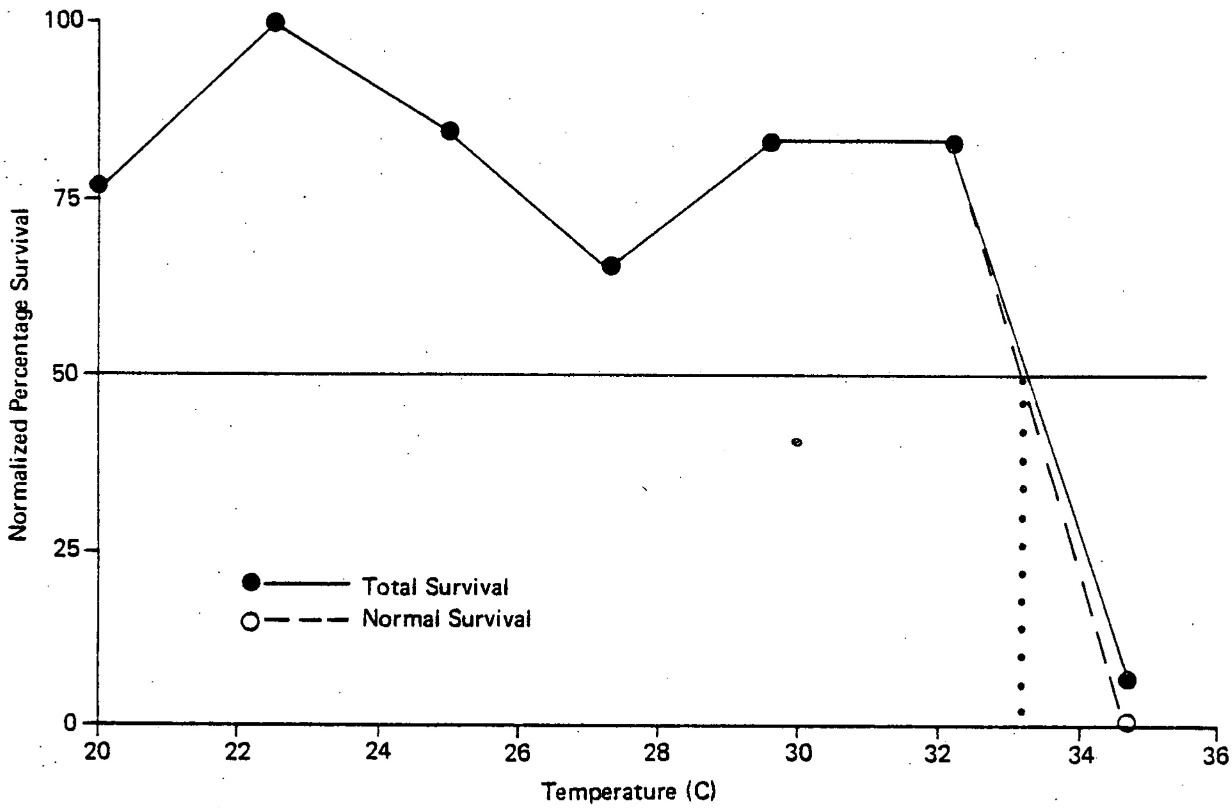


Figure 9.2-19. Normalized percentage survival of spottail shiner juveniles reared at seven constant temperatures for 21 days. (TL50 for normal survival was 33.1 C.)

CHAPTER 10: THERMAL PREFERENCE STUDIES

Behavioral information provided by thermal preference studies has been recognized as an important aspect of 316(a) demonstrations (Gift 1977). Laboratory determinations of thermal preference are often useful for predicting the zones within thermal plumes that may attract organisms. This is particularly important in the evaluation of cold-shock potential. However, the actual presence or absence of organisms in thermal plumes also depends upon the availability of suitable habitat types, food sources, natural migration patterns, and other factors in addition to temperature (Coutant 1970, 1975; Reynolds 1977; EA 1978c). Therefore, predictions of fish behavior in the vicinity of a thermal discharge based on temperature preferences determined in the laboratory are best applied in conjunction with actual field studies.

Temperature preference information can also be used to approximate the optimum temperatures for growth and performance where results of more direct measurements of the temperature requirements for these activities are not available. Final thermal preferenda have been shown to generally coincide with the optimum temperatures for several physiological functions (Brett 1971; Coutant 1975). Final thermal preferendum has been defined as the temperature toward which fish will finally gravitate regardless of its previous thermal history (acclimation) and where preferred and acclimation temperature are equal (Fry 1947; Reynolds 1977). To predictively evaluate the effects of heated discharges on the growth and performance of juvenile and adult fish populations that may be residing in areas influenced by thermal plumes from Hudson River power plants, final thermal preferenda were determined for several representative important species (RIS). These estimates of optimum temperatures for performance and growth were used to assess the thermal effects of heated discharge on RIS as presented and discussed in 316(a) demonstrations for the Indian Point, Bowline Point, and Danskammer Point and Roseton Generating Stations.

10.1 METHODS AND MATERIALS

10.1.1 Experimental Procedures

Thermal preference experiments were conducted using two vertical gradient tanks and one horizontal gradient tank (modified from the design of Gift and Wyllie [1975]). Species adapted for living on the bottom (e.g., white catfish, Atlantic tomcod) were tested in the horizontal tank, and those adapted for a more open-water existence were tested in the vertical tanks.

The vertical preference apparatus consisted of a 7-ft fiberglass tank, 3 ft in diameter, with a 1-by-7-ft observation window (Figure 10.1-1). A 1-2 gpm mixture of hot and ambient water flowed into the top of the tank via a head box and exited through a circular drain at the bottom of the tank. The warm water was cooled as it traveled down the tank by a 150-ft coil containing chilled ethylene glycol. The glycol flow was automatically adjusted by a mixing valve that was pneumatically regulated by a Foxboro temperature controller, enabling the effluent water temperature from the preference tank to be set to any specified level. The influent temperature was set by adjusting the flow of hot and ambient water into the head box. Twelve temperature probes spaced evenly from the top to the bottom of the tank were used to record the vertical gradient. Observations were made from a dark enclosure constructed around the observation window, and the observation window was covered with a sheet of Solar-X plastic, allowing undetected

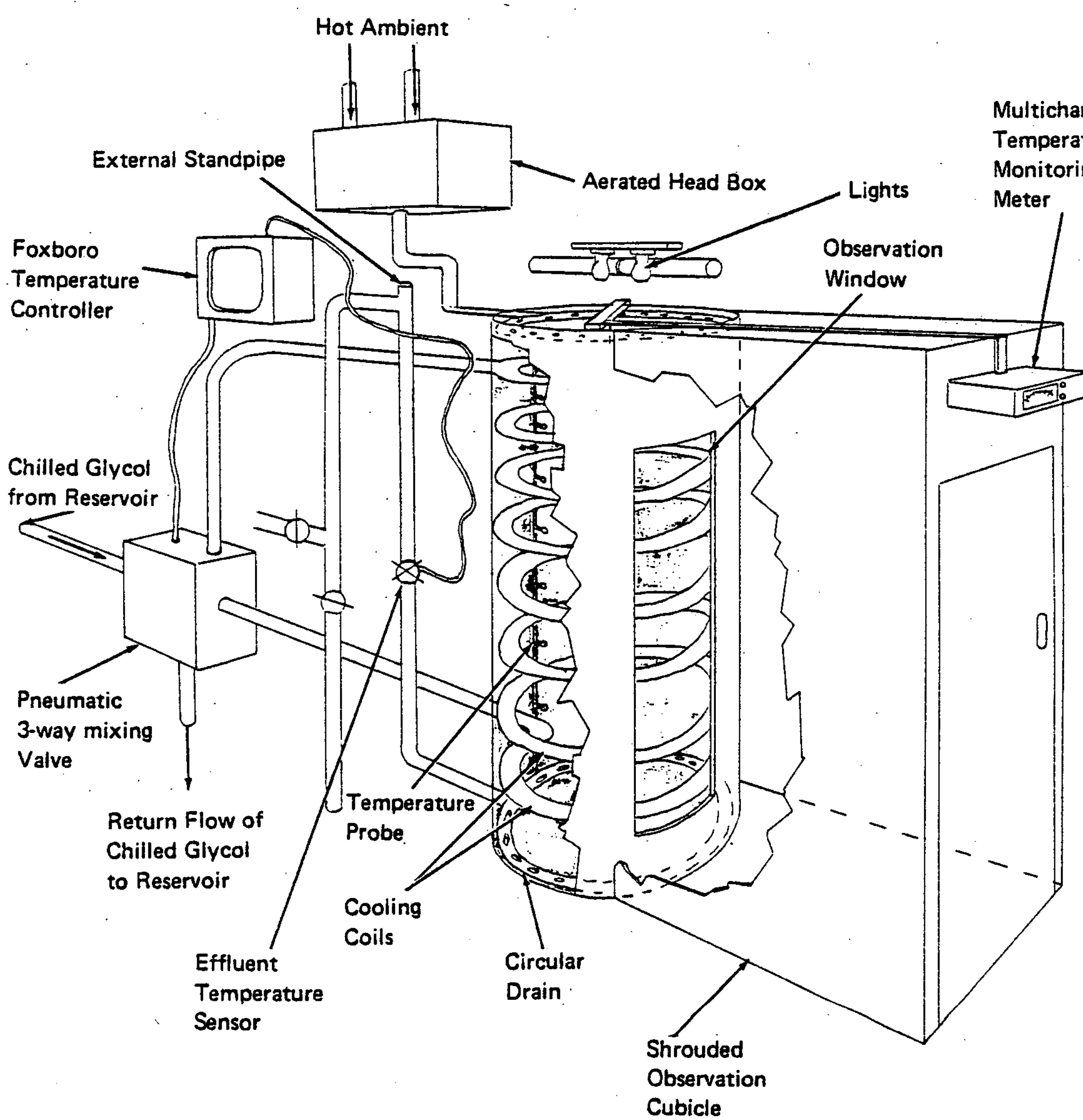


Figure 10.1-1. Vertical preference tank.

observation of the test fish. Each tank was provided with a set of incandescent and fluorescent bulbs installed directly over the tank. The light intensity at the surface of the tank was less than 0.05 footcandles at night, 4.8 footcandles at dusk/dawn, and 88 footcandles during daylight.

The horizontal preference apparatus was a trough 20 ft long, 18 in. wide, and 8 in. deep (Figure 10.1-2). The water depth in the trough could be adjusted from 2 to 6 in. via an external standpipe. A mixture of hot and ambient water was introduced at one end of the tank at a flow of 0.5-1.5 gpm, depending on the water depth selected. The bottom of the trough consisted of a stainless steel heat exchanger plate through which chilled ethylene glycol flowed, cooling the warm water as it traveled the length of the trough. The flow of glycol in the heat exchanger was automatically regulated in the manner used for the vertical tanks. A false bottom of 3/16-in. nylon screening prevented the test organisms from coming in contact with the heat exchanger surface (after Richards and Ibara 1978). The trough was aerated along both sides to prevent vertical stratification. Twenty-three temperature probes spaced evenly along both sides of the tank were used to record the horizontal gradient. The entire tank was shrouded with black plastic to eliminate visual disturbance of the test fish during experimentation. Observations were made using overhead mirrors. A set of fluorescent and incandescent bulbs were located above the entire length of the tank. The light intensity at the surface of the tank was less than 0.05 footcandles at night, 0.7 footcandles at dusk/dawn, and 10 footcandles during daylight.

As indicated, temperature gradients were established by cooling heated water, rather than by the more conventional method of heating cooled water. This modification was employed to reduce the potential for supersaturation of

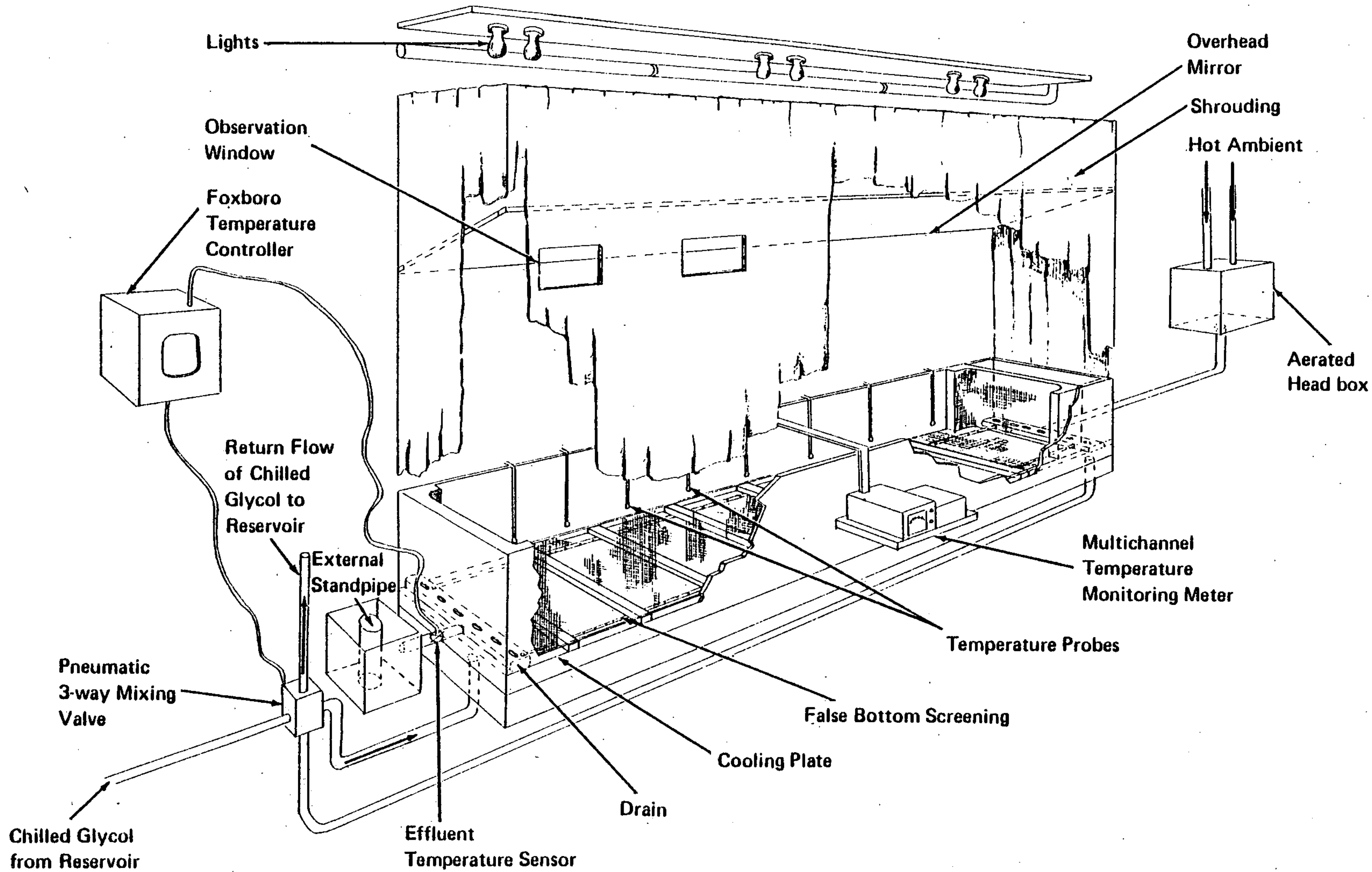


Figure 10.1-2. Horizontal preference tank.

gases in the warmer zones of the gradient. The heated influent water for all tanks was aerated in the head boxes with air stones to further reduce supersaturation of gases. The percentage saturation of dissolved oxygen typically ranged from 60 to 100 percent at the cold end of the tanks and 80 to 110 percent at the hot end.

Test fish were transferred from holding tanks or directly from the river to the test tanks. In most cases, the fish were allowed to acclimate to the test tanks at ambient river temperatures for 1-2 days prior to initiation of the gradient. Observations were made by recording the position of each fish along with a temperature record of the thermal gradient. The position of each fish was therefore associated with a temperature. Three observations taken at 5-minute intervals constituted an observation unit. An observation unit was completed each hour of a normal working day, usually for 4 days. The test was extended beyond 4 days when an upward or downward trend was observed in the latter stages of the test. In these cases, the test was continued until the preferred temperature remained constant for several observations. Pregradient observations served as a control. The gradient was shifted occasionally throughout the test to eliminate the possibility of spatial preference being misinterpreted as temperature preference. Fish were not fed during the experiment.

10.1.2 <u>Analytical Procedures</u>

Final thermal preferenda are determined in this study as the temperature(s) to which fish will eventually gravitate if left in a thermal gradient for a sufficient length of time. A cursory review of the literature revealed that various statistical approaches have been taken by researchers to "quantify" temperature preference responses of fish, but that most were employed for short-term preference studies. After utilizing several of these methods on data collected in this study, it was determined that none adequately and completely reflected the results of these experiments. Critical points are as follows:

1. The overall mode, that temperature at which fish were most frequently observed throughout the entire test, is the most commonly used estimator of the preferred temperature. The advantage of the mode determination is that it is less sensitive to extreme values. However, in many cases the mode represents the response of less than 25 percent of the sample size, resulting in an estimate of the final preferred temperature based on a small fraction of the fish tested. Furthermore, gravitation of fish to high or low temperatures during the course of the test is not evident. In addition, reliable statistical estimates of dispersion about the mode are not available.

2. Calculation of the mode for each observation will reveal trend development. The end point is usually calculated as the mean of the modal preferred temperatures, but again this only represents the response of a fraction of the fish tested. In addition, difficulties are encountered when bimodality occurs.

3. The overall mean, the average temperature at which fish were observed throughout the test, is a good estimator of the preferred temperature when temperature preference remains stable throughout the test, and corresponds closely with the modal estimate. All fish tested are represented in the estimate. Calculation of the standard deviation about the mean provides for a sound statistical estimate of dispersion. However, in cases where the preferred temperature did not stabilize until later in the test, creating skewed distribution of preferred tempera-

ture observations, the overall mean is biased by the earlier observations. Likewise, the standard deviation becomes biased owing to the non-normal distribution of preferred temperatures.

The statistical procedures used to analyze preference data in this study combine the advantages of the mode and the mean as midpoint estimators, and utilize the standard deviation to estimate dispersion. The mean and standard deviation of the temperatures at which fish were observed were calculated for each observation unit by combining the data from the three consecutive observations into a single sample. This provided a midpoint estimator for each observation unit of the individual responses of all fish tested. Since the majority of individual preferred temperatures appeared to be distributed normally within each observation unit, the standard deviation provided a statistically sound estimator of dispersion. Gravitation of fish to high or low temperatures during the course of the test was revealed by plotting the mean and standard deviations of each observation unit against time.

The final preferred temperature for each test was estimated by the mode of the observation unit means. This estimate prevented extreme or nonrepresentative values, usually occurring during observations early in the test, from biasing the final preferred temperature estimate. In cases where the preferred temperature did not stabiize until late in the test, the midpoint estimate was determined only from observations taken during the last 24 to 48 hours of the test.

The range of preference temperatures for each test was estimated using a semi-quantitative approach, as suitable quantitative methods could not be determined. After plotting the mean and standard deviation of each observation unit against time, a range of preferred temperatures bounded by the typical limits of the standard deviations was defined. The range estimate was limited to the latter portions of the test to eliminate bias due to upward or downward trends often exhibited early in the test. Comparison of this "observed preference temperature range" estimate to the actual observations recorded for each test over the portion of the test used to estimate the range revealed that 70 to 95 percent of all recorded occurrences fell within the range estimator. An example is presented in Figure 10.1-3.

The final preferendum for a species was determined by calculating the mean of the final preferred temperatures determined for several tests. Where size effects were evident, the final preferenda for discrete size groups within a species were estimated by taking the mean of the final preferred temperature determination for tests of similar-sized fish.

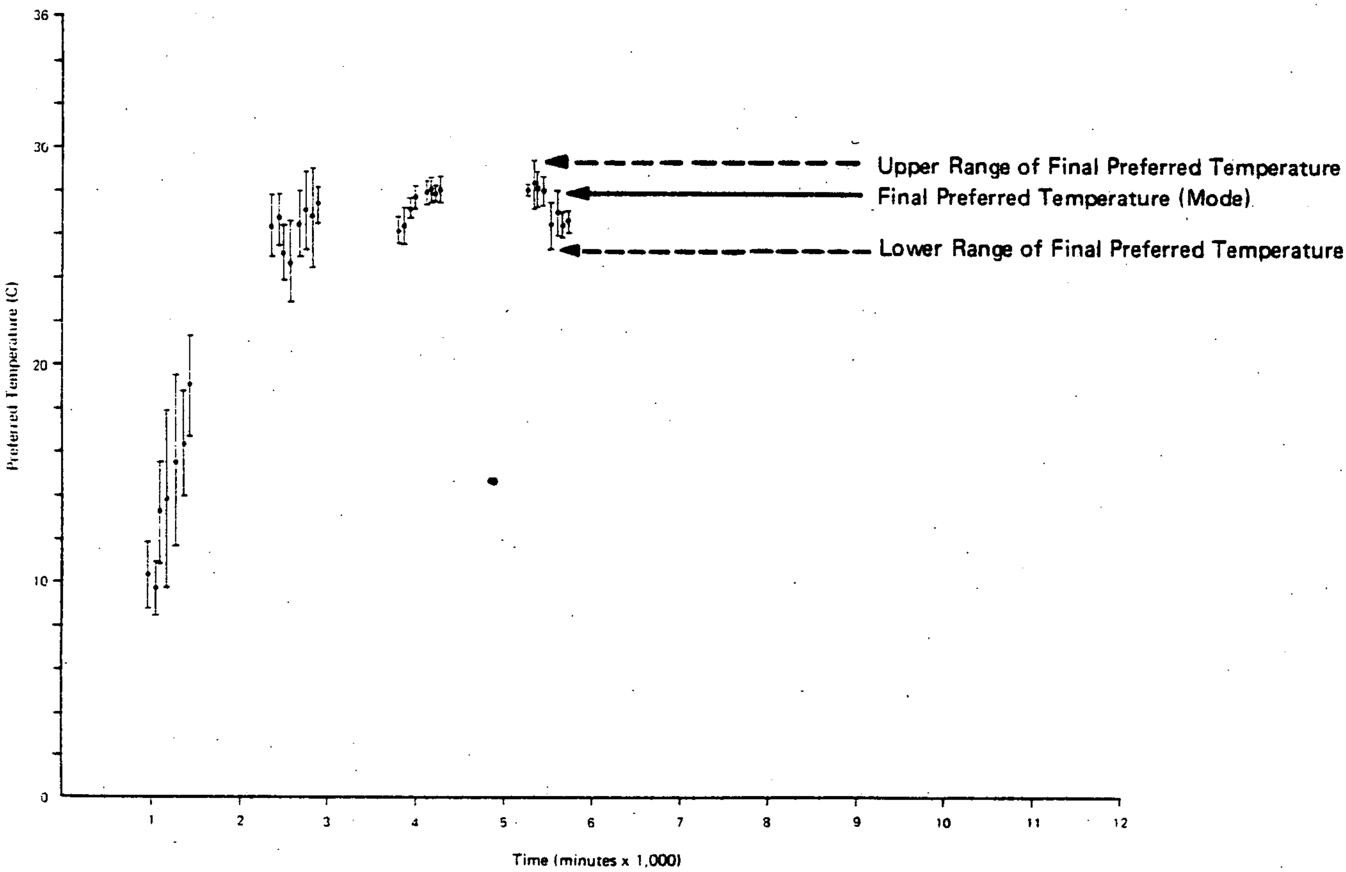


Figure 10.1-3. Mean preferred temperatures (•) and range of one standard deviation of sample above and below mean (I) for seven white perch juveniles acclimated to an ambient temperature of 5.0 C. Test number: TP 067. Starting date: 5 December 1976. Mean length = 120 mm, range = 110-133 mm. Modal preferred temperature = 28 C. Observed preference temperature range = 25-29 C. Vertical preference tank.

10.2 RESULTS AND DISCUSSION

Examples of typical behavioral responses observed in this study are presented in Figure 10.2-1. In general, fish tested at summer ambient temperatures rapidly moved to their final preferred temperature and deviated only slightly from it after the first day of the test (Figure 10.2-1[a]). Where the acclimatization temperature differed to a greater extent from the final preferred temperature, the move to the final preferred temperature usually took more time, as was the case for white catfish acclimatized to 2.5 C in the winter (Figure 10.2-1[b]). It was necessary to extend this test to 8 days in order to determine the final preferred temperature.

Observed ranges of preferred temperatures were due to two factors: (1) imprecise temperature selection by individual fish and (2) variability of temperature preferences among individuals. The extent of the preferred temperature range tended to be species-specific, with schooling fish generally exhibiting smaller preferred temperature ranges. The broad standard deviations observed for Atlantic sturgeon (Acipenser oxyrhynchus) depicted in Figure 10.2-1(c) were due to differences in preferred temperatures among the individuals, although these differences decreased slightly as the test progressed.

Mortality due to low thermal responsiveness was rarely observed, and in all instances appeared to be attributable to conditions created by the testing apparatus. During gradient shifts, and sometimes during the initial phase of the test, a tightly compressed gradient near the influent area of the tank sometimes contained temperatures outside the zone of thermal resistance for the species being tested. Most fish avoided these areas completely. However, a "wandering" individual would occasionally enter this lethal zone, exhibit a "panic" reaction, and swim erratically from one end of the tank to the other

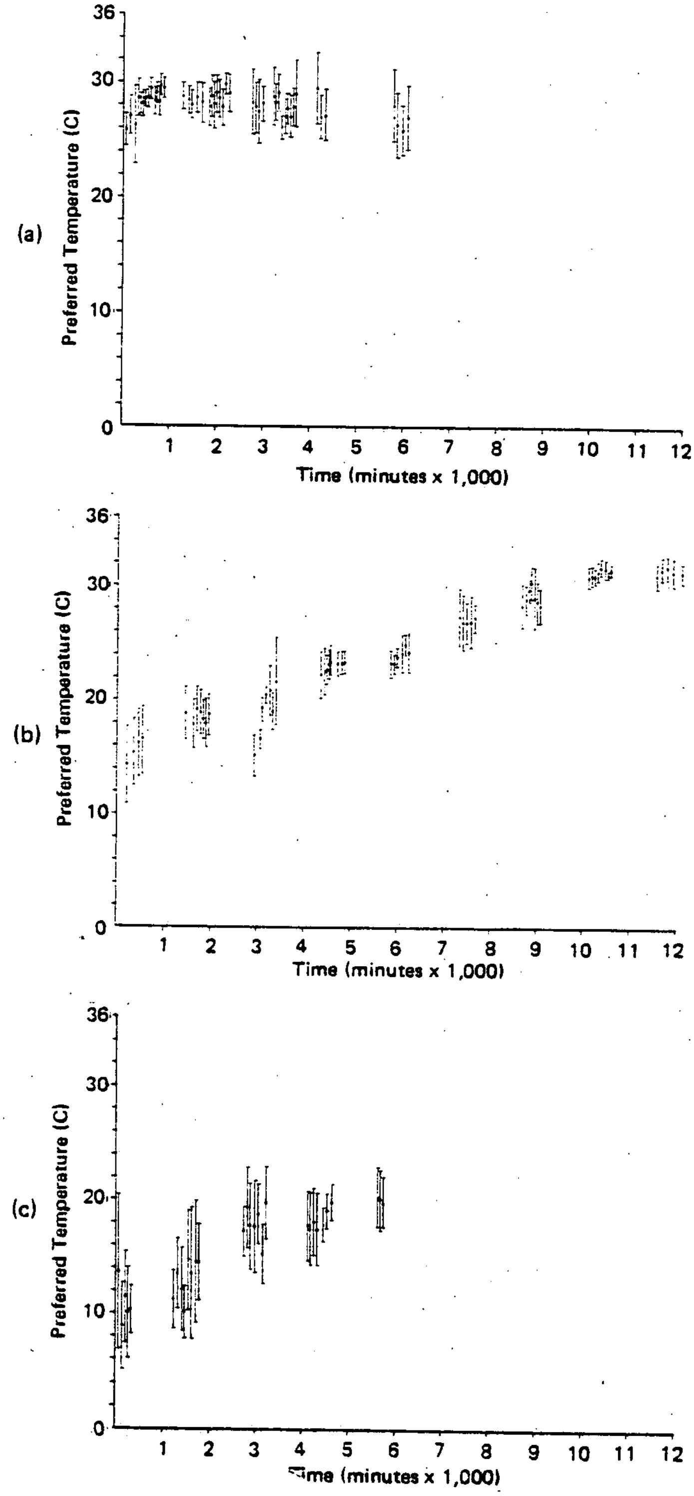


Figure 10.2-1. Mean preferred temperature (●) and range of one standard deviation of sample above and below mean (I) for observation units vers. time: (a) striped bass young of the year acclimatized to 25.0 C; (b) white catfish young of the year acclimatized to 2.5 C; (c) Atlantic sturgeon juveniles acclimatized to 8.5 C.

in an apparent attempt to escape. This behavior, if continued, would eventually result in death due to multiple heat and cold shocks. On a few occasions, a fish was observed to enter the warmest portion of a tightly compressed gradient and lose equilibrium, resulting in death. This phenomenon was most likely due to the failure of fish to avoid artificially steep gradients under laboratory conditions (i.e., gradients so steep that fish entered stressful temperatures prior to responding to them). However, mortality due to this low thermal responsiveness was observed infrequently, and block nets to prevent fish from entering the warmer portions of the gradient were not employed often.

Mortality of test fish due to handling stress factors was occasionally a problem during early operation of the laboratory, especially with the more sensitive species. Improved handling techniques and prophylactic treatments (Chapter 4) reduced this mortality considerably. Final preferendum estimates from tests with significant mortality occurring during the test may be biased owing to small sample sizes remaining at the end of the test, or possible poor health of the remaining test fish. To eliminate this potential bias, tests with greater than 35 percent mortality over the test period are not included in summary tables presented in the following sections (two exceptions are noted).

10.2.1 Striped Bass

Preference tests were conducted on striped bass young of the year and yearlings at acclimatization temperatures ranging from 7.0 to 26.0 C (Table 10.2-1; Figures C-24 through C-34, Appendix C). Final preferred temperatures ranged from 26 to 30 C for all but one test. Striped bass young of the year acclimatized to 7.0 C (test code TP059) exhibited a final preferred temperature of

TABLE 10.2-1 SUMMARY OF THERMAL PREFERENCE TESTS FOR STRIPED BASS CONDUCTED IN A VERTICAL PREFERENCE APPARATUS, 1976-1977

Test Code	Date	Number Fish/Test	Mean Length (mm)	Acclimatization Temperature (C)	Final Preferred Temperature (C)	Observed Preference Temperature Range (C)
TP027	28 JUL 76	12	44	25.0	28	26 - 30
TP038	1 SEP 76	10	146	24.0	28	25 - 30
TP052	1 NOV 76	10	163	11.5	30	27 - 31
TP051	1 NOV 76	11	169	11.5	28	27 - 30
TP059	22 NOV 76	11	85	7.0	16	13 - 18
TP119	5 JUL 77	15	37	24.0	28	27 - 30
TP120	5 JUL 77	15	37	24.0	26	25 - 29
TP126	25 JUL 77	9	59	26.0	27	25 - 30

16 C. However, this test was terminated after 96 hours, which may not have provided sufficient time for the fish to acclimate to the final preferendum. Multiple linear regression analysis, omitting test TP059, indicated that neither size nor acclimatization temperature was a significant variable ($p = 0.01$) over the ranges tested, as shown in the following multiple linear regression analysis.

$$\text{Final Preferendum} = b_o + b1\ (\text{Length}) + b2\ (\text{Accl. Temp.})$$

$b_o = 28.78$ Standard Error of $b_o = 3.44$

$F = 1.638$ $R2 = 0.6710$ $N = 7$

i	xi	$\bar{x}$	bi	Standard Error of bi	Computed t-value
1	Length (mm)	93.6	0.0063	0.0121	0.5206
2	Accl. Temp. (C)	20.9	0.0724	0.1172	-0.6184

Since neither size nor seasonal factors were significant, the final preferendum of striped bass young of the year and yearlings can be estimated by the mean of the final preferred temperatures (omitting TP059), 27.8 ± 1.2 C (± standard deviation).

10.2.2 White Perch

Preference tests were conducted on white perch young of the year, subadults, and adults at acclimatization temperatures ranging from 5.0 to 26.0 C (Table 10.2-2; Figures C-1 through C-23, Appendix C). Final preferred temperatures ranged from 25 to 32 C. Multiple linear regression analysis revealed that both acclimatization temperature and size were significant variables ($p = 0.01$) in determining the final preferendum, as shown in the multiple linear regression analysis following Table 10.2-2.

TABLE 10.2-2 SUMMARY OF THERMAL PREFERENCE TESTS FOR WHITE PERCH CONDUCTED IN A VERTICAL PREFERENCE APPARATUS, 1976-1977

Test Code	Date	Number Fish/Test	Mean Length (mm)	Acclimatization Temperature (C)	Final Preferred Temperature (C)	Observed Preference Temperature Range (C)
TP006	26 MAY 76	6	180(a)	15.0	26	24 - 27
TP020	9 JUL 76	11	95	26.0	32	31 - 33
TP026	28 JUL 76	12	36	25.0	32	29 - 34
TP035	17 AUG 76	10	103	24.0	29	28 - 31
TP045	8 SEP 76	13	56	23.0	32	30 - 35
TP054	8 NOV 76	11	135	8.5	26	23 - 28
TP055(b)	8 NOV 76	11	67	8.5	28	26 - 29
TP067	5 DEC 76	7	120	5.0	28	25 - 29
TP065	5 DEC 76	4	68	5.0	27	25 - 28
TP090	12 APR 77	8	118	8.0	26(c)	24 - 27(c)
TP113	10 MAY 77	10	118	13.0	25	24 - 29
TP112	17 MAY 77	7	164(a)	16.0	26	24 - 28
TP110	31 MAY 77	9	160(a)	20.0	26	24 - 28
TP111	31 MAY 77	10	115	20.0	30	27 - 31
TP118	21 JUN 77	7	152	22.5	29	28 - 32
TP125	18 JUL 77	12	35	26.0	31	29 - 33
TP126	18 JUL 77	12	30	26.0	30	28 - 33

(a) Spawning condition.
(b) Mortality during test exceeded 35 percent.
(c) Final preferred temperature determined on basis of thermal preference during the last 24 hours of the experiment.

Multiple Linear Regression Model

Final Preferendum = b_o + b1 (Length) + b2 (Acclimation Temperature)

b_o = 28.17   Standard Error of b_o = 1.28
F = 19.2*   R2 = 0.8561   N = 17

i	xi	$\bar{x}$	bi	Standard Error of bi	Computed t-value
1	Length (mm)	103	-0.0260	0.0074	-3.518*
2	Accl. Temp. (C)	17	0.1700	0.0451	3.766*

* Significant at p = 0.01.

Although acclimatization temperature was a significant variable in these test it is questionable whether true seasonal differences (as reflected by acclimatization temperatures) in final preferred temperatures of white perch exist. Fish tested at ambient river temperatures less than 10 C preferred temperatures 17.5 to 23.0 C above ambient. It is likely that these fish would have eventually gravitated to temperatures similar to fish tested at higher acclimatization temperatures if the tests had been extended and a food supply had been made available.

Final preferred temperatures for white perch also decreased significantly as length increased (Figure 10.2-2). Adults typically preferred temperatures 4-6 C below temperatures preferred by young of the year. Young of the year tested at acclimatization temperatures greater than 10 C exhibited final preferred temperatures exceeding 30 C, while adult white perch preferred temperatures equal to or slightly greater than maximum ambient river temperatures. Final preferred temperatures of yearling white perch ranged from 25 to 30 C. On the basis of the mean final preferred temperatures for discrete size groups, final thermal preferenda were estimated to be 31.2 C for white perch young of the year (less than 50 mm total length) and 26.8 C for adults (greater than

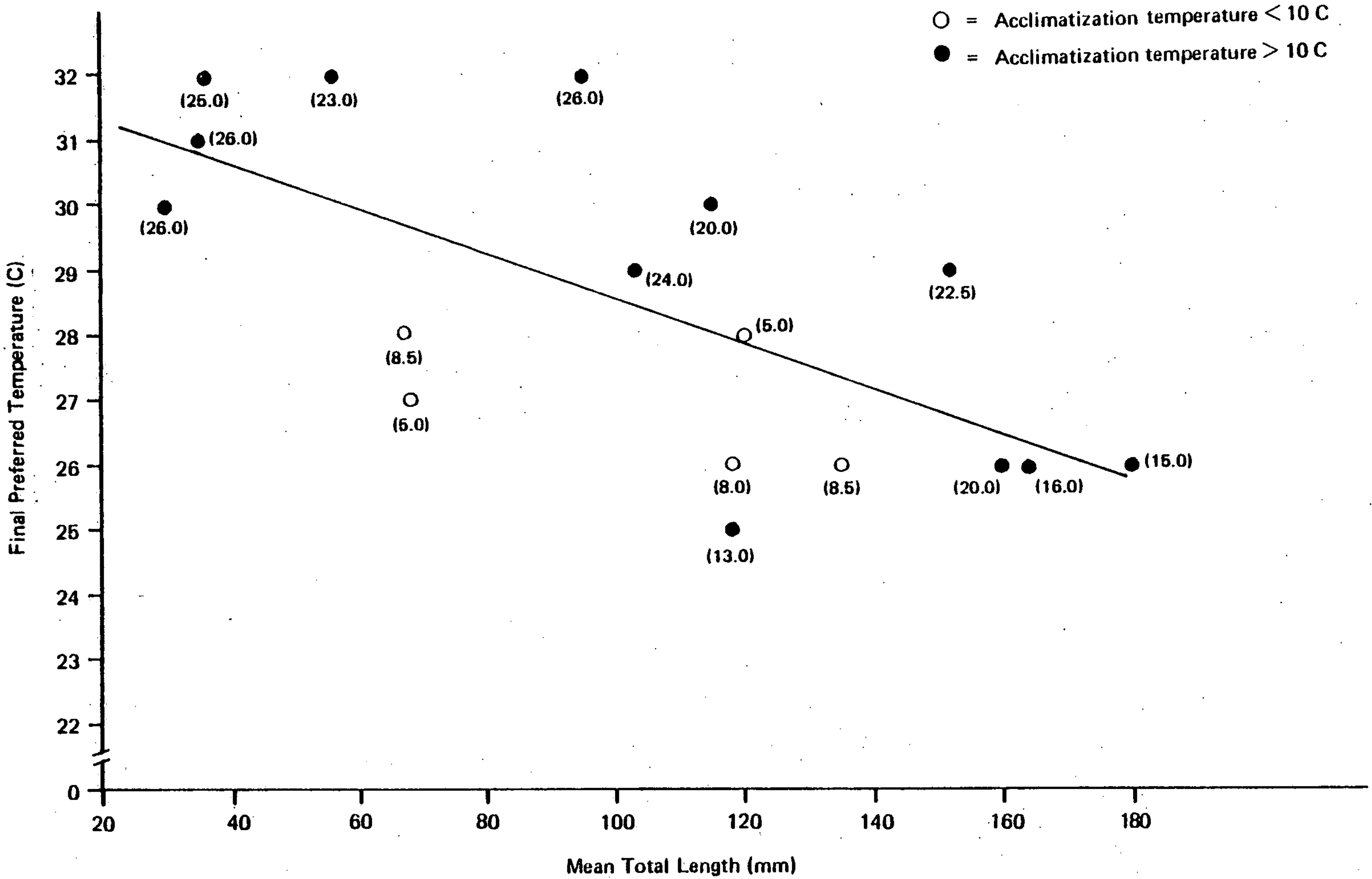


Figure 10.2-2. **Variation in final preferred temperatures of white perch according to size. Acclimatization temperatures are in parentheses. Final preferenda (C) = 31.97 – 0.0346 (length in mm).**

150 mm total length). Linear regression of length versus final preferred temperatures produced the following equation:

$$\text{Final preferendum (C)} = 31.97 - 0.0346(\text{length in mm}).$$

10.2.3 Atlantic Tomcod

Eight preference tests were conducted on Atlantic tomcod acclimatized to temperatures ranging from 2.5 to 24 C (Table 10.2-3; Figures C-35 through C-44, Appendix C). Juvenile tomcod tested at an acclimatization temperature of 24 C exhibited final preferred temperatures averaging 10.0 C. This temperature is much lower than normal summer river temperatures. Tests performed during the winter on adults did not result in specific final preferred-temperature determinations for two reasons: (1) temperature gradients could not be cooled enough to permit fish to exhibit precise temperature selection at lower temperatures, and (2) during portions of the tests, some individuals exhibited a preference for temperatures warmer than temperatures preferred by the majority of the fish tested, resulting in bimodal distributions. With the exception of a few individuals, tomcod adults generally preferred the coldest temperatures available within the gradient. The observed ranges of preferred temperatures for Atlantic tomcod are given in Table 10.2-3 both for the majority of fish tested (primary range) and for the few individuals that remained in the warmer portion of the gradient (secondary range). There was no apparent difference in preferred temperatures between adults in spawning condition and those in postspawning condition.

These results indicate that the final preferendum for Atlantic tomcod juveniles is higher than the preferred temperatures of tomcod upon reaching sexual maturity. To test this hypothesis, spawning Atlantic tomcod adults

TABLE 10.2-3 SUMMARY OF THERMAL PREFERENCE TESTS FOR ATLANTIC TOMCOD CONDUCTED IN A HORIZONTAL PREFERENCE APPARATUS, 1976-1977

Test Code	Date	Number Fish/Test	Mean Length (mm)	Acclimatization Temperature (C)	Final Preferred Temperature (C)	Observed Preference Temperature Range (C) Primary	Secondary
TP042	24 AUG 76	23	89	24.0	12	10 - 14	--
TP060	22 NOV 76	11	152(a)	6.0	--	≤ 4 (b)	17 - 21
TP066	6 DEC 76	10	160(a)	5.0	--	≤ 2 (b)	12 - 16+(b)
TP069	13 DEC 76	9	247(a)	4.0	--	≤ 2 (b)	4 - 7
TP071	30 JAN 77	15	142	10.0(c)	--	≤ 4 (b)	5 - 8
TP080	1 MAR 77	10	156(d)	2.5	--	≤ 2 (b)	--
TP088	5 APR 77	8	144(d)	8.0	--	≤ 2 (b)	15 - 20
TP127	26 JUL 77	10	75	24.0	8	6 - 10	--

(a) Spawning condition.
(b) Temperature limited by tank extremes.
(c) Acclimated to 10.0 C from 1.0 C.
(d) Postspawning condition.

Note: Dashes indicate no data.

were acclimated to an above-ambient temperature of 10 C (the average final preferred temperature of juveniles) before testing. The majority of adults consistently preferred temperatures less than or equal to 4 C, the coldest temperature available within the gradient. This phenomenon corresponds to the low temperatures necessary for successful spawning and the relatively higher temperatures resulting in optimal growth rates of tomcod larvae (Chapter 9). The occurrence of fish preferring temperatures within the "secondary" range of observed preference temperatures may have been a response to the final preferendum exhibited by tomcod juveniles, rather than to the lower temperatures necessary for successful spawning.

10.2.4 <u>Alewife</u>

Tests were conducted on post-yolk-sac larvae (approximately 60 days old), young-of-the-year, and adult alewife at acclimatization temperatures representative of the seasonal occurrence of the three life stages (Table 10.2-4; Figures C-45 through C-50, Appendix C). Alewife young of the year acclimatized to temperatures of 21 and 25 C exhibited final preferred temperatures of 19 and 20 C, respectively. Therefore, the final preferendum of alewife young of the year is estimated to be 19.5 C. Advanced post-yolk-sac larvae preferred temperatures as high as 26 and 27 C, which corresponded closely to the optimum temperature for net biomass gain of alewife larvae (26.4 C) (Subsection 9.2.4). Temperature selection of post-yolk-sac larvae was somewhat less precise than that of young-of-the-year alewife; the observed preference temperatures ranged from 23 to 29 C.

Adult alewife could not be successfully tested for temperature preference in either the vertical or horizontal preference tanks. The constant movement of fish coupled with the large size of the fish prevented the gradient from be-

TABLE 10.2-4 SUMMARY OF THERMAL PREFERENCE TESTS FOR ALEWIFE, 1976-1977

Test Code	Date	Number Fish/Test	Mean Length (mm)	Acclimatization Temperature (C)	Final Preferred Temperature (C)	Observed Preference Temperature Range (C)	Modal Avoidance Temperature (C)	Observed Avoidance Temperature Range (C)
TP029(a)	4 AUG 76	8	73	25.0	20	18 - 21	--	--
TP049(a)	21 SEP 76	15	85	21.0	19	18 - 20	--	--
TP092(a)	7 JUN 77	7	24(b)	20.0	26	24 - 29	--	--
TP093(a)	7 JUN 77	15	23(b)	20.0	27	23 - 29	--	--
TP094(c)	23 MAY 77	10	285(d)	16.0	--	--	26	24 - 28
TP098(c)	12 JUN 77	10	291(e)	20.0	--	--	30	26 - 30

(a) Test conducted in vertical preference tanks.
(b) Primarily advanced post-yolk-sac larvae. Some individuals were early juveniles.
(c) Test conducted in horizontal preference tanks.
(d) Spawning adults.
(e) Postspawning adults.

Note: Dashes indicate no data.

coming established. However, it was possible to obtain avoidance information using the horizontal tank. Temperatures were slowlin increased each day, forcing the fish to the cooler end of the gradient. The gradient was cooled again each night. In addition to the position of each fish, the turnaround temperatures were recorded over the 15-minute observation period. Because alewife adults were constantly moving, turnaround temperatures on most of the test fish were obtained during each observation. The most frequently occurring mean turnaround temperatures were 26 and 30 C for spawning and postspawning adults, respectively.

10.2.5 White Catfish

Seventeen tests were performed with white catfish young of the year and adults acclimatized to temperatures ranging from 2.5 to 26.0 C (Table 10.2-5; Figures C-51 through C-67, Appendix C). White catfish consistently preferred temperatures greater than ambient river temperatures, with final preferred temperatures ranging from 22 to 33 C. Multiple linear regression analysis revealed that size was a significant variable (p = 0.01) in determining the final preferenda of white catfish, whereas acclimatization temperature was nonsignificant, as shown in the following multiple linear regression analysis.

$$\text{Final Preferendum} = b_o + b1(\text{Length in mm}) + b2\ (\text{Accl. Temp.})$$

$$b_o = 28.696 \qquad \text{Standard Error of } b_o = 1.558$$

$$F = 7.844^{*} \qquad R2 = 0.727 \qquad N = 17$$

i	xi	$\bar{x}$	bi	Standard Error of bi	Computed t-value
1	Length (mm)	192.35	-0.0181	0.0054	-3.3727*
2	Accl. Temp. (C)	15.32	0.1897	0.0759	2.4986

* Significant at p = 0.01.

TABLE 10.2-5 SUMMARY OF THERMAL PREFERENCE TESTS FOR WHITE CATFISH CONDUCTED IN A HORIZONTAL PREFERENCE APPARATUS, 1976-1977

Test Code	Date	Number Fish/Test	Mean Length (mm)	Acclimatization Temperature (C)	Final Preferred Temperature (C)	Observed Preference Temperature Range (C)
TP007	19 MAY 76	10	319	15.0	25	22 - 28
TP025	21 JUN 76	8	313(a)	22.0	28	24 - 30
TP036	17 AUG 76	10	312	23.0	30	29 - 31
TP048	14 SEP 76	10	53(b)	24.0	31	30 - 33
TP050	1 NOV 76	6	170	10.0	28(c)	24 - 30
TP056	15 NOV 76	11	88	7.0	28	25 - 30
TP064	29 NOV 76	10	85	16.5(d)	33	31 - 34
TP076	8 JAN 77	5	89	2.5	31	30 - 32
TP081	6 MAR 77	4	162	2.5	26(c)	24 - 28
TP091	12 APR 77	8	255	8.0	22	19 - 25
TP102	25 APR 77	6	393	12.0	22	20 - 24
TP101	2 MAY 77	10	87	12.0	30	27 - 32
TP100	10 MAY 77	9	169	13.0	25	22 - 28
TP103	7 JUN 77	7	257	20.0	30	28 - 34
TP116	20 JUN 77	10	233	22.0	31	29 - 33
TP123	11 JUL 77	7	258	25.0	28	25 - 30
TP124	18 JUL 77	9	27(b)	26.0	30	28 - 32

(a) Spawning condition.
(b) Reared from eggs.
(c) Represents mode of the observation means during the last 24 hours of the test.
(d) Acclimated from 8.0 to 16.5 C prior to test.

Final preferred temperatures of white catfish generally decreased as length increased (Figure 10.2-3), according to the following linear regression equation:

$$\text{Final Preferred Temp. (C)} = 31.26 - 0.0164(\text{length in mm}).$$

Although acclimatization temperature was not a statistically significant variable, some seasonal variation in adult final preferred temperatures was apparent. Tests performed during early spring (April and May) resulted in the lowest final preferred temperatures exhibited by white catfish, averaging 23.5 $\pm$ 1.7 C ($\pm$ standard deviation). The final preferendum of adults tested from June through March was 5.2 C higher, averaging 28.7 $\pm$ 1.7 C. The observed reduction in final preferred temperature for adults in early spring does not appear to be related to lower acclimatization temperatures, as adults acclimatized to ambient temperatures of 2.5 and 10.0 C preferred temperatures similar to adults acclimatized to higher temperatures. These results indicate that the preferred temperature (23.5 C) of adults during gamete development is lower than the final preferendum (28.7 C) for white catfish adults during other seasons.

Seasonal variation was not observed for young-of-the-year white catfish. Final preferred temperatures for these younger fish tested at acclimatization temperatures of 2.5-26.0 C ranged from 28 to 33 C. The final preferendum for young-of-the-year, as estimated by the mean final preferred temperature, is 30.5 C.

10.2.6 Spottail Shiner

Twenty-eight preference tests were performed with spottail shiners acclimatized to temperatures ranging from 2.5 to 26.0 C (Table 10.2-6; Figures C-68

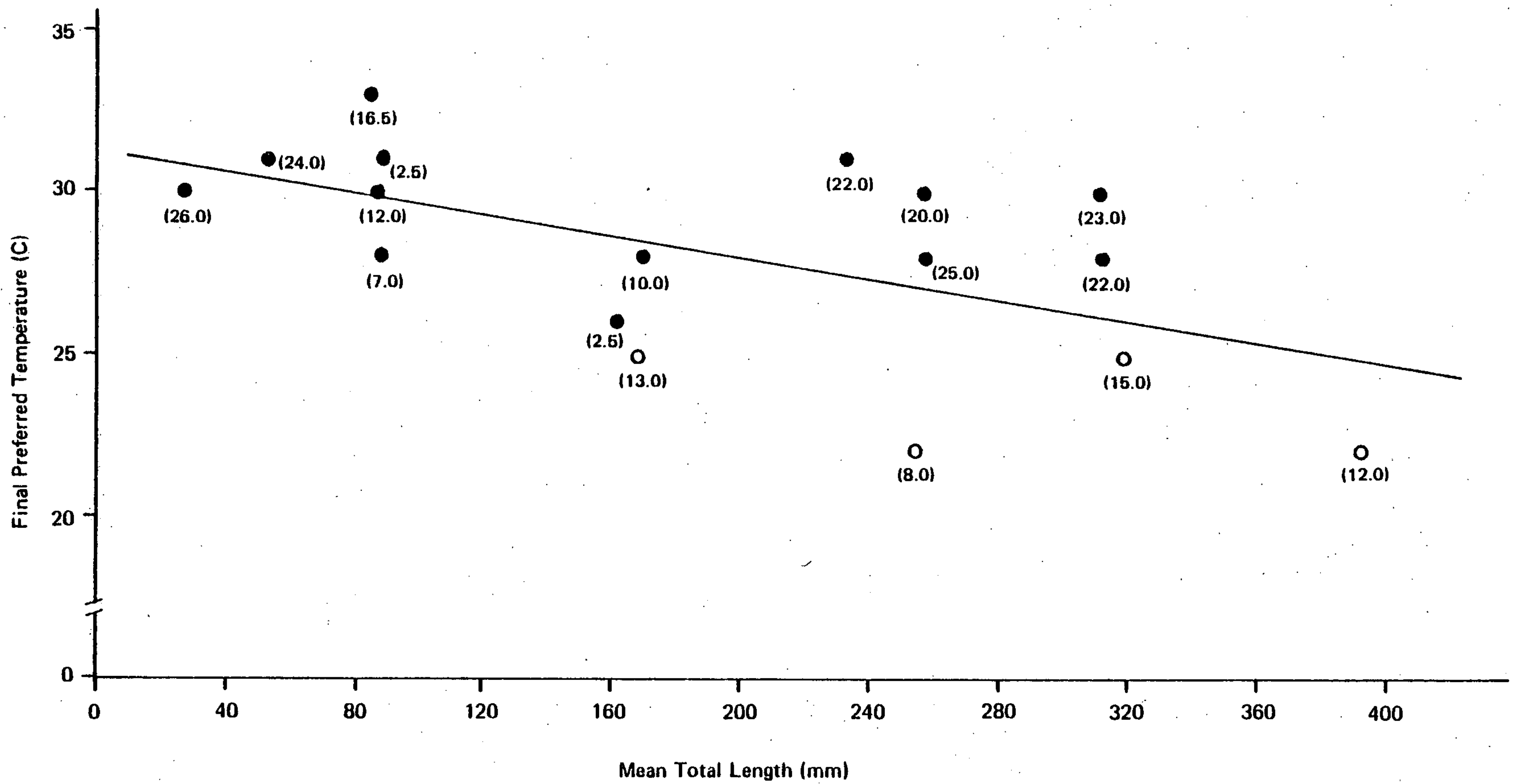


Figure 10.2-3. Variation in final preferred temperatures of white catfish according to size. Acclimatization temperatures are in parentheses. Final preferenda (C) = 31.26 – 0.0164 (length in mm). Tests on adults during April and May are noted by an open circle.

TABLE 10.2-6 SUMMARY OF THERMAL PREFERENCE TESTS FOR SPOTTAIL SHINER CONDUCTED IN A VERTICAL PREFERENCE APPARATUS, 1976-1977

Test Code	Date	Number Fish/Test	Mean Length (mm)	Acclimatization Temperature (C)	Final Preferred Temperature (C)	Observed Preference Temperature Range (C)
TP009	21 MAY 76	12	108(a)	15.0	18	17 - 20
TP010	4 JUN 76	8	110(a)	16.0	19	17 - 20
TP011(b)	4 JUN 76	8	105(a)	16.0	20	18 - 22
TP015	20 JUL 76	11	85	25.0	25	23 - 26
TP013	22 JUL 76	15	29	25.0	28	27 - 32
TP033	11 AUG 76	15	45	24.0	27	26 - 29
TP041	24 AUG 76	14	98	24.0	22	19 - 24
TP040	25 AUG 76	13	94	24.0	21(c)	19 - 23
TP046	14 SEP 76	15	54	23.0	25	22 - 27
TP057	15 NOV 76	12	63	8.0	13	10 - 14
TP058	15 NOV 76	12	112	8.0	10	9 - 12
TP061	22 NOV 76	11	78	7.0	11	11 - 12
TP062	29 NOV 76	10	103	17.0(d)	10	9 - 11
TP063	29 NOV 76	12	63	17.0(d)	11	10 - 12
TP070	13 DEC 76	9	69	4.0	7	6 - 8
TP072	31 JAN 77	14	108	2.5	≤4(e)	3 - 4(e)
TP073	31 JAN 77	14	112	10.0(f)	7	6 - 8
TP086	5 APR 77	12	107	8.0	17	16 - 20
TP087	5 APR 77	14	109	8.0	17	15 - 19
TP106	25 APR 77	10	113	12.0	17	16 - 19
TP107	25 APR 77	10	111	8.0(g)	16	15 - 17
TP104	23 MAY 77	10	68	16.0	25	23 - 27
TP105	23 MAY 77	12	108(a)	16.0	21	20 - 22
TP108	11 JUN 77	10	82	20.0	24(c)	21 - 26
TP109	11 JUN 77	10	113	20.0	20	18 - 21
TP121	11 JUL 77	15	24	25.0	29	25 - 31
TP122	11 JUL 77	15	23	25.0	29	27 - 33
TP125	25 JUL 77	10	44	26.0	28	25 - 29

(a) Spawning condition.
(b) Test conducted in horizontal preference apparatus.
(c) Represents mode of the last 24 hours of the test.
(d) Acclimated from 8.0 to 17.0 C.
(e) Tank limits randed from 3-4 C. Fish were usually observed within 1 C of coldest temperature available.
(f) Acclimated from 2 to 10 C.
(g) Held at 8 C for 3 weeks prior to test.

through C-95, Appendix C). Spottail shiners generally preferred temperatures equal to or slightly higher than ambient river temperatures. Multiple linear regression analysis indicated that both size and acclimation temperature were significant variables (p = 0.01) in determining the final preferendum. However, multiple linear regression of tests performed from May through September revealed that only size was significant (p = 0.01) at acclimatization temperatures ranging from 15.0 to 26.0 C, as shown below. (When tests performed in April were included in the analysis, acclimatization temperature became significant.) The significance of acclimatization temperature is indicative of seasonal variations in final preferred temperatures (Figure 10.2-4).

To test this hypothesis, 3 groups of spottail shiners were acclimated 8-9 C above ambient river temperatures during the winter and tested for temperature preference. For all three tests, fish preferred temperatures cooler than the acclimatization temperature, and preferred temperatures similar to final preferred temperatures of spottail shiners acclimated to normal winter temperatures (Table 10.2-6). A group of spottail shiner adults were also held at 8 C for 3 weeks in the spring. Ambient river temperatures increased to 12 C during this time. These fish similarly preferred temperatures equal to final preferred temperatures of fish acclimatized to ambient river temperatures. These results indicate that the final preferenda for spottail shiners vary seasonally, but remain independent of acclimation state. See the following multiple linear regression model.

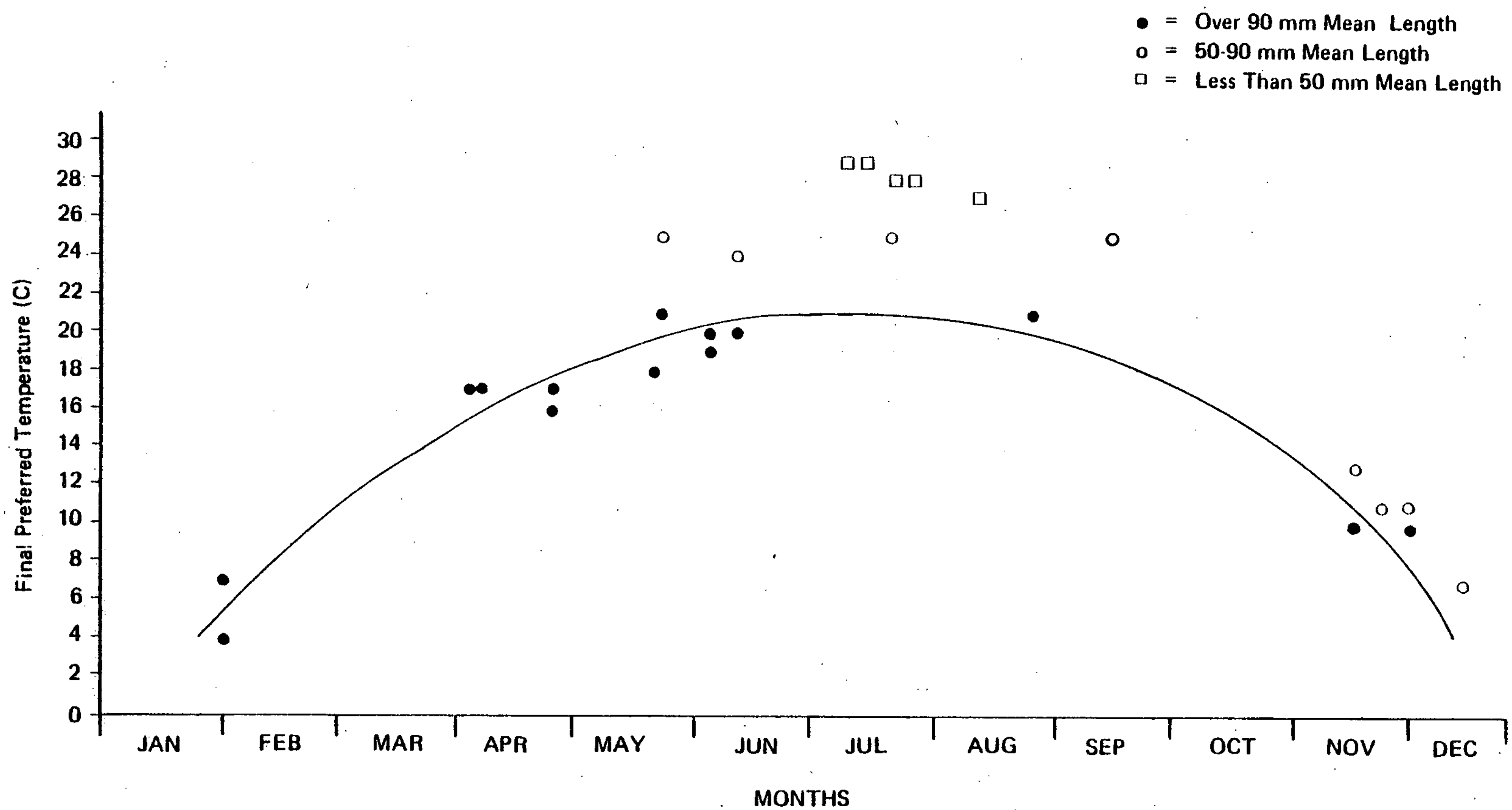


Figure 10.2-4. Seasonal variation of final preferred temperatures for spottail shiners. The curve for adults was fitted by inspection.

Multiple Linear Regression Model

Final Preferendum = $b_o + b1$ (Length in mm) + $b2$ (Accl. Temp.)

$b_o = 26.92$ Standard Error of $b_o = 3.43$

$F = 42.35^*$ $R^2 = 0.93110$ $N = 16$

i	xi	$\bar{x}$	bi	Standard Error of bi	Computed t-value
1	Length (mm)	74.4	-0.0866	0.0149	-5.7994*
2	Accl. Temp. (C)	21.2	0.1482	0.1199	1.2359

* Significant at p = 0.01.

Size was also a significant variable determining temperature preferences of spottail shiner (Figure 10.2-5). Since final preferred temperatures did not vary significantly (p = 0.01) with acclimatization temperatures from May through September, it was possible to estimate the final preferenda for three size groups of spottail shiners during summer months. Young of the year less than 50 mm mean length exhibited the highest final preferred temperatures, averaging 28.2 ± 0.8 C (± standard deviation). Final preferred temperatures of fish 50-90 mm in mean length (mostly immature fish) averaged 24.8 ± 0.5 C. Adult spottail shiners (greater than 90 mm) exhibited a mean final preferred temperature of 20.1 ± 1.3 C, 5-6 C lower than ambient river temperatures during summer months. Adults acclimatized to temperatures greater than 20 C actually gravitated to temperatures cooler than ambient river temperatures. Linear regression of final preferred temperatures determined from May through September versus mean total length in mm produced the following equation:

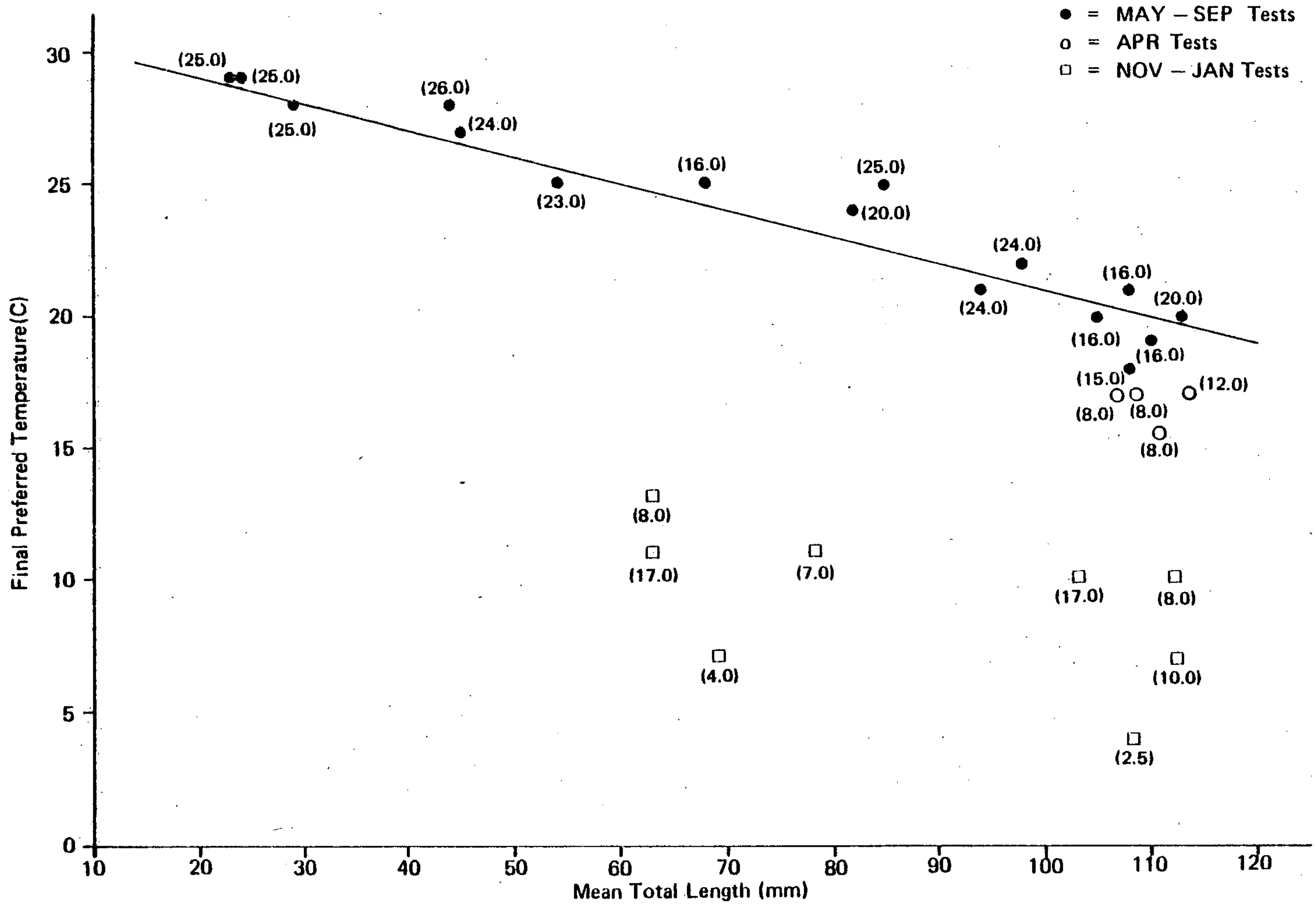


Figure 10.2-5. Variation in final preferred temperatures of spottail shiners according to size. Acclimation or acclimatization temperatures are in parentheses. Final preferenda during spring and summer months (C) = 31.01 – 0.0993 (length in mm).

Final Preferendum (C) = 31.01 - 0.0993(length in mm).

It is not possible to precisely estimate spottail shiner final preferendum for other seasons of the year, as the preferendum appears to change with the season from September to May. The general trend, however, can be described. Final preferred temperatures of fish tested during late fall and early winter were 2-5 C above ambient river temperatures. Fish tested in early spring (April) preferred temperatures 5-9 C above ambient river temperatures. During the winter, fish 60-80 mm in mean length preferred temperatures slightly higher than adults over 100 mm.

10.2.7 Other Hudson River Fishes

Eleven tests were conducted on nine other species common to the Hudson River estuary (Table 10.2-7; Figures C-96 through C-106, Appendix C). A sufficient number of tests were not conducted to assess seasonal or size factors. Therefore, final preferred temperatures represent estimates of the final preferendum only for the sizes of fish and season tested.

Final preferred temperatures of bay anchovy subadults were slightly lower than ambient river temperatures during the summer. Fish tested in late August and acclimatized to 24 C typically preferred temperatures ranging from 21 to 24 C.

Three Atlantic sturgeon subadults were tested in November at an ambient river temperature of 8.5 C. The fish slowly gravitated to higher temperatures, exhibiting a final preferred temperature of 18 C. However, the variation between individuals was large; the observed preference temperature ranged from 16 to 22 C.

TABLE 10.2-7 SUMMARY OF THERMAL PREFERENCE TESTS FOR OTHER HUDSON RIVER FISHES, 1976-1977

Species	Test Code	Date	Number Fish/Test	Mean Length (mm)	Acclimatization Temperature (C)	Final Preferred Temperature (C)	Final Observed Preference Temperature Range (C)
Alosa aestivalis(a) (Blueback herring)	TP028	3 AUG 76	15	36	25.0	27	24 - 29
Alosa sapidissima(a) (American shad)	TP032	11 AUG 76	14	69	24.0	24	22 - 25
Trinectes maculatus(b) (Hogchoker)	TP037	31 AUG 76	10	76	24.0	26	22 - 29
Anchoa mitchilli(a) (Bay anchovy)	TP039	31 AUG 76	19	46	24.0(c)	22	21 - 24
Ictalurus nebulosus(a) (Brown bullhead)	TP044	8 SEP 76	15	57(d)	24.0	31	30 - 34
Notemigonus crysoleucas(a) (Golden shiner)	TP024	30 JUN 76	9	167	25.5	28	28 - 30
	TP047	14 SEP 76	10	195	23.0	27	26 - 28
Acipenser oxyrhynchus(b) (Atlantic sturgeon)	TP053	8 NOV 76	3	209	8.5	18	16 - 22
Lepomis auritus(a) (Redbreast sunfish)	TP077	21 FEB 77	5	141	2.5	28	25 - 29
Lepomis gibbosus(a) (Pumpkinseed sunfish)	TP078	21 FEB 77	11	103	2.5	27	25 - 30
	TP082	6 MAR 77	7	135	2.5	26(e)	25 - 28

(a) Vertical preference tank.
(b) Horizontal preference tank.
(c) Test performed at 8 ppt salinity. Mortality during test was 47 percent.
(d) Reared from eggs 45-50 days old.
(e) Represents mode of the last 48 hours of the test.

Blueback herring and American shad young of the year acclimatized to 25 and 24 C, respectively, preferred temperatures equal to or slightly greater than ambient river temperatures. This is in contrast to similar tests performed with alewife young of the year, which resulted in final preferred temperatures 5-6 C lower than ambient river temperatures during the summer. American shad young of the year preferred temperatures slightly lower than blueback herring.

GLOSSARY

The following are a few specific terms defined accordng to their application in this report.

Yolk-sac larvae: Fish larvae that have not initiated exogenous feeding.

Post-yolk-sac larvae: Fish larvae that have initiated feeding but have not completed development to an adult form.

Juveniles: Young fish that have essentially completed morphological development, but are not sexually mature.

Early juveniles: Young juvenile fish, usually less than 2 months old.

Young of the year: Juvenile fish less than 1 year old.

Subadults: Juvenile fish older than 1 year that have not attained maturity (used specifically for striped bass yearlings and 2-year-olds).

Adults: Fish that are sexually mature (i.e., capable of reproducing).

Thermal shock tolerance: Ability to tolerate abrupt temperature increases, quantified by the difference between the acclimation temprature and the TL95. This term is applied only to simulated entrainment thermal exposures (10 seconds - 60 minutes).

Acclimation: 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 (Fry 1971).

Acclimatization: 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 fluctuatng temperature regimes and tested soon after capture.

Tolerance limit: The temperature that destroys the integrity of the organisms (Fry 1971), resulting in death. Bioassay results using aquatic organisms are expressed in terms of TL, followed by the percentage of survival and preceded by the time of exposure, e.g., "24-hour TL95" (Standard Methods for the Examination of Water and Wastewater, 13th Edition).

Median tolerance limit: The lethal temperature that results in 50 percent survival (mortality) expressed as TL50 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). 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).

Threshold lethal limit: The highest temperature above the acclimation temperature that results in no appreciable mortality. The threshold lethal limit is estimated in this report by the TL95 (i.e., the thermal tolerance limit resulting in 95 percent survival).

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.

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.

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 (Coutant 1970). The resistance time defines the limits for survival within the zone of resistance.

Preferred temperature: The range of temperatures in which animals congregate or spend the most time in a gradient or free-choice situation (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; Reynolds 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.

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. For growth studies, the optimum range was defined as those temperatures producing a growth rate at least 90 percent of the highest growth rate observed.

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