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PHASE I PRELIMINARY REPORT

INFORMATION AVAILABLE RELATED TO EFFECTS OF THERMAL DISCHARGE AT MERRIMACK STATION ON ANADROMOUS AND INDIGENOUS FISH OF THE MERRIMACK RIVER

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EXECUTIVE SUMMARY

This report was prepared as part of Public Service Company of New Hampshire's (PSNH's) initial response relative to six issues concerning thermal discharge effects on anadromous and resident fish that were raised in the NPDES Permit for Merrimack Station. The report summarizes presently available information relative to the six issues and, where appropriate, provides analyses relevant to resolution of the issues. The report is intended primarily to serve as a working document supporting consultation among participants in the Merrimack Station Technical Advisory Committee (TAC), which comprises representatives from the U.S. Environmental Protection Agency (EPA), New Hampshire Department of Environmental Services (NHDES), New Hampshire Fish and Game Department (NHFGD), U.S. Fish and Wildlife Service (USFWS) and PSNH.

The review of available information concentrates on seven anadromous and resident "target" species that were selected in consultation with the TAC. The target species, American shad, alewife, Atlantic salmon, smallmouth bass, largemouth bass, pumpkinseed and yellow perch, are considered representative of the present and future fish community of the Hooksett Pool of the Merrimack River, which is the segment of river affected by the discharge of heated water from the cooling system at Merrimack Station. The major sources of information used for preparation of this report included reports from monitoring studies conducted at Merrimack Station by Normandeau Associates, Inc. and the NHFGD from 1967 through 1978, scientific and technical literature, and unpublished data available from PSNH and other utilities.

A summary of information on the temperature requirements and thermal tolerances of the target species was prepared to support discussions relative to several of the issues. The available information indicates that maximum summer ambient temperatures fall within the range of summer preferred temperatures for adults of all target species except Atlantic salmon. Maximum summer ambient temperatures may approach lethal levels for adult salmon if they are present. Juvenile life stages of the target species generally appear to have higher temperature preferences and tolerances than adults. The upper thermal tolerance limits of American shad, alewife and yellow perch are similar (in the low 30°C range). Smallmouth bass, largemouth bass and pumpkinseed are increasingly more tolerant of higher temperatures (upper incipient lethal temperatures for these species range from around 35°C for smallmouth bass to the upper 30°C range for pumpkinseed). Both adults and juveniles of the target species respond to temperature gradients and seek areas of preferred temperature.

Anadromous fish migrations are controlled by water temperatures, which largely determine the specific time of the year at which migrations will occur. In the Merrimack River, operation of fish passage facilities may modify the adult upstream migration period because fish will not be able to move upstream until passage facilities begin operating. Presently there are no fish passage facilities at Hooksett dam and upstream migrating alewives are able to enter the Hooksett Pool only when spill conditions are favorable.

Salmon and shad have not yet reached the Amoskeag dam in appreciable numbers and probably will not have access to the Hooksett Pool for at least a decade.

Adult alewives migrate upstream in early spring, followed by shad and salmon. Alewife and shad migrations are substantially complete by early and late June, respectively. Peak salmon migration occurs from May through July but fish may enter the river through October. Adult shad and alewife migrate downstream in June and July, shortly after spawning. Salmon remain in the river until spawning is completed in October and November and either migrate downstream immediately or overwinter and migrate downstream in early spring. Young shad and alewife migrate from the river during September and October. Salmon smolts migrate downstream from mid-April through mid-June.

Studies of upstream migrating adult shad and downstream migrating juvenile shad and salmon indicate that their migrations are not impeded by thermal plumes if an opportunity to pass under or around the plume exists. Prolonged periods of ambient temperatures outside the range in which migration normally occurs will, however, inhibit migration by most anadromous fish.

The configuration of the thermal plume is important in determining whether anadromous fish migrations may be affected by the Merrimack Station thermal discharge. Thermal plume monitoring data were reviewed and the data for two dates considered representative of low flow conditions, high ambient temperatures and high station thermal output were selected for analysis. The analysis established that there is a substantial area of water temperatures within 1-2°C of ambient in those portions of the river cross section that are more than 1-1.5 m below the surface. With the exception of the discharge transect, this region of near-ambient temperatures comprises approximately 45% or more of the river cross sectional area downstream from the discharge. At the discharge transect the near-ambient region comprises about one third of the cross sectional area. This region of near-ambient temperatures is present at flows that are exceeded at least 80% of the time during any anadromous fish migration season, thus constituting a "zone of passage" for migrating fish.

During the summer low flow period surface temperatures in some parts of the thermal plume may exceed the acute thermal preference of most resident target species. Since there is an area of near-ambient temperatures extending from a depth of a meter or so below the surface to the bottom, resident fish are expected to avoid the warmest areas of the plume and seek out nearby areas of preferred temperatures.

Because adults and juveniles of the target species can readily avoid areas that are too warm, and because eggs of the target species are likely to remain in a fixed location or tend to remain near the bottom, it was determined that the surface-oriented larvae of yellow perch and American shad were likely to be most vulnerable to elevated temperatures associated with the thermal plume. Laboratory studies of yellow perch indicate that prolonged exposure to maximum discharge temperatures likely to occur when larval yellow perch are present in the Hooksett Pool overlap the reported range of upper incipient lethal temperatures for juvenile perch. Temperature restrictions based on such studies may be overly conservative because they do not simulate the transitory exposure to maximum plume temperatures that would occur in the river. Both in situ and laboratory studies of larval shad temperature tolerances were conducted at Merrimack Station in 1975-1976. Laboratory studies that simulated passage through the thermal plume established that decreased survival of temperature on shad larvae could be observed at temperatures above 33.3°C. There was insufficient information available to draw any conclusions as to the magnitude of ΔT's that might affect larval perch survival. Larval shad were found to tolerate ΔT's of 11.1°C or greater to maximum temperatures above 34°C.

Fisheries field sampling data for the period from 1967 through 1978 indicated a decreasing trend in yellow perch abundance. The initial decreases in abundance occurred sooner than would have been expected if they were due to the startup of Unit II, thus they may have been an artifact of natural variability in population size. Available thermal tolerance information in conjunction with the abundance data does suggest that further study of larval perch temperature tolerances, larval distribution and/or population structure should be conducted.

Restrictions on maximum discharge temperatures and ΔT's at the point of discharge may be necessary in the future to protect larval shad. Presently, however, only a few, or no, adult shad spawn in the Hooksett Pool in any given year. Until shad reach Hooksett Pool in appreciable numbers, discharge temperature restrictions designed to protect shad are unnecessary. Studies of temperature effects on later shad larval stages may be necessary because there is evidence that older test specimens in the original studies conducted at Merrimack Station were affected by starvation and thus may have been more susceptible to thermal stress than "wild" larvae would be.

Sudden winter shutdowns of the cooling system at Merrimack Station are a concern because resident fish attracted to the warm temperatures of the thermal plume may suffer cold shock. Attraction to thermal plumes when ambient temperatures are below preferred temperatures was noted for largemouth and smallmouth bass, yellow perch and pumpkinseed. Telemetry studies indicated that perch are not subject to entrapment in thermal plumes and readily move between near 0°C, ambient temperatures and areas of thermal plumes at 10°C or more above ambient. Laboratory studies of smallmouth bass provided a basis for defining conditions that could potentially result in cold shock for bass. A review of plant operating data indicated that such conditions occur several times each winter and that there have been no reported incidents of related fish kills or fish in distress in the discharge canal. The likely explanation for the discrepancy between laboratory studies and the actual situation is that fish do not seek out the warmest areas of the plume and are able to adjust to the temperature change because the canal typically cools at a rate of less than 1.4°C per hour. On this basis it appears that winter temperature restrictions are unwarranted.

The discharge canal may be attractive to various of the target species at different times of the year. The portion of the Hooksett pool fish population that is present in the canal may be of concern if it represents a substantial portion of the total population and if it is also vulnerable to changes in the thermal environment that are likely to occur as a result of station operation. The data available to assess this issue were limited. Relative abundance data for the summer period of 1972-1976 did indicate that relative abundances of pumpkinseed and bass in the old canal were high relative to their mean abundances in the Hooksett Pool. Temperatures at the time of sampling, however, were generally within or below the preferred temperature ranges of those species. The results indicate that, as expected, resident target species were preferentially occupying an area of favorable temperatures when collected from the old canal. The lack of reported incidents of fish kills or distressed fish that could be related to high temperatures in the canal indicates that as temperatures increase to unfavorable levels, fish leave the canal. There were no data available to support an analysis of relative abundances of target species for the winter months. The need for a population assessment for the winter months is, however, questionable because the assessment of chill events indicates that fish present in the canal during winter are not adversely affected by station outages.

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1.0 INTRODUCTION

Part I, Sub-part 17 of the NPDES Permit for Merrimack Station identifies six issues (Part I.17.a-f) that must be addressed by PSNH to resolve resource agencies' concerns relative to thermal effects of once-through operation of Merrimack Station on the aquatic community of the Merrimack River. Extensive information relevant to those issues is available in a series of reports on biological monitoring and impact assessment studies conducted from 1967 through 1978 for PSNH by Normandeau Associates, Inc. (NAI), St. Anselm's College, and by the N. H. Fish and Game Department. Additional information is available from literature published since 1977, files of State and Federal resource agencies, other utilities, local organizations and from PSNH. PSNH believes that the information available substantively addresses Part I.17.a-f and that, following review and assessment of the available information as per Part I.17.g of the NPDES permit, it is likely that several of the issues will have been resolved and that the scope of studies required to address the remaining issues (i.e., Phase II) will be focused on a few critical areas.

This document reviews available information relative to the issues identified in the NPDES Permit. The approach followed in preparing this document was developed in consultation with the Technical Advisory Committee for Merrimack Station (TAC). The purpose of this preliminary report is to summarize available information that relates specifically to each of the issues identified in Part I.17.a-f of the NPDES Permit, evaluate the quality and completeness of that information, and identify the type of information required to complete assessment of the issue. This report will provide the basis for developing a scope of work for Phase II studies to be conducted by PSNH in the summer of 1993. The actual scope of work for 1993 studies will be prepared in consultation with the TAC after their review of this report.

1.1 Target Species

The NPDES permit for Merrimack Station identifies anadromous and indigenous fish as the main focus for studies of the effects of heated water discharge on the aquatic community. In a meeting held on August 20, 1992, the

TAC agreed that American shad, alewife, and Atlantic salmon were the anadromous species of primary concern. Resident species considered representative of the fish community include largemouth and smallmouth bass, pumpkinseed and yellow perch. These seven anadromous and resident species together comprise the target species considered in this report. Seventeen additional resident species have been collected from the vicinity of Merrimack Station (NAI 1979a). In addition to the target species, species that were numerous in resident fish collections conducted from 1967 through 1978 include brown bullhead, white sucker, golden and common shiners, and redbreast sunfish.

Adult brook, brown and rainbow trout and domestic Atlantic salmon (i.e., offspring of anadromous parents raised to adult size in the hatchery and spawned prior to release) may occur as a result of stocking. These stocked salmonids (trout and domestic salmon) are not considered indigenous since temperature monitoring records show that ambient temperatures annually approach or exceed incipient lethal temperatures for adult salmonids. In addition, there is no spawning and nursery habitat for salmonids in the Hooksett Pool (although there may be access to suitable habitat in the Soucook River). Because salmonids would be expected to be maintained only by put-and-take management due to naturally limiting conditions, they are not considered in this report.

1.2 Information Sources

In addition to published literature from scientific journals and books, a number of technical reports that have received limited circulation were included in the review of available information. These include a number of reports detailing environmental monitoring studies conducted at Merrimack Station prepared by Normandeau Associates, Inc. (NAI) and reports on related studies conducted by PSNH and other utilities. Other potential sources of information contacted included:

- NH Fish and Game Department
- U.S. Fish and Wildlife Service

- o Merrimack River Watershed Council
- o Vermont Yankee

A literature search was conducted to identify recent scientific reports, papers, etc. relating to thermal effects on the representative important species. This search concentrated on literature published since 1977 because NAI had developed a review of pertinent literature on thermal effects on most target species as part of the monitoring program and associated studies conducted at Merrimack Station from 1970-1978 (NAI 1977a, 1979a).

1.3 Report Structure

Information on temperature requirements of anadromous and resident target species is pertinent to several of the issues that this report seeks to address. To avoid excessive repetition the information pertinent to the temperature requirements of the target species is presented on a species-by-species basis in Section 2.0. Section 3.0 addresses the issues of anadromous fish migrations raised in the NPDES Permit, Part I.17.a. Section 4.0 addresses issue I.17.b, the configuration of the thermal plume and its effects on anadromous and resident fish. Section 5.0 addresses the three related issues relative to the need for temperature restrictions to protect fish on a seasonal basis. Finally, Section 6.0 provides an assessment of the proportion of the fish community that may be present the discharge canal.

1.4 Study Area

Throughout this report references will be made to sampling stations that were established by NAI during the monitoring studies. The sampling stations are designated in terms of their location in Hooksett Pool relative to (north or south of) the mouth of the discharge canal (see Figure 1-1). Station Zero or S-0 is the mouth of the discharge canal. Proceeding north from Station Zero, stations N-1 through N-6 were located at 500 foot (150 m) intervals, stations N-7 through N-10 were at 1000 foot (300 m) intervals and stations N-11 through N-16 (not shown in Figure 1-1; N-16 is Garvins Falls dam) were located at 1500 foot (450 m) intervals. Proceeding south from Station Zero, stations S-1 through S-24 were located at 500 foot (150 m) intervals with Hooksett dam at the location that would have been designated S-25. Ambient temperatures, when referred to in this report were measured at either station N-10 or N-5 (the cooling water intake location).

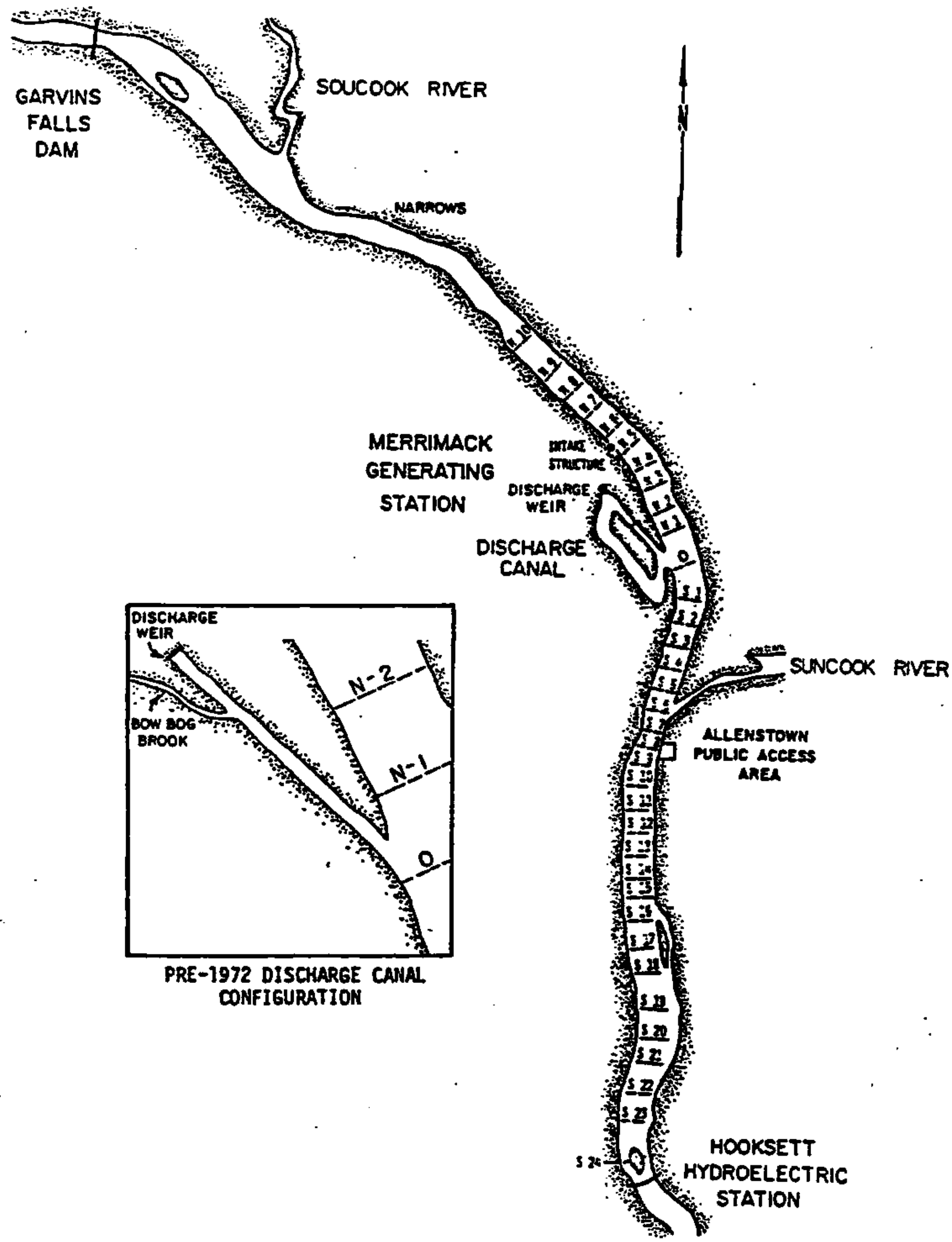


FIGURE 1–1.

Map of the Hooksett Pool study area showing sampling locations referred to in this report. (from Merrimack River Summary Report, NAI, 1979a)

2.0 TEMPERATURE REQUIREMENTS OF ANADROMOUS AND RESIDENT FISH

The issues identified in the Merrimack Station NPDES Permit as Part I.17.a, c, d and e are related to various aspects of the thermal requirements and temperature tolerances of fish that may be affected by the Merrimack Station thermal plume. The Merrimack Station monitoring studies contain the results of a comprehensive review of the literature (as of 1978) on thermal tolerances of resident species, point-of-capture temperatures for fish sampling and results of in situ and laboratory thermal bioassays. In addition, NAI reviewed literature and conducted a series of studies relative to thermal tolerances of eggs and larvae of American shad. This section provides the literature review information from the monitoring studies and supplements it with information on temperature requirements that became available after the Merrimack River Monitoring Program was completed.

Information on the ambient water temperature regime in the Hooksett Pool and the ΔT's associated with the discharge are necessary to place the literature review provided in the preceding sub-sections of the report in its proper perspective. A review of temperature data contained in reports prepared by NAI during the 1970-1978 monitoring program as well as data from annual reports on continuous biological monitoring conducted at Merrimack Station from 1980-1991 indicates that typical summer (mid-June to mid-September) ambient temperatures are in the range of 20-25°C with peak daily average temperatures reaching 26-29°C. Winter ambient temperatures are in the 0-5°C range. The theoretical ΔT through the condenser cooling system is 13.9°C. Cooling occurs as discharged condenser cooling water passes down the 1.2 km cooling canal prior to being returned to the river. A system of power spray modules (psm's) in the canal is used to increase evaporative cooling during periods when ambient temperatures exceed 20.5°C. In general average daily ΔT's near the end of the cooling canal are 10-12°C above ambient during periods when the station is generating at near maximum capacity and the psm's are not operating. When the psm's are operating average daily ΔT's at the end of the canal are typically less than 10°C above ambient. Thus, average daily temperatures near the downstream end of the discharge canal are generally in the upper 20's to mid-30°C range during the summer, although temperatures above 36°C occur occasionally. Further cooling occurs when the discharge plume enters the river. The degree of cooling is dependent on the relative flow volumes in the canal and the river mainstem but surface temperatures 600 m (2000 feet) downstream from the discharge canal are usually more than 2°C cooler than those at the end of the canal during low flow periods.

2.1 American Shad

The following was taken from the "Final Report: Merrimack River Anadromous Fisheries Investigations, 1975-1976" prepared by NAI (1977a).

> American shad eggs are semi-buoyant and non-adhesive; they either remain suspended in the water column or sink to the bottom, depending on water velocity and turbulence. Although the larvae are difficult to capture by normal plankton sampling techniques, they are considered to be somewhat planktonic. Both of these life history phases, then, are potentially entrainable. At Merrimack Station, they may be entrained either directly in the cooling water or by momentum entrainment in the thermal discharge plume. Either form of entrainment may represent a potentially lethal condition depending on hydraulic and mechanical stresses and the time-temperature histories encountered.
>
> After transformation from larvae to juveniles, young shad become surface-oriented in their feeding behavior, consuming mostly insects (Massman, 1963). At this time, they may be exposed to thermal stresses imposed by Merrimack Station's surface-oriented warmwater discharge. Adult shad may also be exposed to the discharge although they do not generally feed while in fresh water.
>
> Literature assessing the potential harmful interaction of an electric generating station is more complete for some American shad life history phases than for others. Entrainment has been studied intensively at the Connecticut Yankee Atomic Power Plant on the Connecticut River, CT. Investigations there have been summarized by Marcy (1976). Marcy (1976) found that although river herrings (Alosa spp.) together made up 97% of the entrained eggs and larvae, American shad eggs and larvae represented less than 1% of the total. American shad ranked ninth in overall ichthyoplankton abundance in the part of the river adjacent to the plant, and both eggs and larvae were present in plankton tows taken at a station located directly upstream of the intake (Marcy, 1976, Table 69), yet few were entrained. Similarly, studies funded by the Central Hudson Gas and Electric Company on ichthyoplankton and entrainment in the Hudson River near Poughkeepsie, NY demonstrated the presence and entrainment of many Alosa spp. larvae but relatively few American shad eggs and larvae (QLM, 1974).

Several thermal bioassay investigations involving American shad have been published. Temperature bioassays were performed by Bradford et al., (1966) on shad eggs and, in a preliminary study, on larvae. This study utilized only steady-state temperature treatments because it was designed to determine the suitability of a river system for shad restoration and was not related to powerplant stresses; no rapid temperature increases were tested. Schubel (1974), testing the effects of time-temperature regimes likely to be encountered at Maryland powerplants, found that hatching success was related to stage of development as well as temperature exposure. However, the earlier studies by Bradford et al., (1966) suggested that thermal effects may be latent and not realized until after hatching. These authors found decreased larval survival and an increase in the proportion of deformed and abnormally developed larvae at elevated temperatures. More recent work by Schubel et al. (1976) has corroborated the sensitivity of the larvae, but the work is as yet incomplete; no precise tolerance limits have been determined. Additionally, sublethal effects reflected in behavioral abnormalities were discovered in this latest series of experiments. Finally, recent work by Koo (1976) corroborated the increased proportion of deformed larvae hatching from eggs exposed to high temperatures for periods of about 3 hours. Although not conclusive, these studies together indicate that shad eggs can tolerate temperatures approaching 90°F (32°C) for at least short periods (<1 hr) without any direct or latent effects but the larvae may be somewhat more sensitive.

The effects of heat shock have been studied in a different manner for other clupeid fishes. Hoss et al. (1971), for example, found that the critical temperature for larval menhaden (*Brevoortia tyrannus*), alewife (*Alosa pseudoharengus*) and blueback herring (*A. aestivalis*) survival was between 28 and 30°C (83-86°F). Similarly, Marcy (1971; 1973) found temperatures of 28-30°C to be lethal to most larval fishes entrained in the cooling water of a nuclear power plant.

Recent studies support earlier beliefs that shad larvae are more sensitive to thermal stress than are eggs. Preliminary work by Schubel et al. (1976) found that some Δt's and maximum temperatures typical of Maryland power plants, which had previously been determined "safe" for shad eggs (Schubel, 1974; Schubel and Koo, 1975), caused decreased survival of larvae within 24 hours of exposure. These most recent findings agree with those of earlier studies (Hoss et al., 1973): Exposure of larvae to temperature increases of 15°C (approximately 28°F) above ambient may cause violent behavioral reactions and death whereas lower temperature increases, for the most part, may be tolerable.

The reactions of juvenile shad to thermal discharges during the fall downstream migration were studied at Connecticut Yankee by Moss (1970) and Marcy et al. (1972). Both investigations concluded that although potentially lethal conditions were present, the migrating juveniles were able to detect and avoid the thermal discharge. The young fish remained beneath the zone of thermal influence. In addition, no evidence of juveniles overwintering or residing in the warm discharge waters were cited. The reactions of upstream-migrating adults in the vicinity of a thermal discharge were also studied intensively at Connecticut Yankee (Leggett, 1976). These studies concluded that adult shad could successfully detect and avoid undesirably warm areas of the river.

Temperature shock tolerances and avoidance-attraction responses were studied experimentally for juvenile blueback herring and alewives by Meldrim and Gift (1971). Results were somewhat inconclusive but suggested that these fish could also detect and avoid potentially lethal conditions. These laboratory studies did not include juvenile shad, however.

References cited in the above discussion may be found in Section 8.2. NAI (1977a) reported on the results of field and laboratory bioassay experiments conducted with American shad eggs and larvae in 1975 and 1976. The field bioassay experiments were conducted by drifting shad eggs through the thermal plume at the surface and mooring the egg boxes at either station S-4 or S-17. Station N-5 or N-10 were control stations for eggs that were drifted but not exposed to the thermal plume. These experiments suggested a correlation between reduced post-hatching survival of late-stage eggs and the temperature history associated with eggs that drifted through the plume at the surface and that were subsequently retained in the "mixing zone" area (S-4). Such a temperature history is not possible, however, both because the eggs are semi-demersal and tend to remain near the bottom where exposure to elevated temperatures would be reduced and because there is no hydrodynamic mechanism to retain eggs in the area of station S-4.

Laboratory bioassay studies conducted by NAI (1977) demonstrated that eggs tolerated brief (10-30 minutes) exposures to elevated temperatures and higher ΔT's than larvae. Younger larvae showed higher tolerance than older larvae. Shad egg survival was not influenced significantly by 30-minute exposures to temperatures $\leq 33.9°C$ or ΔT's $\leq 13.9°C$. The oldest larvae tested suffered mortality significantly different from controls following 20-minute exposures to temperatures $> 34.4°C$ or ΔT's $> 11.1°C$. Younger larvae survived 30-minute exposures to temperatures $\leq 33.3°C$ and ΔT's $\leq 12.8°C$. Difficulties with maintaining older larvae resulted in high control mortalities in the experiments with the oldest larvae. High control mortality indicates that the results of experiments with older larvae may not have been valid. It also suggests that the experiments overestimated the adverse effects of temperature exposure due to the presence of other significant sources of stress on older larvae.

2.2 Alewife

Coutant (1977) reported an upper avoidance temperature for adult Great Lakes alewives of 22°C; however, Spotila et al. (1979) reported that adult alewives have a summer preferred temperature of 26.5°C. Adult anadromous alewives were captured in the lower Connecticut River from April through July (Marcy 1976a). Mean ambient temperatures in the lower Connecticut during July are 22-25°C while monthly maxima may exceed 30°C in some years. Otto, et al. (1976) reported the 7-day upper incipient lethal temperature (UILT) for adult Great Lakes alewives was approximately 23.5°C for fish acclimated to 10°C and 15°C and 24.5°C for fish acclimated to 20°C. They cited work by Graham (1956) as generally supporting their results with "lethal temperatures" of 20°C for fish acclimated to 10°C and 23°C for fish acclimated to 15 and 20°C. McCauley and Binkowski (1982) reported the 7-day UILT to be 28.2°C for fish acclimated to 27°C. They stated that this is higher than temperatures reported elsewhere in the literature, probably due to use of lower acclimation temperatures in other experiments (McCauley and Binkowski 1982). Colby (1973), however, cited the work of Stanley and Holzer (1971) that determined UILT's for alewives acclimated at 16.9 and 24.5°C to be 29.8 and 32.8°C, respectively.

Juvenile alewives are able to tolerate higher temperatures than adults. Otto et al. (1976) reported that 7-day UILT's for young-of-the-year alewives (2.8-4.7 cm Standard Length) were 26.5, 30.3 and 32.1°C for fish acclimated to 12, 20 and 26°C, respectively. Spotila et al. (1979) cite an UILT of 32.1°C for young-of-the-year (YOY) alewives acclimated to 25°C and a summer final preferred temperature of 31.3°C. No specific information was found on juvenile alewife behavior in the presence of thermal gradients. Sampling of the thermal plume and discharge canal at the Connecticut Yankee Nuclear Power Station (12°C maximum ΔT) indicated that juvenile alewives were not present in the thermal plume when ambient temperatures decreased in the fall decreased below the range reported for migration (Marcy 1976a).

2.3 Atlantic Salmon

The ultimate temperature limit for Adult Atlantic salmon is 27°C (Strawn 1958; cited in Carlander 1969). Huntsman (1942; cited in Carlander 1969) found that fresh grilse (1-sea-winter adults) died at 29.5°C and acclimated grilse died at 30.5°C in the Mosers River, Canada. This is consistent with observed temperatures (27-29°C) associated with death of a number of salmon in the Penobscot River (Shepard and Hall 1991). Mills (1989) cites an incident of mass salmon mortality in the River Wye associated with maximum temperatures of 27.6°C and reduced dissolved oxygen. The optimum temperature range for juvenile salmon is 15.5-18.5°C (Markus 1962; cited in Carlander 1969) or 15-18.8°C DeCola (1970). For juvenile salmon acclimated at 20°C, the 6-hour TL_{50} was 28°C and the 1-hour TL_{50} was 29.4°C (DeCola 1970). Huntsman (1942; cited in Carlander 1969) noted deaths of large salmon parr at 32.9°C and small parr at 33.8°C in the Mosers River.

2.4 Smallmouth Bass

The following was taken from the "Merrimack River Monitoring Program Summary Report" prepared by NAI (1979a).

> Smallmouth bass inhabit moderately shallow, rocky and sandy areas of rivers. Spawning occurs from May through June in New England at temperatures of 12.8 to 20°C, although most egg deposition occurs between 16.1 and 18.3°C (Scott and Crossman, 1973). Male smallmouth bass guard the eggs and fry while they are in the nest, and may continue to guard them up to 28 days after the fry leave the nest (Carlander, 1977). Sudden increases in river flow or turbidity usually do not damage nests with eggs or fry, but advanced fry that have just left the nest may be displaced downstream by slight flow increases (Carlander, 1977). The protective behavior of the adults helps to prevent the downstream displacement of the fry, thus minimizing the probability that the larvae would be entrained. For this reason, it is understood why smallmouth bass larvae have been absent in ichthyoplankton entrainment samples at Merrimack Station (Appendix Tables E-3 and E-4).

Egg survival in the laboratory was shown to be highest at an incubation temperature of 23°C; survival decreased at higher or lower incubation temperatures (Wallace, 1973). Eggs near the hatching stage and newly-hatched fry appear to be resistant to mild (< 7°C) thermal shock (Tester, 1930; Webster, 1945).

The smallmouth bass has a summer thermal preference between 25 and 35°C, although differences exist among seasons and between adults and juveniles (Figure 8-1; Coutant, 1977). Juvenile smallmouth bass tend to choose temperatures between 28 and 31°C during the summer and grow best at 26 to 29°C (Horning and Pearson, 1973). The NTAC (1968) has recommended 28.9°C as the maximum temperature compatible with adequate growth of juvenile smallmouth bass. General field observations indicate that young bass remain in warmer waters than older individuals (Ferguson, 1958), but this is not indicated by the thermal preferences illustrated in Figure 8-1.

Wrenn (1976), Hokansen (1969), Stauffer et al. (1976) and Trembley (1960) have indicated that thermal effluents do not create a barrier to smallmouth bass movements, and have observed smallmouth bass in waters warmer than 34°C. Trembley recorded body temperatures up to 33.3°C for smallmouth bass taken from the Delaware River below a thermal outfall; in the associated discharge lagoon, smallmouth bass body temperatures ranged up to 34.4°C. Although smallmouth bass do enter thermal plumes, Van Vliet (1957; cited in Brown, 1974) indicated that the smallmouth bass abundance within a Delaware River thermal discharge increased as decreasing river water temperatures approached 26.7°C. Similarly, Gammon (1971; cited in Brown, 1974) observed that smallmouth bass avoided a Wabash River heated effluent during summer, but returned to the heated regions when temperatures decreased to 27°C in the autumn.

Hooksett Pond smallmouth bass have been collected most frequently near the discharge canal and within the mixing zone, but have also been found at far-field and control regions during the summer. Modal seining temperatures from 1974 to 1978 were 30-34°C (Figure 8-2), indicating a distribution pattern favoring the warmest portions of Hooksett Pond. Because temperatures in this range occur primarily in the discharge canal area, this distribution pattern may also be influenced by preference of other habitat parameters. This distribution does, however, indicate that the thermal discharge from Merrimack Station does not normally restrict smallmouth bass movement throughout Hooksett Pond.

Smallmouth bass were used in thermal toxicity studies from 1975 through 1977 to determine if the Merrimack Station thermal discharge was acutely toxic to centrarchids. Bass were held for a three-day acclimation period and a subsequent ten-day test period in live cars at the discharge canal mouth (experimental station) and upstream of the generating station intakes (control station). Mortality between these stations was compared over the ten-day test period. Only one of eight test series resulted in significantly (α=.05) higher mortality at the discharge canal mouth than at the ambient river location (Table 8-3; Appendix Tables E-7 to E-9). During the third series in September 1975 (Appendix Table E-7) an accidental chemical discharge from Merrimack Station caused a fish kill in the discharge canal and induced complete mortality among the experimental fish. Only two such station-related fish kills were observed during the 12-year monitoring program (April 1971: September 1975). In both instances, effects were limited to the discharge canal; there was no evidence that these effects extended into the river. The construction of a wastewater (chemical) treatment facility at Merrimack Station during 1977 will help to further preclude any such inadvertent chemical discharges.

Growth rates of smallmouth bass during the pre-operational period (1967 and 1968) were similar to present growth rates, as indicated by back-calculated lengths at annulus formation (Appendix Table E-10). Growth rates to the first annulus from 1972 through 1974 appeared to be unusually rapid, and the length-at-capture data for age 0 and 1 fish indicate that these growth rates were artificially inflated, likely through mis-reading of the scales and omitting the first annular ring. Thus, these data have been disregarded, although they were presented in annual reports. The 1975 to 1978 growth rates, however, were similar to pre-operational growth rates.

Length-weight relationships for smallmouth bass in Hooksett Pond indicate that bass from all portions of this river section are healthy and have a condition factor near 3.0 (Appendix Table E-13). The value of this index should be near 3.0 since the weight of an object will vary as the cube of its length if shape and specific gravity remain the same (Carlander, 1977). Thus, the thermal discharge does not tend to accelerate growth in length at the expense of weight and cause emaciation within the smallmouth bass population.

The figures referred to above as Figures 8-1 and 8-2 are presented as Figures 2-1 and 2-2 herein; other tables and figures referred to by the NAI discussion are not included in this report. References cited in the above discussion may be found in Section 8.2.

In addition to the temperature information presented above, a number of more recent studies have examined various aspects of juvenile and adult smallmouth bass response to temperature. Wrenn (1984) studied the ability of smallmouth bass to reproduce at elevated temperatures. Smallmouth bass held in artificial outdoor channels at temperatures of 3, 6 and 9°C above ambient

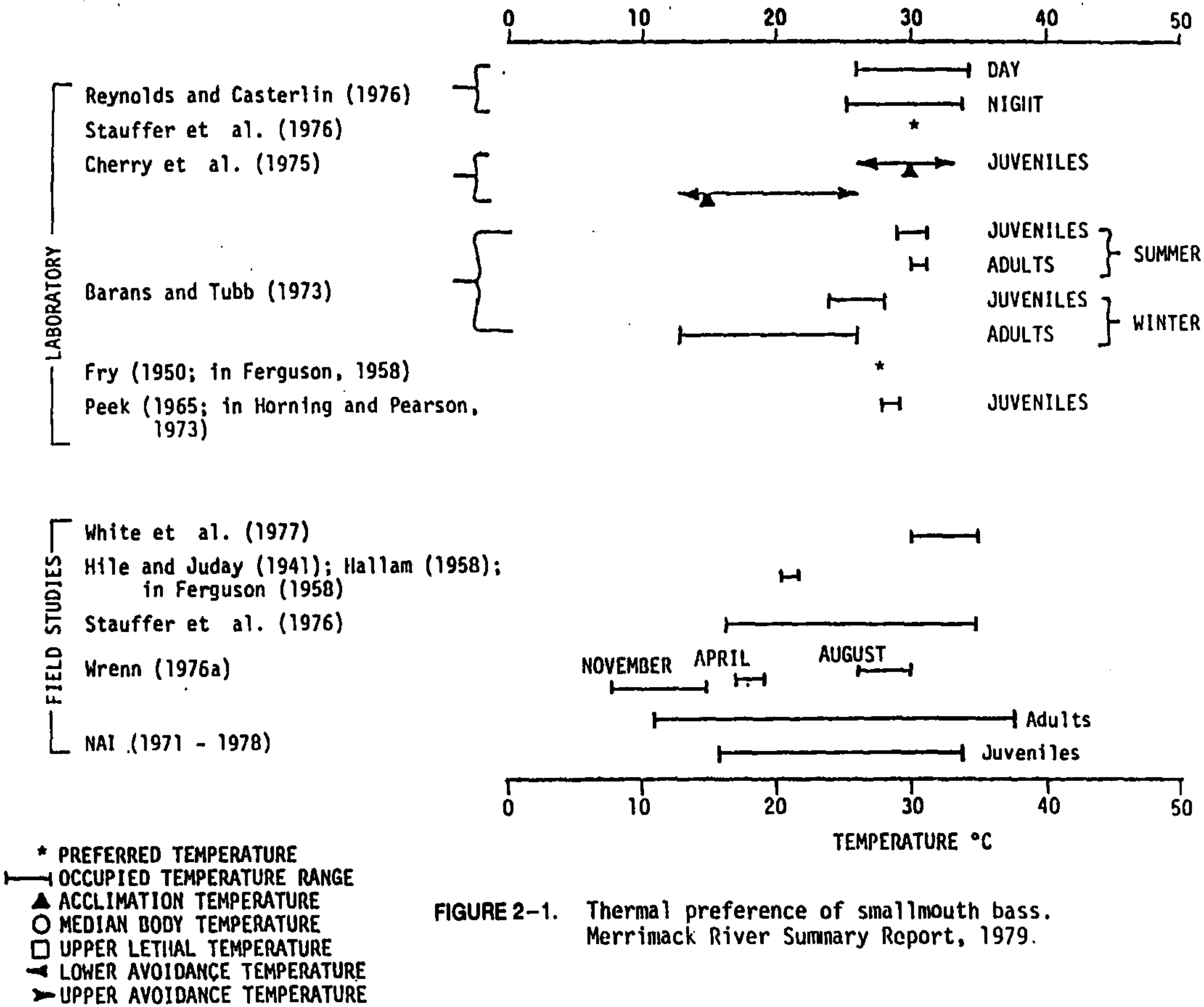


FIGURE 2-1. Thermal preference of smallmouth bass. Merrimack River Summary Report, 1979.

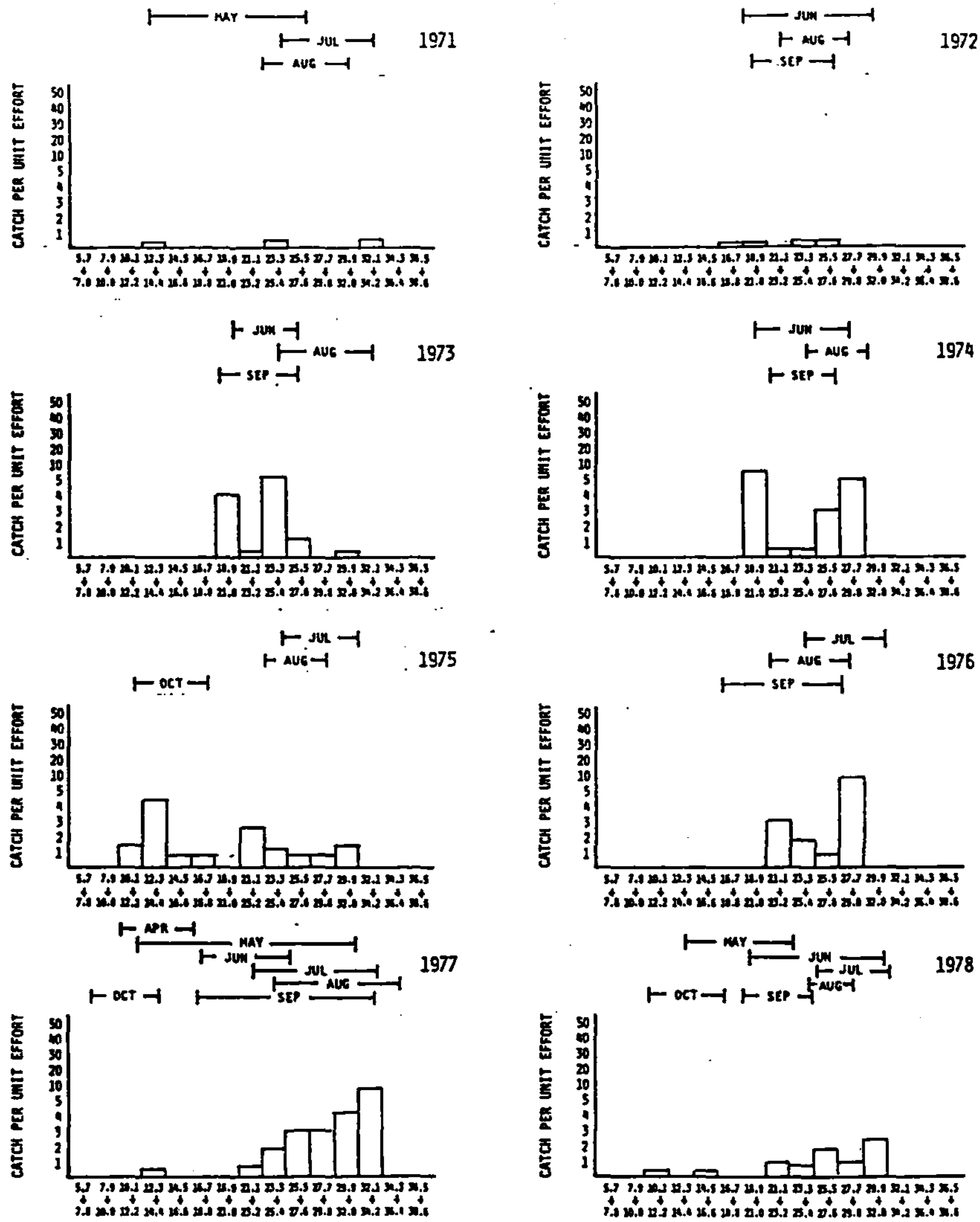


FIGURE 2-2. Catch per unit electrofishing effort (1971 to 1976) and seining effort (1977 and 1978) per 2.2°C (4°F) interval for smallmouth bass. Merrimack River Summary Report, 1979.

spawned earlier in the season than bass held at ambient temperatures. Spawning period duration was similar for bass in all temperature regimes. Growth rates of bass fry during the first 42 days after hatching showed no consistent relation to temperature. Growth rates through October of their first year were not different; however, YOY bass held at the highest temperature were the largest in October due to the increased length of the growing season. Wrenn (1984) indicated that a seasonal maximum temperature of 26°C would be appropriate for protection of smallmouth bass spawning and embryos. Coutant and DeAngelis (1983) examined growth rates of smallmouth bass fry (10-15 mm in length at the start of the experiment) at temperatures between 15.2 and 32.5°C in the laboratory and found that optimum growth rates were obtained at temperatures of 25-26°C and that growth rates were relatively high between temperatures of 23.2-28.5°C. Coutant and DeAngelis (1983) found that smallmouth bass fry could be acclimated to temperatures up to 32.5°C and that they exhibited growth at that temperature.

Cherry et al. (1977) reported preferred, extreme avoidance and 7-day incipient upper lethal temperatures for smallmouth bass less than 1 year old. They found that the final thermal preferendum for young bass was 30.3°C. The upper extreme avoidance temperature for young bass acclimated to 24-30°C was 33°C and bass acclimated to 33°C avoided temperatures of 35°C. The highest temperature at which 100% survival occurred during a 7-day exposure was 35°C. Wrenn (1980) held young smallmouth bass (YOY 111 mm in length at start of experiment) in outdoor channels over an 11 month period at temperatures of 0, 3, 6 and 9°C above ambient. Survival at the end of the period did not differ significantly between the ambient and 9°C treatments. Growth was essentially the same in all treatments. Wrenn (1980) concluded that "(1) a mean weekly average temperature of 32-33°C in the mixed water body would permit satisfactory growth; and (2) a maximum temperature of 35°C for short-term exposure during the summer growth period would avoid potentially lethal effects."

Information on smallmouth bass response to decreasing temperatures was not discussed by NAI (1979). Horning and Pearson (1973; cited in Carlander 1977) determined that the 96-hour lower TL_{50} for juvenile smallmouth acclimated to 15°C was 1.7°C while the 96-hour lower TL_{50} for juveniles acclimated to 26°C was 10.1°C. Survival of 90% or greater was obtained at ΔT's of 10.8-12.5°C for juvenile smallmouth acclimated at 15-18°C, ΔT's of 12.0-13.7°C for juveniles acclimated at 22°C and ΔT's of 13.3-15.6°C for juveniles acclimated at 26°C. Coble (1975) stated that smallmouth bass begin to seek deeper water at temperatures as high as 15.6°C and that activity noticeably decreases at temperatures below 10°C. At temperatures of 6.7-7.8°C most fish enter the substrate. They become torpid at temperatures of 4.4°C. One laboratory study (Barans and Tubb 1973; cited in Coutant 1977) determined the final thermal preferendum of adult smallmouth bass to be 12-13°C in winter while YOY bass preferred 18°C during winter.

2.5 Largemouth Bass

The following was taken from the "Merrimack River Monitoring Program Summary Report" prepared by NAI (1979a).

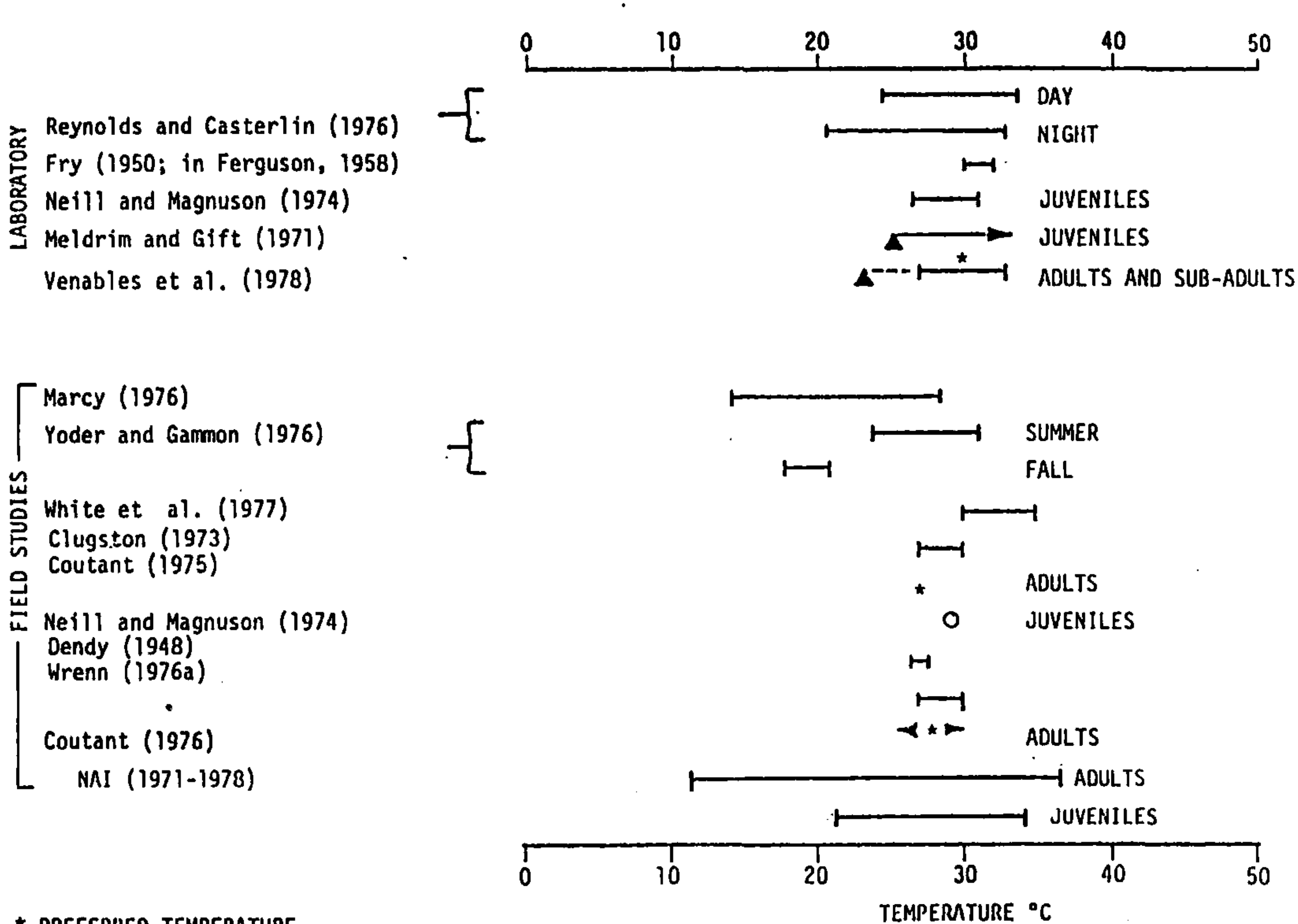
> Largemouth bass generally inhabit the warm, upper levels of lakes or slow river sections with mud substrates and extensive vegetation (Scott and Crossman, 1973). They spawn from late spring through mid-summer at water temperatures of 15.6 to 26.4°C, although optimum spawning temperature is 20.5 to 22.0°C (Carlson and Hale, 1972). Eggs are deposited in a nest constructed by the male, and hatch in 47 (26.1°C) to 96 hr (15.6°C; Carr, 1942; Kramer and Smith, 1960). Males guard the nest after spawning, but may desert the nest if temperatures fluctuate extensively (Kelley, 1968). This nesting behavior and guarding of the eggs and fry helps to decrease the entrainment potential for the eggs and larvae, particularly compared to broadcast-spawning species of species with pelagic larvae. Largemouth bass can spawn successfully in heated waters, and although juveniles often appear in heated regions before unaffected areas, it does not appear that thermal effluents significantly alter the annual reproductive cycle (Clugston, 1973; Bennet and Gibbons, 1975). Growth studies have shown that largemouth bass fry held at temperatures between 17.5 and 30°C grew best at 27.5°C (Strawn, 1961), and juveniles reared between 24 and 35.5°C grew most rapidly between 26 and 28°C (Coutant and Cox, 1974).
>
> The preferred temperature range for largemouth bass is 25 to 32°C (Figure 8-3). Neill (1971), Neill and Magnuson (1974), Busacker (1971), Marcy (1976) and Gibbons et al. (1972) report largemouth bass concentrations in thermal discharges, particularly

during winter. These aggregations appear to be transitory; no distinct plume population is established (Clugston, 1973). Largemouth bass distributions around thermal outfalls may also be controlled by forage fish movements rather than by temperature preference (Hatch, 1973). The ability of this species to move through thermal gradients has been supported by work demonstrating that largemouth bass can occupy widely-ranging thermal habitats through physiological tolerance rather than through direct adaptation (Denyes and Joseph, 1956).

Hooksett Pond largemouth bass have been captured in water as warm as 25.5°C [sic; **Figure 8-4 indicates maximum temperature of 34.2°C**] (Figures 8-3 and 8-4). Juveniles were collected primarily at near-field regions during June and July, and from areas farther from the discharge canal during August (Figure 8-4). During 1977 and 1978, adult and juvenile largemouth bass were collected most frequently within the mixing zone. Modal seining temperatures suggest a distribution pattern favoring the warmest regions of Hooksett Pond. This distribution may be influenced by other factors such as habitat type, cover and distribution of forage species. However, largemouth bass were commonly encountered near the discharge canal mouth, and the maximum water temperature discharged into the Merrimack River rarely exceeded the maximum temperatures tolerated by this species. This indicates that existing thermal discharges from Merrimack Station would not restrict the distribution of largemouth bass in Hooksett Pond.

The figures referred to above as Figures 8-3 and 8-4 are presented as Figures 2-3 and 2-4 herein; other tables and figures referred to by the NAI discussion are not included in this report. References cited in the above discussion may be found in Section 8.2.

In addition to the information discussed above, several studies have examined thermal tolerance and growth of largemouth bass fry or juveniles. Coutant and DeAngelis (1983) examined growth rates of largemouth bass fry (10-15 mm in length at the start of the experiment) at temperatures between 15.2 and 35.5°C in the laboratory and found that optimum growth rates were obtained at temperatures of 27°C and that growth rates were relatively high between temperatures of 23.2-29.3°C. Coutant and DeAngelis (1983) found that largemouth bass fry could be acclimated to temperatures up to 35.5°C and that they exhibited growth at that temperature. Venables et al. (1978) examined the ability of largemouth bass fry to withstand nearly instantaneous thermal



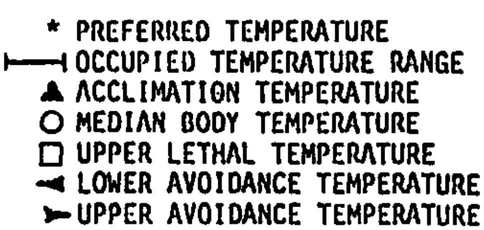


FIGURE 2-3. Thermal preference of largemouth bass. Merrimack River Summary Report, 1979.

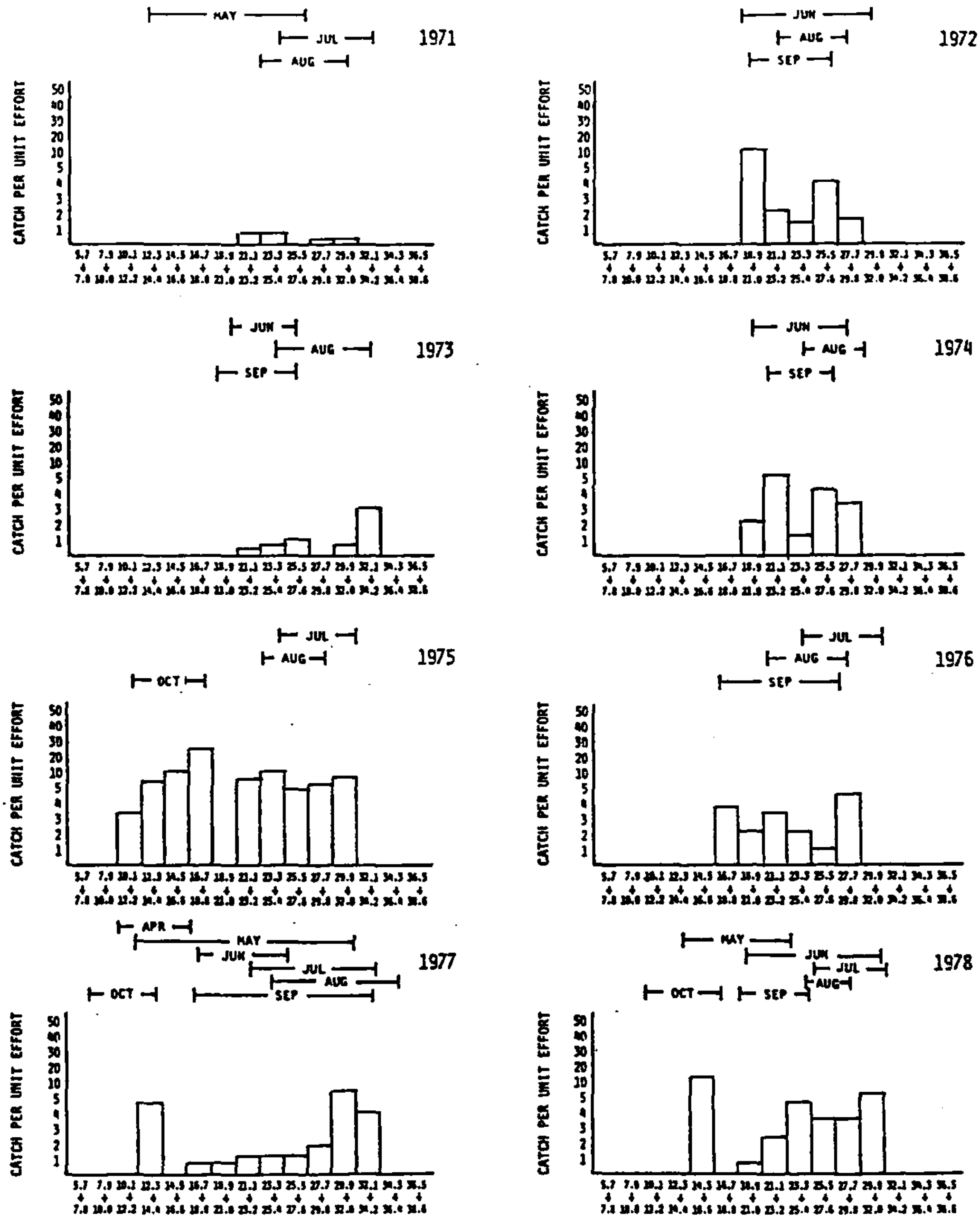


FIGURE 2-4. Catch per unit electrofishing effort (1971 to 1976) and seining effort (1977 and 1978) per 2.2°C (4°F) interval for largemouth bass. Merrimack River Summary Report, 1979.

shocks. Fry survival at the end of a 48-hr period was determined for fish acclimated at 15-35°C that were transferred to test temperatures of 10-40°C and held at test temperature until the experiment was terminated (increments in acclimation and test temperatures were 5°C). Survival of 100% at 30°C test temperatures was found for fish acclimated at 15 and 20°C at 35°C or fish acclimated at 25 and 30°C; at 15°C for fish acclimated at 35°C and at 10°C for fish acclimated at 15-30°C. Venables et al. (1978) also cited results of a study by Hart (1952) in which the upper median tolerance limits (TL_{50}'s) for adult bass acclimated to 20, 25 and 30°C were 32.5, 34.5, and 36.4°C, respectively and the lower TL_{50}'s for adults acclimated to 30 and 20°C were 11.8 and 5.5°C, respectively. They concluded that adult and fingerling bass had similar thermal tolerances at comparable acclimation temperatures.

Koppelman et al. (1988) examined temperature preferences of YOY largemouth bass (50-60 mm total length) from different genetic stocks. Northern largemouth bass had spring and fall final temperature preferrenda of 27.5 and 28°C, respectively. Bass acclimated at temperatures of 8°C (fall) and 12°C (spring) preferred temperatures of 24.6 and 25.8°C, respectively. Fields et al. (1987) examined critical thermal maxima (CTM's) and chronic thermal maxima of YOY largemouth bass (50-60 mm total length) from different genetic stocks. Northern largemouth bass had CTM's ranging from 29.2°C for fish acclimated at 8°C to 40.9°C for fish acclimated at 32°C. The chronic thermal maximum, based on an acclimation temperature of 32°C, was 37.3°C.

Block et al. (1984) documented the behavioral response of largemouth bass and bluegill in a nuclear reactor cooling reservoir in which summer surface temperatures during reactor operation reached 50°C, well above lethal limits for largemouth bass. Bass sought out areas where water temperatures were tolerable. Larger bass occupied deeper, cooler areas (< 31°C). Juvenile bass occupied warmer areas (32-34°C). Block et al. (1984) suggested that juvenile bass were competitively excluded from areas with lower temperatures by larger bass. They also noted that bass appeared to be attracted to the discharge area of the plant when temperatures were suitable due to the presence of high prey densities. When reactor operation commenced, fish left the discharge area before potentially lethal temperatures occurred.

Ross and Winter (1981) used radio telemetry to study behavior of four fish species in the vicinity of a thermal plume during winter. Largemouth bass sought warmer areas of the plume (approximately 10°C or less above ambient; maximum temperature available were 13°C) and confined their movements to the area within the thermal plume during the course of the study. They were the only species studied that did not move freely between ambient and thermally affected areas.

2.6 Pumpkinseed

The following was taken from the "Merrimack River Monitoring Program Summary Report" prepared by NAI (1979a).

> The pumpkinseed is a warm-water species usually found in weedy bays of large lakes and in slow-moving rivers and streams. They nest from May through August at temperatures of 20 to 28°C and spawn at temperatures around 28°C (Breder, 1936; Scott and Crossman, 1973). Males prepare a nest on clay, sand or gravel substrate, usually near submerged vegetation, and guard the nest, eggs and newly-hatched fry.
>
> Young (18 mm) pumpkinseed can survive exposure to water temperatures up to 38°C (Bailey, 1955), but the final thermal preferendum for juveniles is approximately 31.5°C (Anderson, 1951; Figure 8-5). Neill and Magnuson (1974) observed that small pumpkinseed were more abundant in a thermal outfall than in similar reference areas from August through October. This affinity of juveniles for warmer water is supported by the work of O'Harra (1966, 1968), indicating that small pumpkinseed are better adapted to warmer water than larger individuals because of a lesser temperature effect on respiratory metabolism.
>
> Neill and Magnuson (1974) captured adult pumpkinseed in Lake Monona, Wisconsin, at temperatures of 27.5 to 32.5°C; median body temperatures for these fish were 30.5°C during the day and 28°C at night (Figure 8-5). Catch per unit effort of large pumpkinseed in that study was not significantly different between the thermal outfall and reference areas. Trembley (1960) reported pumpkinseed body temperatures up to 31.7°C below a thermal effluent in the Delaware River, and up to 35.6°C for pumpkinseed captured within the discharge canal. Pumpkinseed were unusually abundant in the discharge canal, although temperatures greater than 32.2°C were generally avoided.
>
> Hooksett Pond pumpkinseed have been found in waters up to 35°C, the warmest available in the river exclusive of the inner

discharge canal. Modal seining temperatures from 1974 to 1978 were 30-35.5°C (Figure 8-6); however, as with other centrarchid species, this pattern may have been influenced by habitat as well as thermal preference. Highest pumpkinseed catches have been recorded near the discharge and mixing zones, and, although no quantified data have been recorded, pumpkinseed spawning and live fry have been observed within the discharge canal.

Pumpkinseed were used in thermal toxicity studies from 1975 through 1977 to determine if the Merrimack Station thermal discharge was acutely toxic to centrarchids. Only one of eight test series resulted in significantly (α=.05) higher mortality at the discharge canal mouth than at the ambient river location (Table 8-3). During the third series in 1975 (Appendix Table E-7) an apparent chemical discharge from Merrimack Station caused a fish kill in the discharge canal and induced complete mortality among the experimental fish (see discussion on page 87, paragraph 1). Mortality was not significantly different between the control and experimental stations during the remaining seven test series (Table 8-3; Appendix Tables E-7 to E-9).

Back-calculated lengths at annulus formation were calculated for pumpkinseed collected from 1975 through 1978 and compared to pre-operational growth rates (Appendix Table E-11). These comparisons indicated that growth rates during the first two years were similar during pre-operational and operational periods. However, growth after the third summer appears to be slower during the 1975 to 1978 period. This discrepancy may be partially due to differences in interpretation of the ages and growth patterns by Wightman (1971) and NAI in the present study. Wightman's pre-operational data indicate that Hooksett Pond pumpkinseed attained 180 mm total length by age 4+, whereas the operational data suggest that 5 to 6 years are required to attain this length. This may reflect a reduction in growth rate among the older fish, but more likely this is a difference in aging of the fish. Growth rates during the pre-operational period appear to be unusually high, while the growth from 1975 to 1978 compares favorably with pumpkinseed growth rates in Massachusetts and New York (Carlander, 1977). Growth rates for Hooksett Pond pumpkinseed occasionally appeared to be higher downstream of the discharge canal (1977 and 1978) but this was not observed consistently and may be attributed to natural variations in growth rates and variability of sampling between years rather than to effects of the thermal discharge.

Length-weight relationships for pumpkinseed captured from 1972 through 1978 show that pumpkinseed throughout Hooksett Pond have a condition factor near 3.0, indicating a healthy increase in weight as a function of length (Appendix Table E-14).

The figures referred to above as Figures 8-5 and 8-6 are presented as Figures 2-5 and 2-6 herein; other tables and figures referred to by the NAI

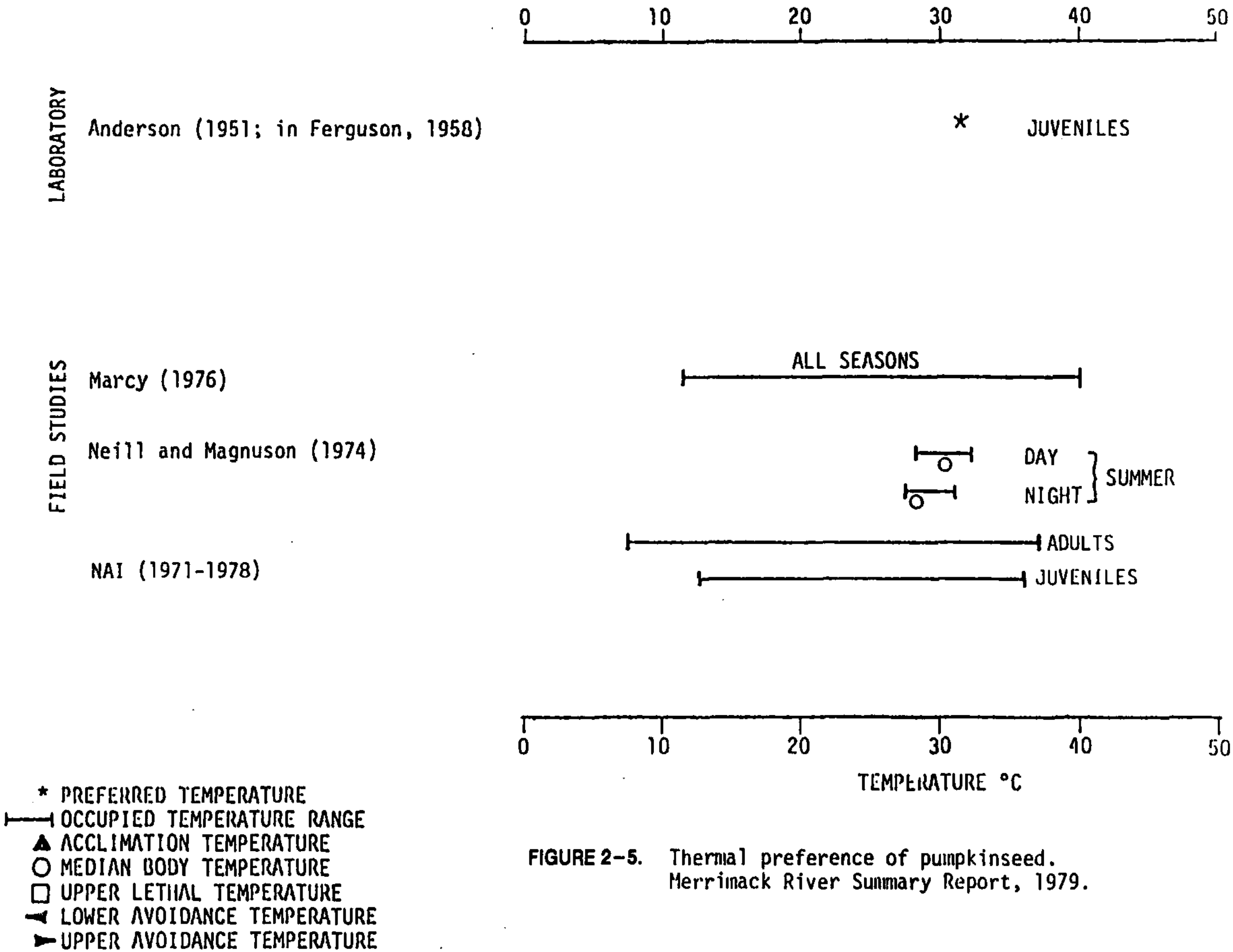


FIGURE 2-5. Thermal preference of pumpkinseed. Merrimack River Summary Report, 1979.

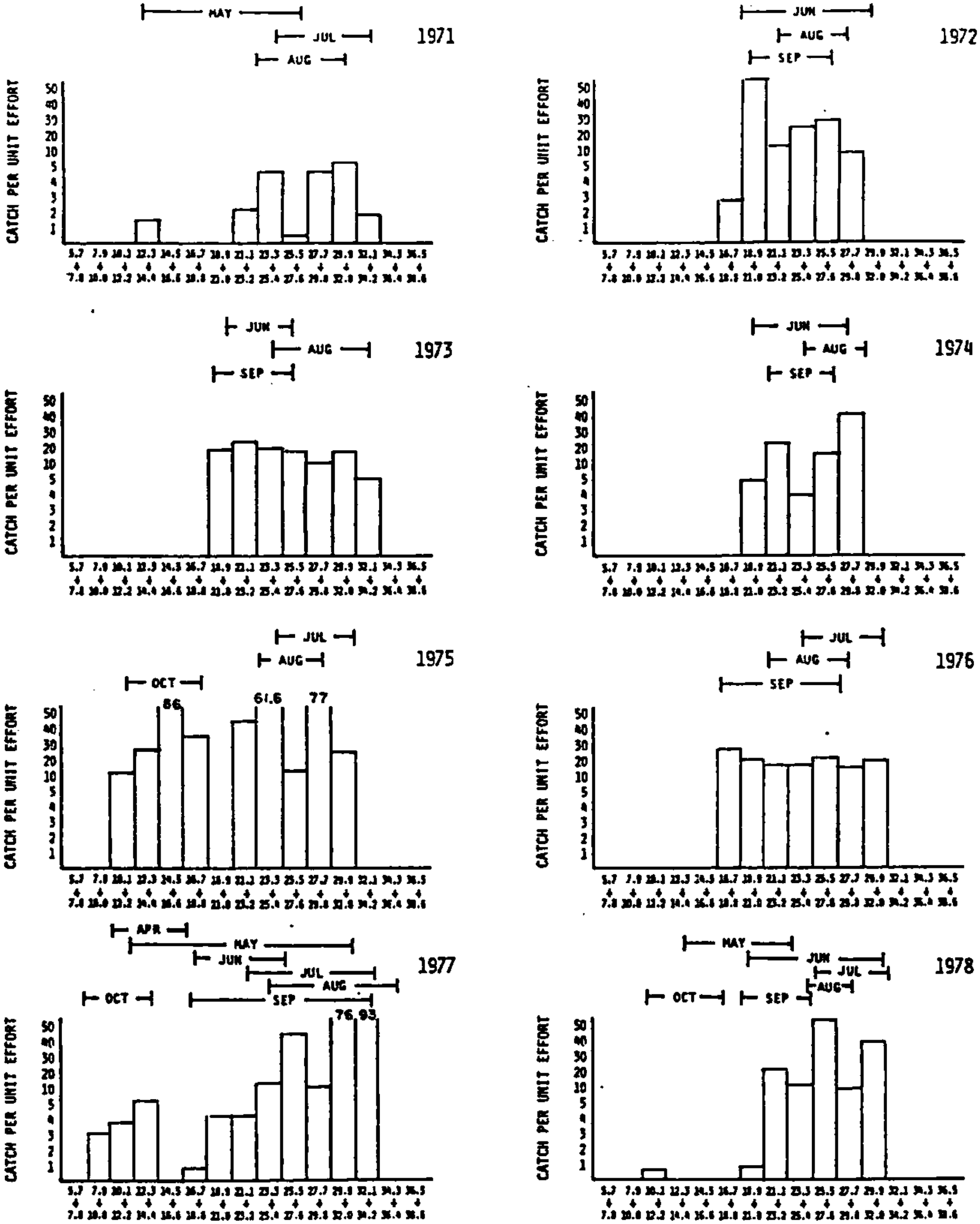


FIGURE 2-6. Catch per unit electrofishing effort (1971 to 1976) and seining effort (1977 and 1978) per 2.2°C (4°F) interval for pumpkinseed. Merrimack River Summary Report, 1979.

discussion are not included in this report. References cited in the above discussion may be found in Section 8.2.

Becker and Genoway (1979) examined the CTM of young pumpkinseed (90-140 mm fork length) acclimated at temperatures of 10 and 20°C. For fish acclimated at 10°C the lowest CTM observed (at a rate of temperature change of 6°C/h) was 29.5°C while fish acclimated at 20°C had a CTM of slightly greater than 35°C at rates of temperature change ranging from 1-30°C/h. Spotila et al. (1979) cited a CTM of 37.5°C for pumpkinseed acclimated at 23.1°C. UILT's for pumpkinseed acclimated at 18 and 24°C were 28.0 and 30.2°C, respectively (Black 1953; cited in Spotila et al. 1979). Brett (1944; cited in Spotila et al. 1979) found an UILT of 34.5°C for pumpkinseed acclimated at 25°C. Jobling (1981) reported lethal temperatures of 34.8-36.6°C for pumpkinseed.

Becker et al. (1977) examined the ability of pumpkinseed to tolerate both abrupt and gradual cold shocks. The 96-hour LT_{50}'s for fish 65-140 mm in fork length were 2.7, 4.5, 9.6 and 12.3°C for acclimation temperatures of 15, 20, 25 and 30°C, respectively. Minimum temperatures for 90-100% survival of test organisms ranged from 4.8°C at a 15°C acclimation temperature to 13.6°C at 30°C acclimation. When test fish were exposed to gradual cold shock (temperature decreases at rates of 18, 10, 5, 3 and 1°C/h) fish were able to tolerate lower temperatures. Loss of equilibrium occurred in 50% of the test specimens (LE_{50}) at 1.1°C or less for fish acclimated to 15°C and exposed to cooling rates of 1-10°C/h. LE_{50} values for fish acclimated to 20°C ranged from 1.8-2.8°C at cooling rates of 1-10°C/h.

Coutant (1977) cited final temperature preferrenda ranging from 24.2°C for adults in spring to 28.5-32°C for large pumpkinseed. Small pumpkinseed had a final preferendum of 31.5°C (Ferguson 1958; cited in Coutant 1977). Large pumpkinseed avoided temperatures > 31°C and < 22°C in another study (Reynolds unpublished data; cited in Coutant 1977). Jobling (1981) cited work by Pessah and Powles (1974) that established an optimum growth temperature of 30°C for this species.

2.7 Yellow Perch

The following was taken from the "Merrimack River Monitoring Program Summary Report" prepared by NAI (1979a).

> Yellow perch prefer cooler water temperatures than the centrarchids, and frequently inhabit lakes and rivers with clear water, moderate amounts of vegetation and substrates of mud, sand or gravel (Scott and Crossman, 1973). Hooksett Pond affords all these habitat characteristics.
>
> Spawning occurs between 2° and 14°C (Muncy, 1962; Brazo, 1973), but is optimal at 7.8 to 12.2°C (U.S. Fish & Wildlife Service, 1970). The National Technical Advisory Committee (1968) recommends 20°C as the maximum temperature compatible with successful egg development. Eggs are spawned in a ribbon-like egg mass over submerged vegetation. Upon hatching, the larvae are positively phototactic and pelagic; generally they cannot sustain themselves against wind-generated currents. These larvae could be subject to entrainment during this pelagic phase, but have not been observed in Hooksett Pond entrainment samples. The larvae become substrate oriented when they attain 25 to 40 mm total length.
>
> Larval yellow perch prefer temperatures of 20 to 24°C (Mount, 1969; Ross et al., 1977). Juvenile temperature preferenda are typically 20 to 25°C (Ferguson, 1958), although Barans and Tubb (1973) reported thermal preferences during the autumn to be as high as 31°C (Figure 8-7).
>
> The preferred temperature of adult yellow perch is 20 to 21°C. Adult yellow perch tend to avoid thermal outfalls during the summer (Neill, 1971; Neill and Magnuson, 1974), but may congregate in thermal effluents during the winter and spring (Marcy, 1976b; Marcy and Galvin, 1973).
>
> Modal seining temperatures for Hooksett Pond yellow perch were 21-25°C from 1974-1977 and 27.7-29.9°C in 1978, although this species was captured from waters as warm as 34°C (Figures 8-7 and 8-8). The 1978 thermal mode reflects the warmer thermal preference of juveniles; most of the yellow perch contributing to this thermal mode were juveniles collected at Station 0-W [sic; western side of river at Station Zero]. This distribution pattern may be related to habitat as well as thermal preference. Adults appeared to prefer the cooler waters north and south of the discharge canal.
>
> Yellow perch were used in thermal toxicity studies from 1975 through 1977 to determine if the Merrimack Station cooling-water discharge was acutely toxic to this species. Two of the eight series indicated significantly higher (α=.05) mortality at the

discharge canal mouth than at the ambient river locations (Table 8-3). An apparent chemical discharge from Merrimack Station during the third 1975 test series induced total mortality among the experimental fish (Appendix Table E-7; see also discussion on page 87, paragraph 1). The other significant mortality difference occurred during the third 1976 series, when 63% of the discharge canal perch died, but none of the yellow perch at the control site died (Appendix Table E-8). It was inconclusive whether this mortality was the result of thermal stress because the maximum discharge temperature (24°C) during this test series was within the acceptable thermal range for yellow perch (Ferguson, 1958; Barans and Tubb, 1973). In addition, the relevance of this mortality may be questioned because the fish were artificially confined within a region that, under normal circumstances, the perch probably would have left when thermal conditions became deleterious. The absence of adult yellow perch in the vicinity of the discharge canal mouth during the summer attests to this ability.

Back-calculated lengths at annulus formation were calculated for yellow perch collected from 1975 through 1978 and compared to pre-operational growth rates (appendix Table E-12). Age 0+ yellow perch grew faster during post-operational years, but growth rates subsequently declined in the older fish. Yellow perch growth rates are extremely variable, depending on population size, habitat and productivity (Scott and Crossman, 1973). Increased growth rate among the younger age classes may reflect changes in population size or habitat (e.g., temperature), whether natural or artificially induced. Faster growth may induce the onset of maturity at an earlier age than before, and thus slow the growth during successive years. This cannot be verified by existing data, however, because the age at maturity was not examined. Growth rates also appeared to be faster downstream of Merrimack Station during the first summer, but this difference was minimal during successive years.

Length-weight relationships of yellow perch from 1972 to 1978 indicate no long-term decreases in condition or consistent variations in condition of perch captured upstream and downstream of Merrimack Station (Appendix Table E-15).

The figures referred to above as Figures 8-7 and 8-8 are presented as Figures 2-7 and 2-8 herein; other tables and figures referred to by the NAI discussion are not included in this report. References cited in the above discussion may be found in Section 8.2.

Hokansen (1977) provided a comprehensive review of temperature requirements of percids including yellow perch. Hokansen (1977) provided evidence that yellow perch require rising temperatures during development and

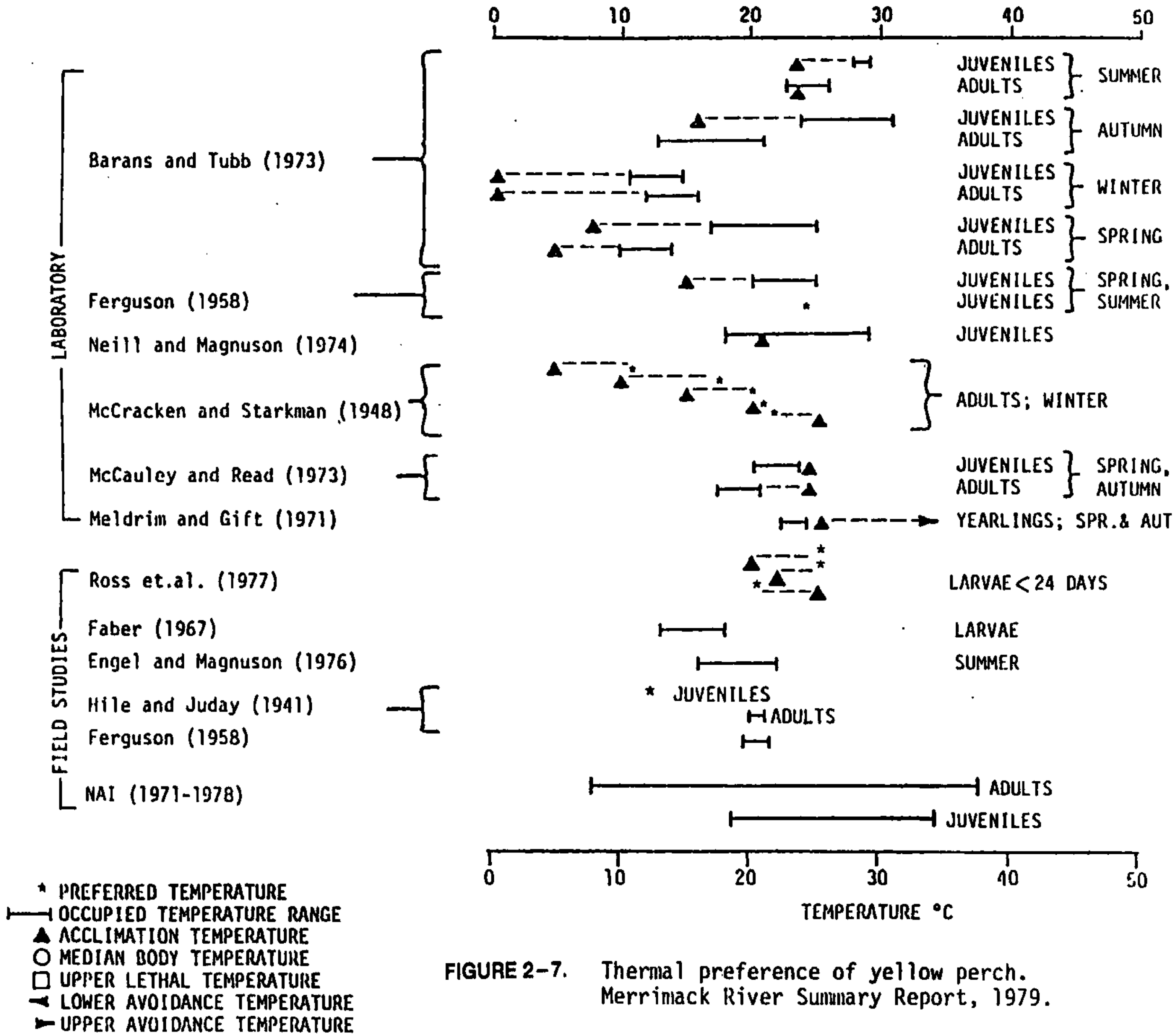


FIGURE 2-7. Thermal preference of yellow perch. Merrimack River Summary Report, 1979.

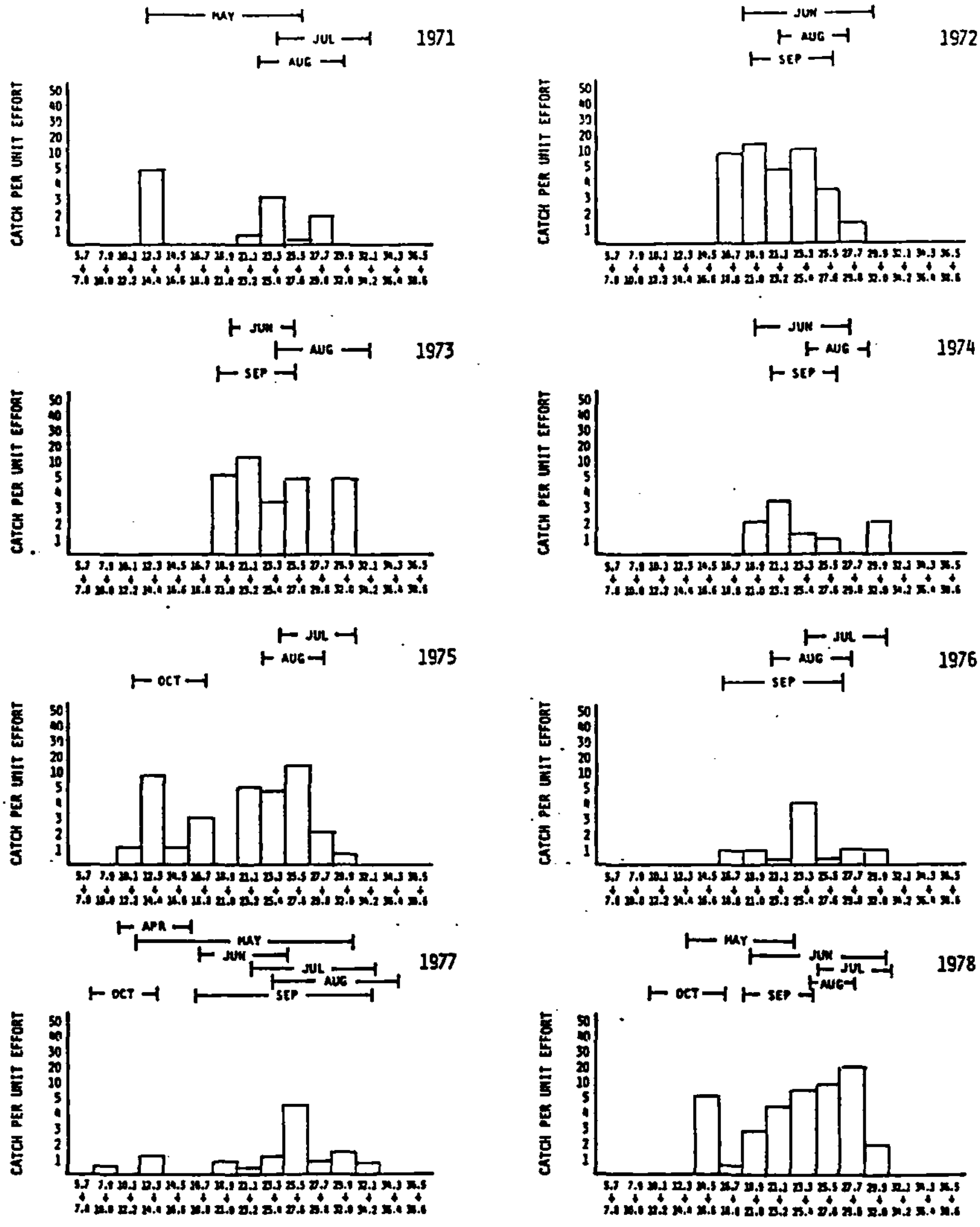


FIGURE 2-8. Catch per unit electrofishing effort (1971 to 1976) and seining effort (1977 and 1978) per 2.2°C (4°F) interval for yellow perch. Merrimack River Summary Report, 1979.

that as development proceeds the upper median tolerance limit (TL_{50}) increases. He cited lower and upper TL_{50}'s of 3.7-21°C for early embryos, 7.0-22.9°C for late embryos, and a lower TL_{50} of 9.8°C for production of swim-up larvae. This is consistent with temperature rises expected during the 2-3 week period reported by Ney (1978) as typically being required for incubation. Hokansen (1977) noted that newly hatched larvae acclimated at 18°C tolerated a temperature range of 3-28°C although the larvae became inactive at 5.3°C. In a review of a number of studies Hokansen (1977) found ultimate UILT's for larger juveniles and adults to be 29.2-32.3°C for test durations between 12 and 24 hours. Smaller (0.5 g) juveniles had a 24-hour ultimate upper incipient lethal temperatures of 33-34°C in one study cited by Hokansen (1977). Cherry et al. (1977) found the maximum 7-day temperature for 100% survival of hatchery reared juvenile perch with fork lengths of 30-50 mm to be 26°C.

Jobling (1981) cited a range of optimum growth temperatures of 23-28°C and final temperature preferenda of 20.1-24.2°C. Coutant (1977) reported temperature preferenda ranging from 7-14.1°C for adults and 10-13°C for YOY in winter to 25-28°C for adults and YOY in summer and fall. Hokansen (1977) noted that perch must be exposed to temperatures of less than 10°C during the winter in order for gonads to mature properly.

Behavior of perch near thermal plumes was studied by Kelso (1976) during the spring and by Ross and Siniff (1982) and Ross and Winter (1981) during the winter. Kelso found that perch entered the plume for brief periods only. Their behavior (swimming speed and turning frequency) was altered by proximity to the discharge; however, this may have been due to the presence of current as fish behaved similarly when discharge temperature was the same as ambient temperature (Kelso 1976). During winter perch in the vicinity of a thermal plume moved freely into and out of the plume (Ross and Winter 1981) and exposure to high temperatures was transitory (Ross and Siniff 1982). The average temperature experienced by perch in the vicinity of the thermal plume during winter was generally within the chill range required for production of viable eggs despite the availability of temperatures up to 15°C (Ross and

Siniff 1982). Ross and Siniff also cited other studies that indicated that exposure to thermal plumes had "little if any effect on gametogenesis."

2.8 Discussion

The literature on temperature requirements and upper thermal tolerances of the target species is voluminous and somewhat confusing. For example, the range in reported UILT's for alewives and yellow perch overlaps the reported range in preferred temperatures for these species. Discrepancies between studies can be attributed to a number of factors such as seasonality in temperature requirements of some species and external sources of stress on laboratory specimens that tend to exaggerate the reaction to thermal stress in some mortality studies (Cotto, et al. 1976, McCAuley and Binkowski 1982). Thermal preferences based on field observations or collections may be different from preferences reported in laboratory studies because factors other than temperature influence distribution in natural settings.

Despite these problems in interpreting the information available, the following general observations can be made concerning thermal tolerances of the target species:

- The adult life stages of all species except Atlantic salmon appear to prefer summer temperatures near or higher than maximum ambient temperatures that occur in the Hooksett Pool (i.e., 25-29°C).

- In some years, Adult Atlantic salmon would not be expected to survive for prolonged periods at maximum summer ambient temperatures in the Hooksett Pool (UILT's in the 27-29°C range).

- Juvenile alewives and shad appear to have similar thermal tolerances (UILT's in the low 30°C range), although alewives may be able to tolerate slightly higher temperatures.

- Yellow perch are more sensitive to high temperatures than other resident target species (UILT's in the low 30°C range).

- Resident target species may be ranked in order of increasing tolerance of high temperatures as yellow perch, smallmouth bass (UILT's around 35°C), largemouth bass (UILT's in the 35-37°C range), and pumpkinseed (reported UILT's in the mid to upper 30°C range and commonly collected in the discharge canal at temperatures up to 35°C).

- Resident target species' reported thermal preference ranges from the literature corresponded with field data on modal temperatures at which those species were captured during fish sampling.

- All resident target species were collected in the Hooksett Pool at temperatures above their reported preference range and yellow perch were collected from areas at temperatures above their reported UILT.

- Adults and young of all target species sense and avoid potentially lethal temperatures when placed in a temperature gradient.

The data available on the ability of most target species to tolerate rapid increases in temperature is relatively complete for some target species and limited for others. Most of the reported laboratory studies may tend to underestimate the range in temperature that can be tolerated because most studies do not attempt to simulate the sequence of temperature exposures that would be typical of fish passing through the warmest part of the thermal plume (i.e., a rapid increase in temperature followed by cooling as the fish seeks out cooler temperatures or drifts downstream).

The information available on target species response to rapid temperature decreases in the laboratory is limited or lacking for most target species. Some behavioral studies of resident target species' response to thermal plumes in winter are available and will be used to supplement discussions of species cold shock tolerance in a subsequent section addressing the need for winter temperature restrictions.

3.0 PART I.17.a: ANADROMOUS FISH RESPONSE TO THE THERMAL PLUME

Determine the seasons at which the anadromous fish will migrate and the temperatures that would affect/impede this migration and life cycle temperature requirements related to each species.

Anadromous fish that may be expected to occur in the vicinity of Merrimack Station include American shad, alewife, Atlantic salmon, sea lamprey and, potentially, blueback herring. Of these anadromous species American shad is the only one expected to spawn in the river mainstem in the vicinity of Merrimack Station. There is no spawning and nursery habitat for Atlantic salmon in the Hooksett Pool. Alewife, blueback herring and sea lamprey typically spawn in smaller tributaries. Thus, analysis of thermal effects should consider all life stages of shad, late juvenile and migratory stages of alewife, and migratory stages of Atlantic salmon. Blueback herring and lamprey are not considered because they have thermal tolerances similar to those for the other anadromous species and they are not likely to occur in large numbers in the foreseeable future.

3.1 Migration Seasons

Anadromous fish migration seasons are summarized in Table 3-1. The information used in determining the migration seasons is discussed below.

3.1.1 Upstream Fish Passage Operation

Migration of anadromous fish into the Hooksett Pool of the Merrimack River is controlled by fish passage facilities at three hydroelectric developments and by flashboard status and river flow at the Hooksett dam. Operation of fish passage facilities on the river is determined by river flows and water temperatures in the spring. There are no fish passage facilities at the Hooksett dam. Alewives have been observed passing over the dam at the west end of the Hooksett dam spillway during periods when there is 1.5 feet or more of spill before flashboards are installed. Fish passage facilities will be installed at the Hooksett dam within 5 years

TABLE 3–1.
MIGRATION SEASONS FOR ANADROMOUS FISH EXPECTED IN THE VICINITY OF MERRIMACK STATION

SPECIES		TEMPERATURE	
LIFE STAGE	DIRECTION	RANGE (C)	PERIOD
AMERICAN SHAD			
ADULT	UPSTREAM	10–24	MAY–JUNE
ADULT	DOWNSTREAM	SUMMER AMBIENT	JUNE–JULY
JUVENILE	DOWNSTREAM	26–6	SEPTEMBER–OCTOBER
ALEWIFE			
ADULT	UPSTREAM	5–24	MAY–JUNE
ADULT	DOWNSTREAM	SUMMER AMBIENT	JUNE–JULY
JUVENILE	DOWNSTREAM	26–6	SEPTEMBER–OCTOBER
ATLANTIC SALMON			
ADULT	UPSTREAM	<24	MAY–JULY
ADULT (minor)	upstream	<24	August–October
ADULT	DOWNSTREAM	4 – 15	APRIL–MAY
ADULT (minor)	downstream	10 – 4	October–December
SMOLT	DOWNSTREAM	8 – 20	APRIL 15 – JUNE 15

NOTE: Period describes the time at which migration would be expected during most years. A negligible proportion of the population may migrate outside of the period described in some years.

following passage of 15,000 American shad at the Amoskeag dam. It is highly unlikely that this threshold will be reached during the life of the present NPDES permit as a maximum of 12 shad has passed the Amoskeag fish ladder during any season since it began operation in 1989 and numbers passing the first dam on the river have rarely exceeded 20,000.

As a practical matter, it is unlikely that sea-run adult Atlantic salmon will intentionally be provided with access to the Hooksett Pool until fish passage facilities are completed at Garvins Falls. This will occur within 5 years following passage of 15,000 American shad at Hooksett dam (i.e., at least 10 years following passage of 15,000 shad at Amoskeag). In the interim, most sea-run salmon will be captured at the fish trap at Essex dam and transferred to hatchery facilities until hatchery capacity is reached (approximately 350 adults). Sea-run salmon captured at either Essex dam or Amoskeag dam will then be trucked either to the Merrimack River above Garvins Falls or to the Pemigewasset River above the Ayers Island dam in Bristol once hatchery requirements are satisfied. Trucking of salmon to the Merrimack above Garvins Falls is probably contingent on completion of a trap-and-truck facility at Eastman Falls dam, which will occur within two years after 50 sea-run salmon reach Amoskeag dam. The likely route of inadvertent introduction of adult sea-run Atlantic salmon to the Hooksett Pool would be through "drop-back" of fish trucked above Garvins or by escapement of adult salmon past the trap facilities at both Essex and Amoskeag prior to installation of flashboards at Hooksett. Once flashboards are installed at Hooksett (which usually occurs in early June - during the period when salmon would be trapped for hatchery facilities), it is unlikely that salmon could jump the dam. Both scenarios are considered unlikely. Concern over thermal plume effects on migrating salmon, therefore, seems premature by at least a decade.

3.1.2 Adult Upstream Migration and Spawning

Adult American shad begin their upstream migration later than alewives. Leggett (1976) noted that in the Columbia and Connecticut Rivers 90% of the shad migration occurs within a narrow temperature range of about 4-4.5°C. At Holyoke dam on the Connecticut River the bulk of the shad migration occurred at temperatures between 16.5 and 21.5°C. Thus the bulk of the adult shad migration in the Merrimack River, based on weekly temperature sampling data for Merrimack Station (NAI 1979a) would be expected to occur in late May and early June. Cheek (1968) stated that spawning is complete by the time water temperatures reach 24°C. Data for the Holyoke fish lift indicate that over 99% of the run is passed by the end of June, although some fish may be passed during July in some years (Scherer 1974, Foote 1976; Reed and Russo 1976, 1977; Reed and Saunders 1978, Saunders et al. 1980). Observed temperatures in the Merrimack River indicate that the upstream adult migration would also be completed by the end of June.

American shad may begin to spawn at temperatures as low as 12°C (Scott and Crossman 1973). Peak spawning occurred at temperatures ranging from 14.8°C to 22°C in the lower Connecticut River (Marcy 1976b). Temperatures below 16°C result in reduced viability of eggs (Marcy 1976b). Peak spawning would be expected to occur in the Hooksett Pool from late May to late June based on weekly temperature data (NAI 1979a).

Although some adult alewife spawning runs may commence when water temperatures exceed 5°C (Loesch 1987), Alewife runs on the Parker River in Massachusetts usually begin in mid-April when water temperatures exceed 11°C (Beltz 1975). The operation of Merrimack River fish passage facilities usually begins in late April at earliest due to high river flows. The fish passage facilities are usually scheduled to begin operation sequentially, with the Essex dam facility in Lawrence, MA opening first; the Pawtucket dam facility in Lowell, MA opening one week after Essex; and the Amoskeag dam in Manchester, NH opening one week after Pawtucket. Thus, the earliest that any anadromous fish would be expected to have access to the Hooksett Pool would be sometime in early to mid-May.

Peak alewife spawning occurred at temperatures between 7 and 10.9°C in the lower Connecticut River, based on abundance of eggs collected in ichthyoplankton tows (Marcy 1976c). Bigelow and Schroeder (1953) reported that alewife spawn at temperatures between 12.8 and 15.6°C. Information presented in Carlander (1969) indicates that alewives spawn at temperatures up to 22°C. The timing of alewife passage at the Amoskeag dam indicates that limited numbers of fish may continue to migrate upstream to spawn through late June; however, peak passage occurs in late May to early June and the spawning run is essentially complete by mid-June. Because alewives spawn in slow flowing stream sections or ponds (Loesch 1987) suitable habitat conditions are limited in the Hooksett Pool and they are not expected to spawn in the vicinity of Merrimack Station.

Atlantic salmon enter the Merrimack River below Essex dam in Lowell from March through October (Stolte 1991). On average, approximately 95% of the run occurs in May, June and July with the peak occurring during June (Stolte 1991). Alabaster (1990) examined data for the river Dee in Great Britain and found that river flow was the major determining factor in whether salmon could be expected to enter the river. Higher flows resulted in greater numbers of salmon entering the river. The attractive effects of higher flows were reduced by rising water temperatures. Weekly average temperatures above 21.5°C caused substantial reductions in the number of fish entering the river. Alabaster also discussed the results of several other studies which seem to indicate that salmon will not enter a river and move upstream when ambient temperatures reach 24-24.9°C.

Atlantic salmon spawn in October and November (Scott and Crossman 1973). Eggs are deposited in deep clean gravel where there is sufficient current. No suitable spawning habitat exists in the Hooksett Pool and summer peak ambient temperatures could potentially result in high mortality of adult salmon in the Hooksett Pool prior to spawning if suitable habitat were available.

3.1.3 Adult Downstream Migrations

Adult alewife and American shad migrate downstream shortly after spawning (Scott and Crossman 1973). Such migrations may be expected to occur from late May through July, primarily in June and July, in the Merrimack River above Amoskeag dam.

Atlantic salmon may either migrate downstream immediately following spawning in November and December or remain in the river until the following spring when they migrate downstream in April and May (Mills 1989).

3.1.4 Juvenile Downstream Migrations

Marcy (1976b) observed that larger juvenile American shad in the Connecticut River began downstream migration in mid-August at temperatures between 26 and 23°C. Migration continued from early September through early October at temperatures between 23 and 17.8°C. Smaller juveniles migrated later in the season at temperatures between 17.8 and 10.9°C. Juvenile shad emigration from the Connecticut River above Holyoke dam was essentially complete when temperatures reached 10°C (Watson 1970). Normandeau Associates Inc. (NAI) observed juvenile shad downstream migration in the Hooksett Pool of the Merrimack River at temperatures between 17 and 10.4°C (NAI 1979b). Marcy (1976c) reported that only one juvenile shad was collected at temperatures below 6°C in the lower Connecticut.

Young-of-the-year (YOY) alewives tend to remain on the spawning grounds until at least the late larval stage (Scott and Crossman 1973). They move into deeper water in late summer. Marcy (1976a) observed peak catches of juvenile river herring (including alewives and blueback herring) in the lower Connecticut River in August. Numbers declined from September through November. No fish were caught after temperatures dropped to 5°C. Observations on emigrating alewives in the Merrimack River at Garvins Falls dam (PSNH unpublished data) indicated that most emigration of alewives from Lake Winnisquam occurred in late September and October.

Atlantic salmon smolts may begin downstream movements at temperatures as low as 2-3°C (Hesthagen and Garnas 1986); however, most studies have reported that the majority of smolt migration begins at temperatures around 10°C (Mills 1989). Saunders (1992) observed that most downstream movements by radio tagged hatchery smolts in the Pemigewasset River occurred in early May when temperatures were in the 8-10°C range. Saunders and Mudre (1988) observed that wild smolt passage peaked in the latter part of

May at Bellows Falls dam on the Connecticut River. In 1992 wild smolts were captured in a trap located at the downstream bypass at Garvins Falls dam from mid-May (when trap operation commenced) until early June when daily minimum water temperatures exceeded 20°C. Wedemeyer et al. (1980) observed that desmoltification occurred rapidly when temperatures exceeded 18°C. McKeon (1991) captured very few wild smolts at a trap on the Pemigewasset River after the first week in June, 1990 when temperatures exceeded 18°C. Based on this information, it appears that smolt movements past the Merrimack Station may begin as early as mid-April, will peak during May, and will be substantially complete by mid-June.

3.2 Temperatures Affecting/Impeding Migrations

Migrations may be affected by temperatures associated with the thermal plume in two ways. First, fish may be prevented from migrating upstream or downstream if the thermal plume presents an area where temperatures are high enough that fish will avoid passing through it. To prevent passage in this instance, the plume must occupy enough of the water column vertically and horizontally so that fish will not seek to pass around it. Second, fish, particularly fall migrants, may be attracted by the warm water and fail to complete their migration before conditions become unfavorable for survival.

Temperatures play a key role in determining anadromous fish migration seasons in any water body. Table 3-1 was developed using literature information on the temperatures at which the anadromous target species life stages migrate in the river. These temperature ranges were translated into the typical annual migration periods using temperature information for the Merrimack River. Typically, when ambient water temperatures are outside the reported temperature range the numbers of fish migrating past any point in the river will be substantially reduced. After a prolonged (e.g., 1-2 weeks) period of temperatures outside the range, migration will cease. The migration periods described in Table 3-1 encompass the temperature range for migration. Water temperature conditions in any given year will tend to cause the bulk of the migration to occur earlier or later within a migration period. The migration periods provide the basis for a description of flow conditions that typically occur during migration. Flow conditions during the migration season will be discussed relative to thermal plume configuration in Section 4.0.

3.2.1 American Shad

Adult shad migration through the thermal plume area at the Connecticut Yankee Nuclear Power Station was studied by Leggett (1976) using ultrasonic telemetry. Of 27 shad released 9 did not pass through an area affected by increased temperatures during their upstream migration past the discharge canal. Of the remaining 18, all but two passed the station without appreciable delay. These fish were released under ambient water temperature conditions ranging from 15-20.5°C. The maximum ΔT recorded in the areas through which the fish passed was 5°C and the maximum temperature 24.5°C. The temperatures to which the fish were actually exposed is unknown as depth could not be determined.

In June 1978 NAI released 13 radio tagged American shad into the Hooksett Pool below Merrimack Station. Daily mean ambient temperatures ranged from 17.7 to 19°C during this study. Only 4 shad exhibited upstream movement during the tracking period. All four fish passed through the thermal plume area (NAI 1979b).

Juvenile shad behavior relative to the thermal plume at the Connecticut Yankee Nuclear Power Station was studied by Marcy (1976b). Juvenile shad will avoid temperatures in excess of 30°C. Rapid temperature increases to 32.2°C resulted in mortality of YOY shad drifted through the plume in live cages. In additional tests Marcy (1976b) found that juvenile shad sensed the temperature gradient and moved downward out of the area of potentially lethal temperatures. Sampling of the thermal plume and discharge canal at the Connecticut Yankee Nuclear Power Station (12°C maximum ΔT) indicated that juvenile shad were not present in the thermal plume when ambient temperatures in the fall decreased below the range reported for migration.

3.2.2 Alewife

No information dealing directly with the effects of thermal plumes on migrating anadromous alewives was found. The timing of adult alewife migration indicates that during the early part of the season they may be attracted to the thermal plume if they seek warmer temperatures for spawning. This has been reported for landlocked alewives (Spigarelli et al. 1982). It may be inferred from the studies conducted by Marcy (1976a) that anadromous alewives are present in the Connecticut River when ambient temperatures approach 30°C. Juveniles do not appear to be attracted to the thermal plume at Connecticut Yankee Nuclear Power Station beyond the normal period of migration from the river.

3.2.3 Atlantic Salmon

Temperatures that impede salmon entry into rivers were discussed above (see Section 3.1.2). No information specifically regarding adult salmon behavior in thermal gradients was found. Information on smolt migration relative to thermal plumes is presented in Section 4.2.

3.3 Life Cycle Temperature Requirements

Ranges of temperatures at which the migration and spawning phases of the life cycles of the anadromous target species take place are discussed above. The American shad is the only species expected to spawn in the vicinity of Merrimack Station. A review of shad life cycle temperature requirements developed by NAI (NAI 1977a) with supplementary information was provided in Section 2.1. NAI also conducted in situ drift bioassays of shad eggs and laboratory bioassays of shad eggs and larvae. The in situ studies suggested a relationship between highest thermal plume temperatures and increased mortality of early life stages; however, because shad eggs are demersal they would not normally be exposed to maximum plume temperatures as they were when drifted through the plume at the water surface. Eggs drifted through the plume near the bottom (i.e., a more representative exposure for semi-demersal eggs) were not affected by the temperatures encountered (NAI 1977a).

Laboratory bioassays of eggs indicated that there was no significant difference in survival between test and control eggs at temperatures below 33.9°C and ΔT's less than 13.9°C. Larval survival was unaffected at temperatures below 33.3°C and ΔT's less than 12.8°C. Leggett (1976) cited several studies that indicated the optimum temperature range for egg and larval development is between 15.5 and 26.5°C. Juveniles apparently prefer temperatures of less than 30°C (Marcy 1976b). Considering the period when adults are present in the Connecticut River, eggs, larval and adults, are able to tolerate temperatures ranging up to 30°C.

4.0 PART I.17.b: THERMAL PLUME CONFIGURATION

Determination of the thermal plume-configuration in the river and its effect(s): 1) on anadromous fish during the migration seasons; and 2) upon indigenous fish under low water conditions.

4.1 Plume Configuration

Thermal cross-section data were collected regularly during the summer months as part of the NAI monitoring studies. The thermal cross-section data were reviewed and the operational conditions (river flow, ambient temperature, generator thermal output) existing during each cross section sampling were determined. Appendix A summarizes the conditions during thermal cross section sampling for all sampling dates reviewed. Several sampling dates were selected as potentially being representative of "near worst case conditions" of high ambient temperature, low river flow and both Merrimack units on line (indicated in Appendix A by shading). Station generation data for those dates were obtained and the dates on which the station was operating at near maximum capacity (approximately 440 MW) were identified. Two dates were identified that had cross section data representing low river flows and high ambient temperature conditions. On July 7, 1975 the average river discharge was 1,476 cfs, ambient water temperatures during sampling ranged from 25.7-26.4°C, station generation averaged 431 MW, air temperature ranged from 18-28°C and relative humidity was between 57 and 100%. On August 4, 1977 the average river discharge was 823 cfs, ambient water temperatures during sampling ranged from 24.6-26.3°C, and station generation averaged 406 MW. The results of the thermal cross section sampling on July 7, 1975 and August 4, 1977 are presented in Figures 4-1 and 4-2, respectively.

To determine how well the cross section data represent near worst case conditions for various life stages of the target species, flow duration curves for the Merrimack River at Merrimack Station were developed. Each flow duration curve (Figures 4-3 through 4-10) represents the season in which one or more target species life stages would be expected to occur. The usual or expected periods of occurrence for target species life stages were defined

FIGURE 4–1.
THERMAL CROSS SECTIONS (degrees F) FOR TRANSECTS SAMPLED ON JULY 7, 1975.

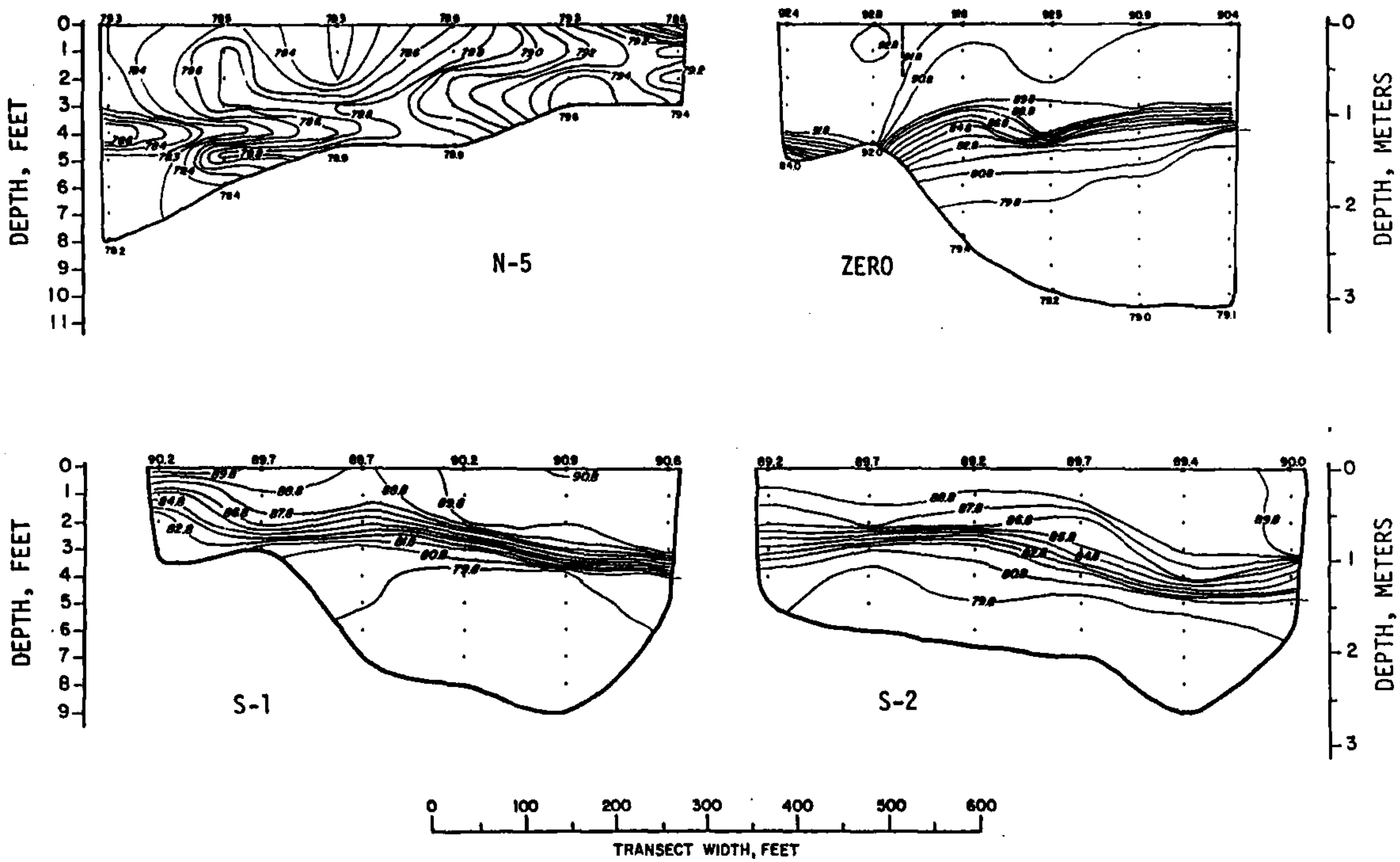


FIGURE 4–1 (continued)

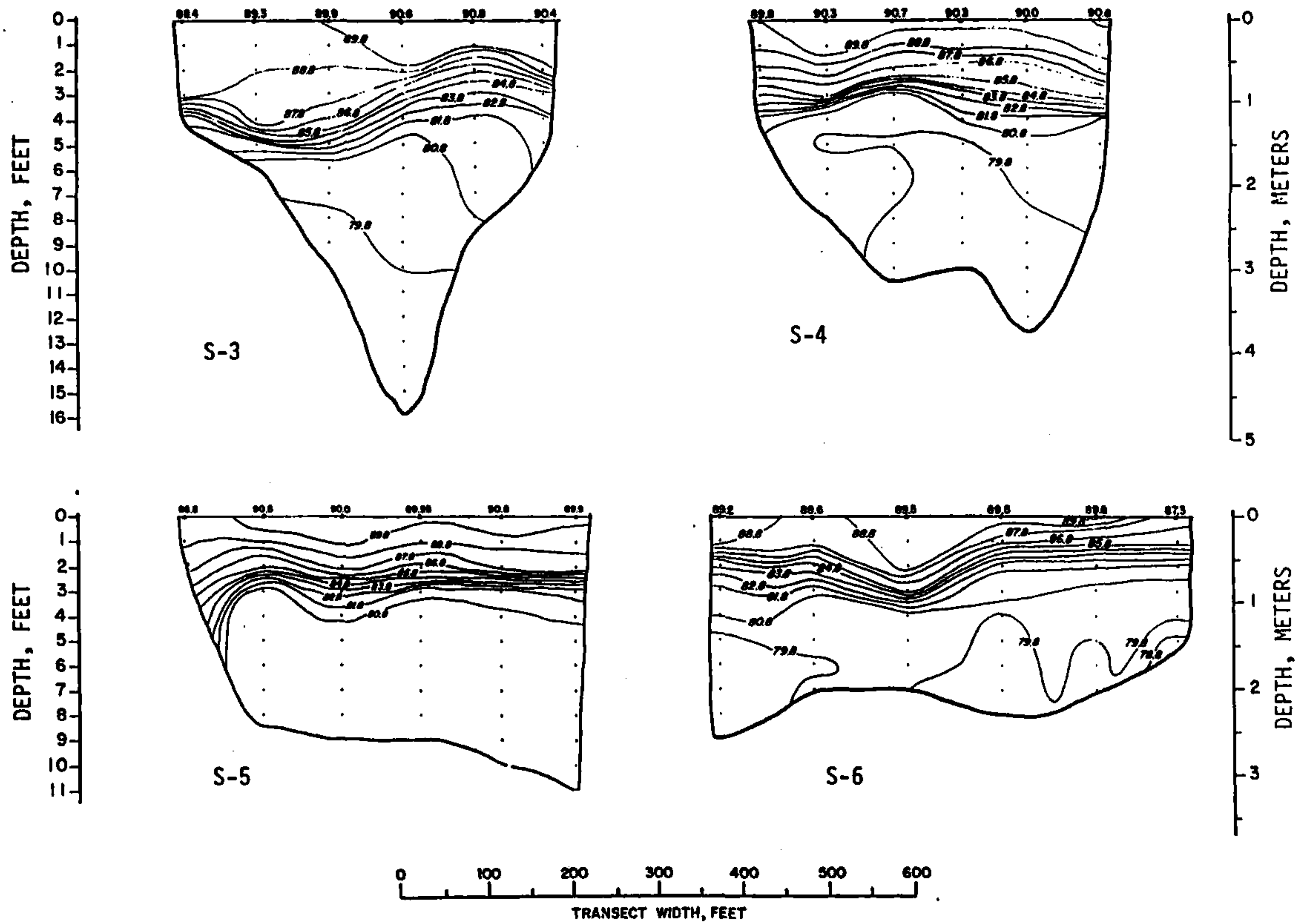


FIGURE 4–1 (continued)

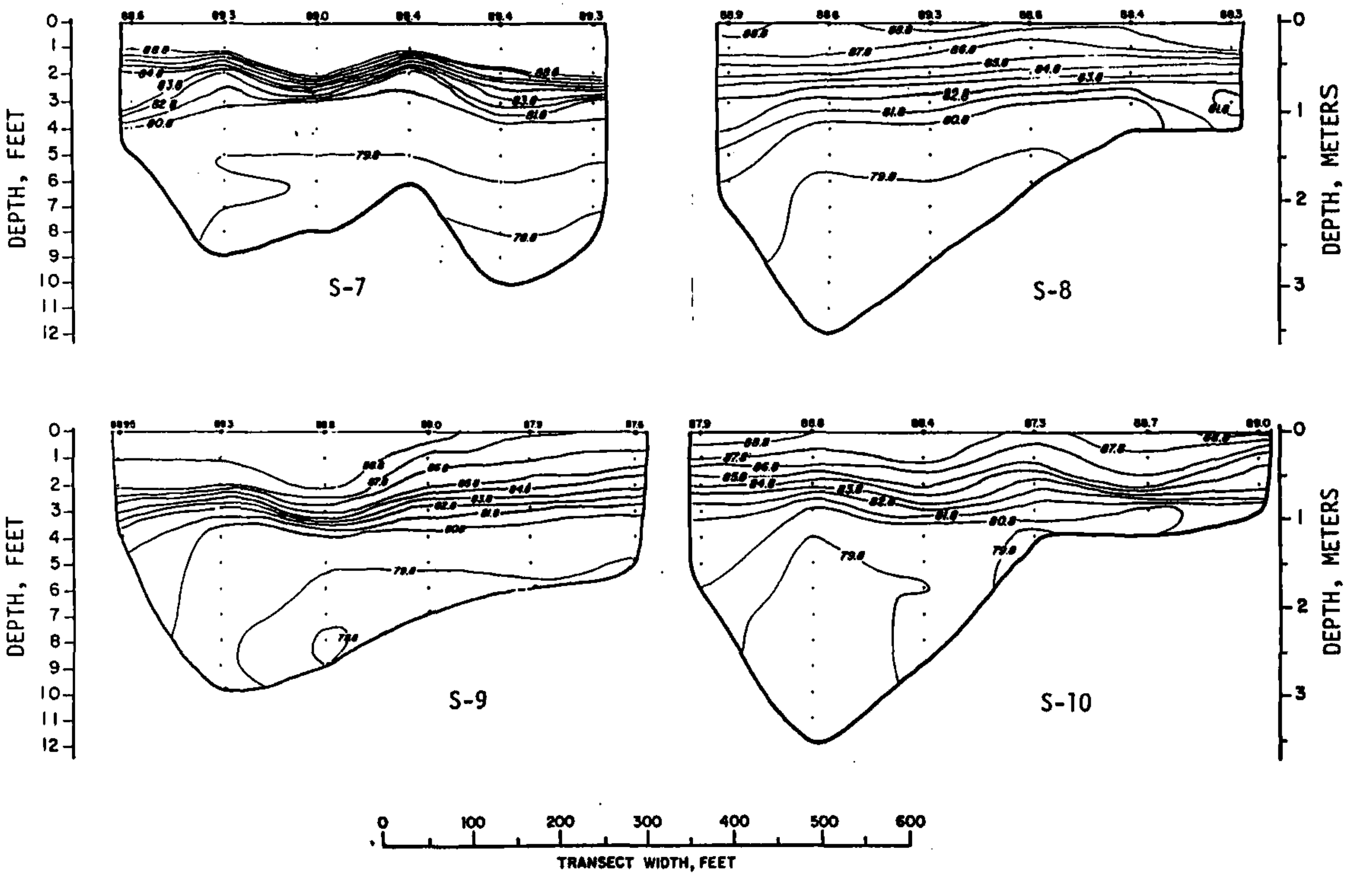
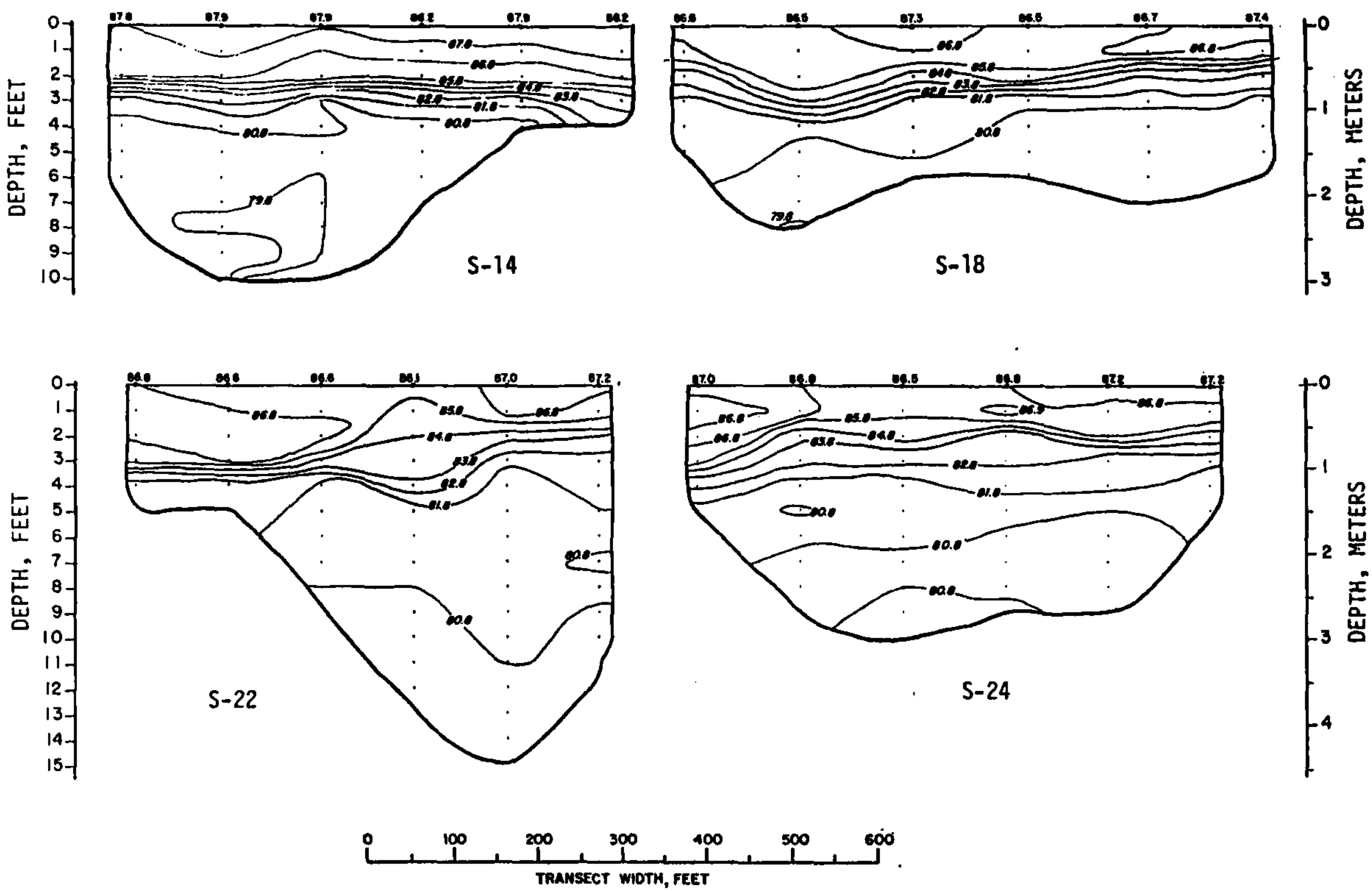


FIGURE 4–1 (continued)



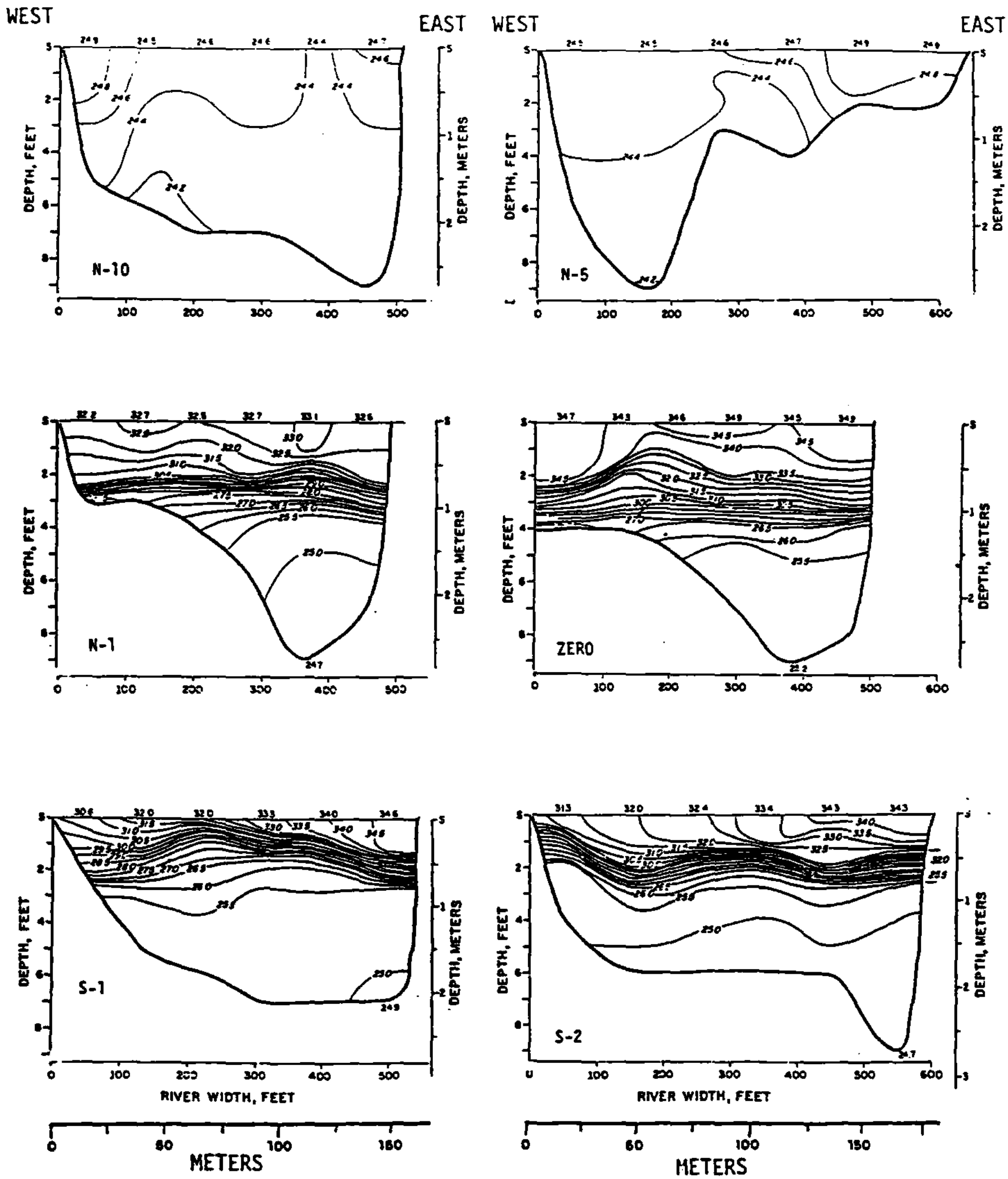


FIGURE 4–2. THERMAL CROSS SECTIONS (degrees C) FOR TRANSECTS SAMPLED ON AUGUST 4, 1977

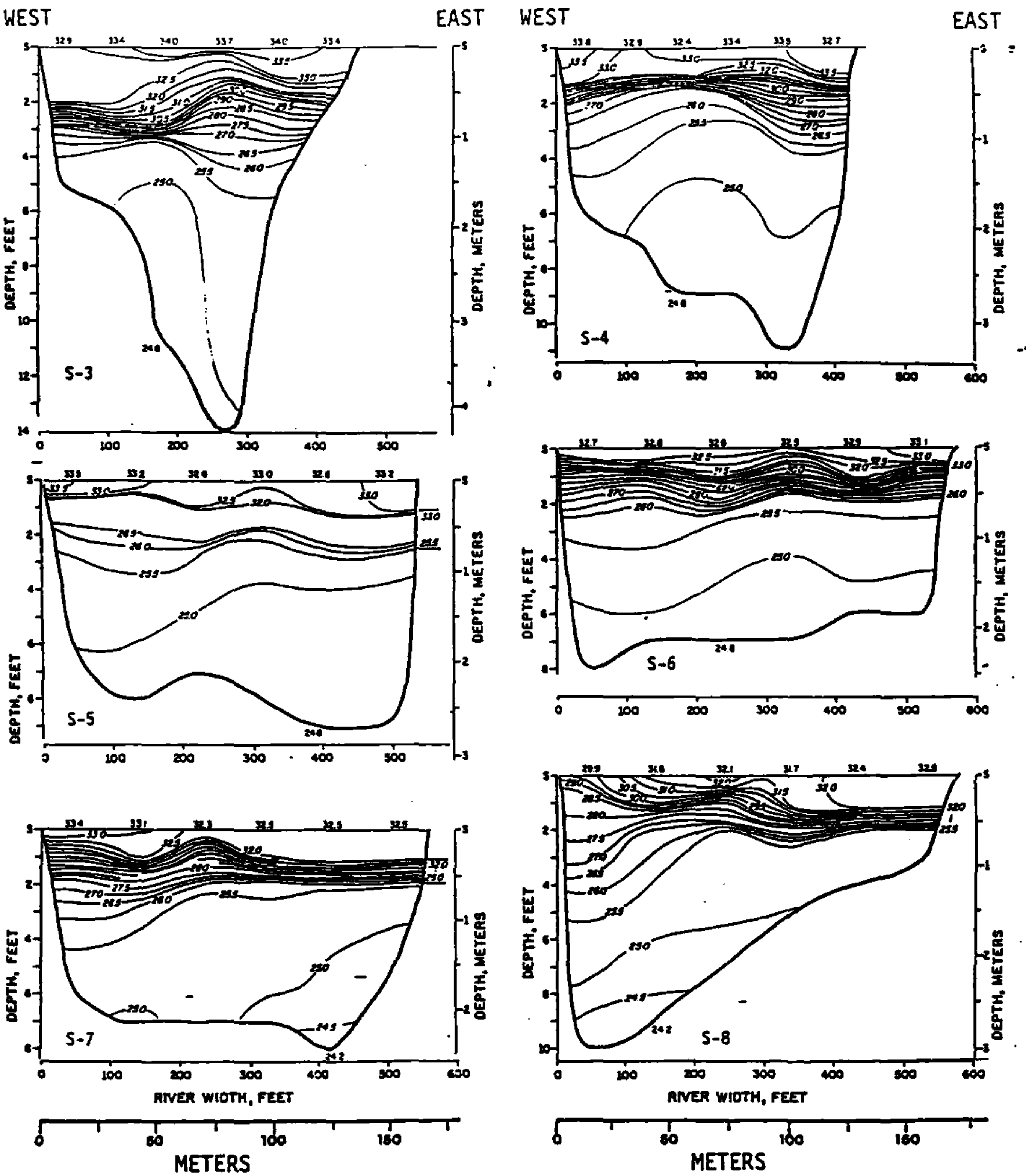


FIGURE 4–2 (continued)

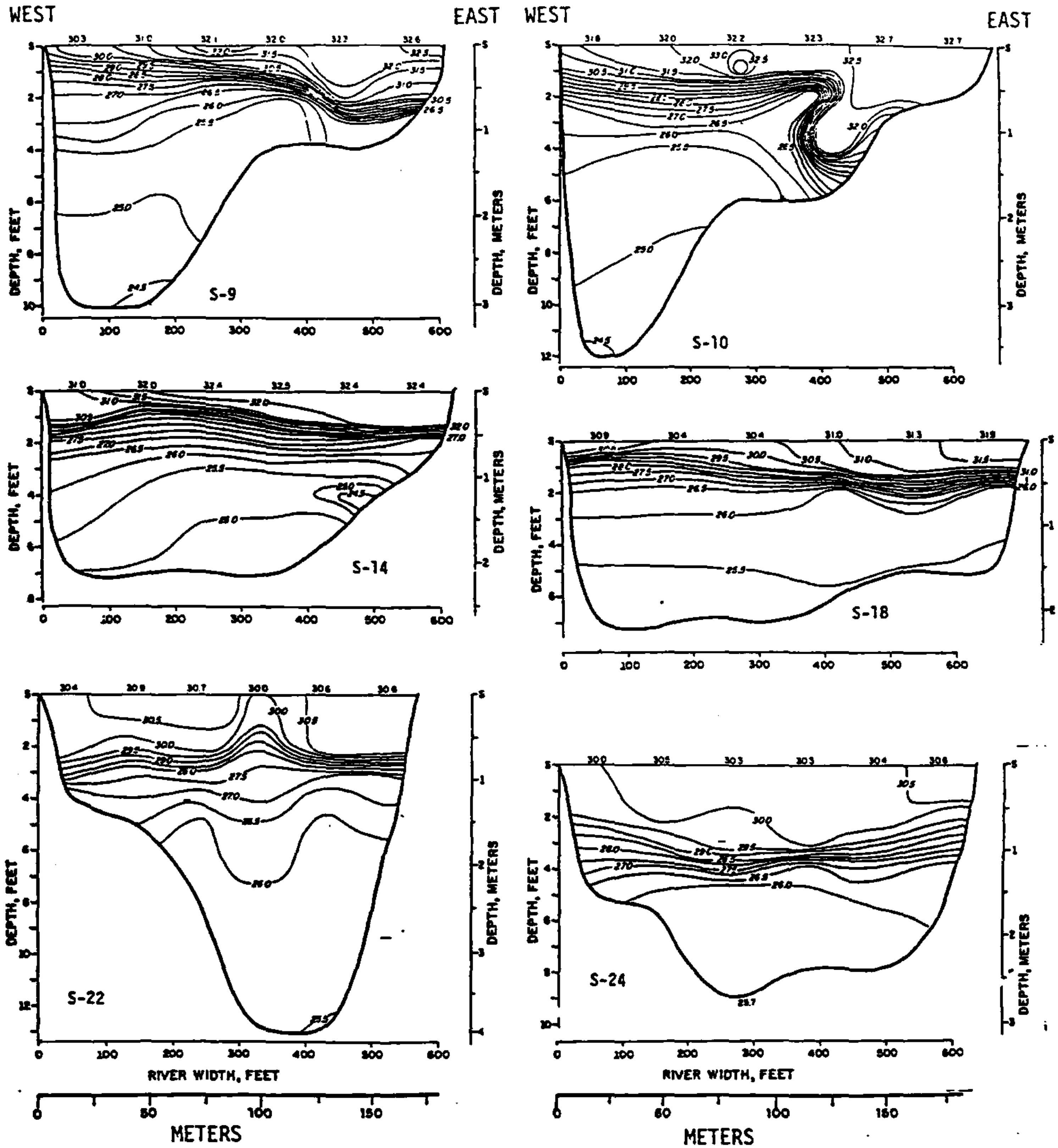


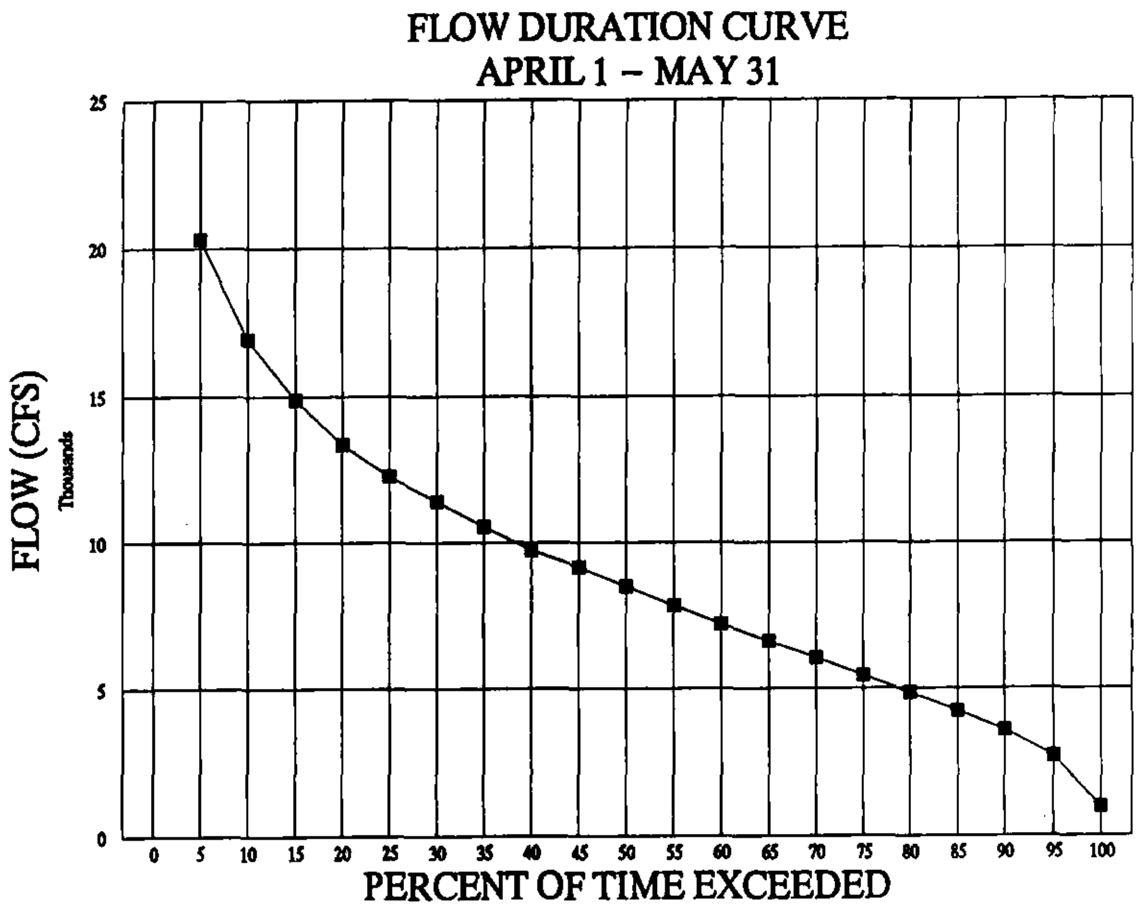
FIGURE 4–2 (continued)

FIGURE 4-3.
FLOW DURATION CURVE FOR APRIL 1 THROUGH MAY 31
MERRIMACK STATION - DRAINAGE AREA 2,535 SQUARE MILES

APRIL 1 - MAY 31
Period of record from Sept 1941 to Oct 1978.

High FLow 45,178 cfs on April 6, 1960
Low Flow 974 cfs on May 31, 1964

Percent Time Exceeded	Flow (cfs)
0	
5	20,319
10	16,905
15	14,886
20	13,366
25	12,279
30	11,408
35	10,536
40	9,726
45	9,137
50	8,496
55	7,842
60	7,207
65	6,604
70	6,059
75	5,442
80	4,853
85	4,249
90	3,589
95	2,705
100	974



The April 1 to May 31 time period applies to the following species:

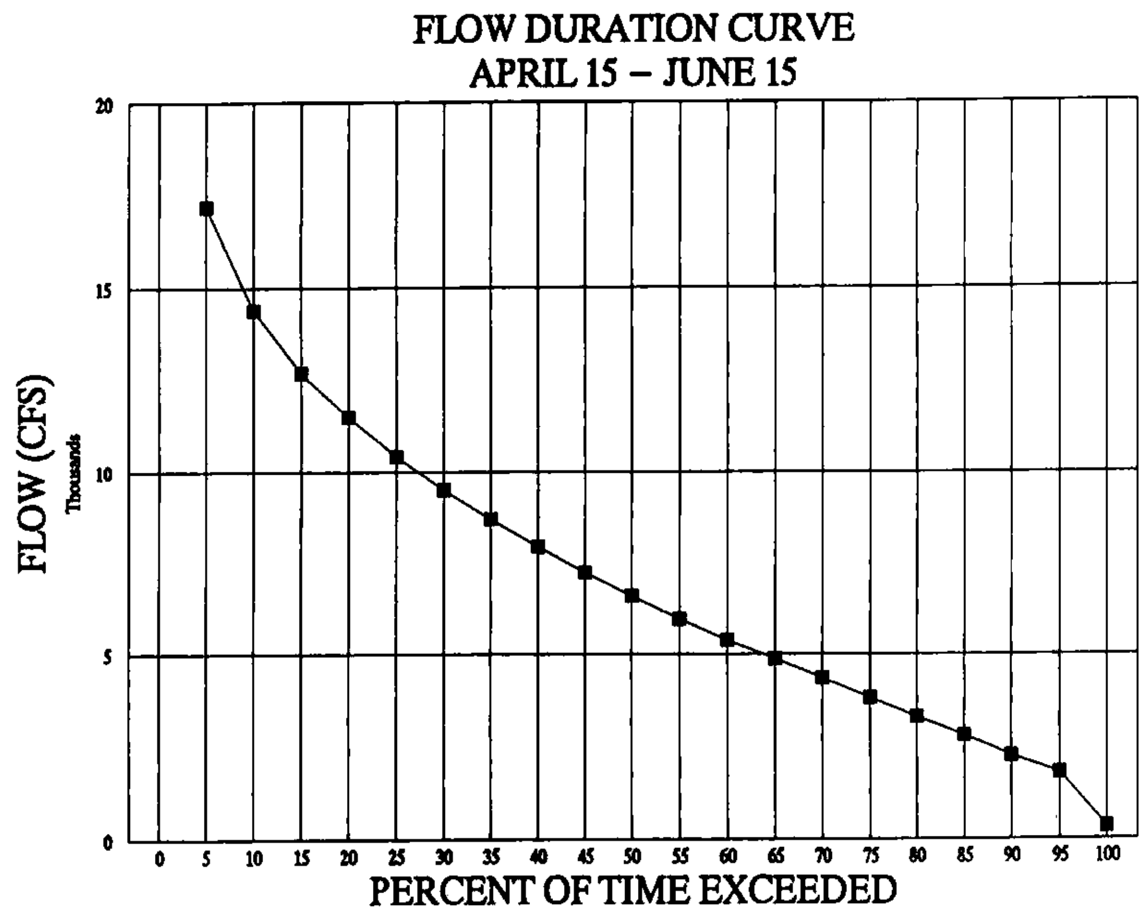
Atlantic Salmon	Adult Downstream Migration (Major)
Yellow Perch	Spawning - Incubation

FIGURE 4–4.
FLOW DURATION CURVE FOR APRIL 15 – JUNE 15
MERRIMACK STATION – DRAINAGE AREA 2,535 SQUARE MILES

APRIL 15 – JUNE 15
Period of record from Sept 1941 to Oct 1978.

High FLow 31,749 cfs on May 11, 1954
Low Flow 318 cfs on June 7, 1964

Percent Time Exceeded	Flow (cfs)
0	
5	17,197
10	14,397
15	12,715
20	11,521
25	10,420
30	9,507
35	8,708
40	7,939
45	7,223
50	6,583
55	5,952
60	5,376
65	4,873
70	4,362
75	3,816
80	3,293
85	2,785
90	2,228
95	1,775
100	318



The April 15 to June 15 time period applies to the following species:

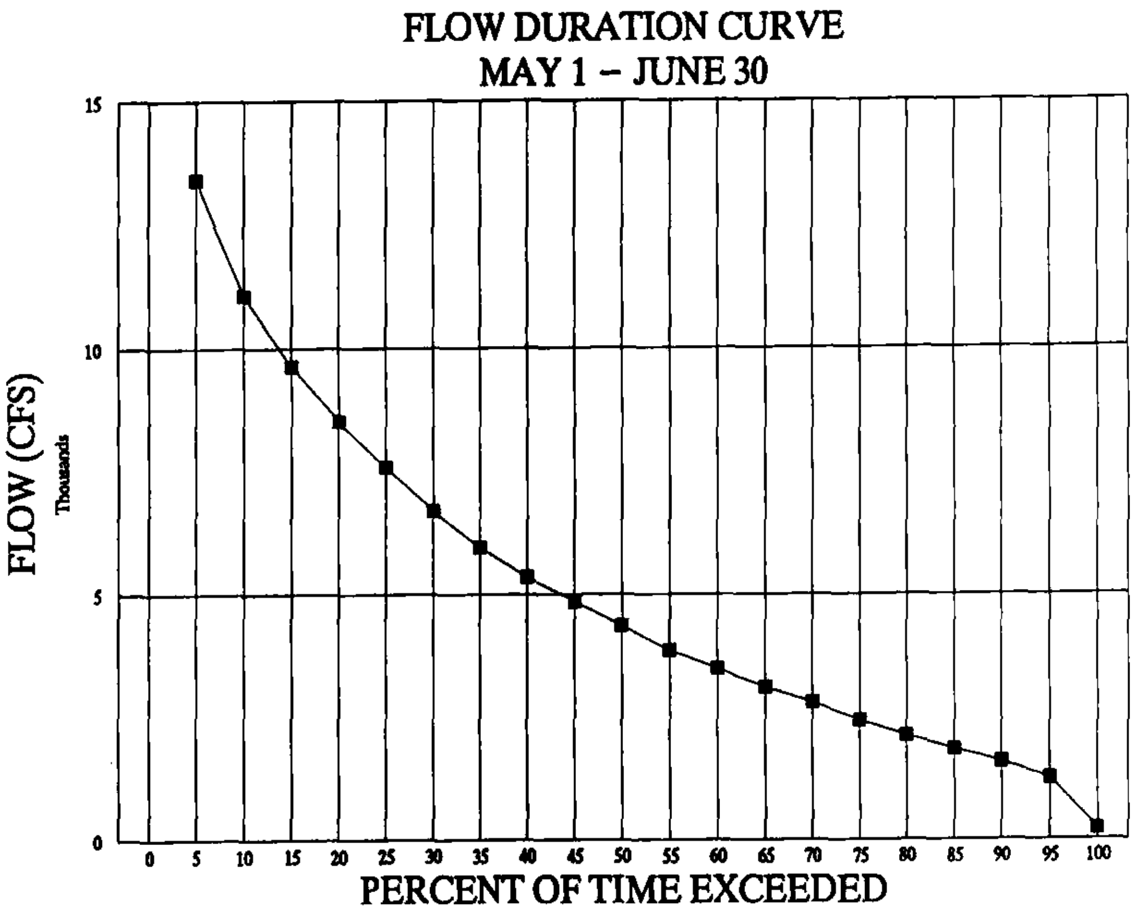
Atlantic Salmon Smolt Downstream Migration

FIGURE 4–5.
FLOW DURATION CURVE FOR MAY 1 – JUNE 30
MERRIMACK STATION – DRAINAGE AREA 2,535 SQUARE MILES

MAY 1 – JUNE 30
Period of record from Sept 1941 to Oct 1978.

High FLow 31,479 cfs on May 11, 1954
Low Flow 212 cfs on June 19, 1949

Percent Time Exceeded	Flow (cfs)
0	
5	13,420
10	11,070
15	9,642
20	8,525
25	7,584
30	6,702
35	5,957
40	5,354
45	4,851
50	4,364
55	3,848
60	3,467
65	3,095
70	2,777
75	2,417
80	2,102
85	1,829
90	1,564
95	1,234
100	212



The May 1 to June 30 time period applies to the following species:

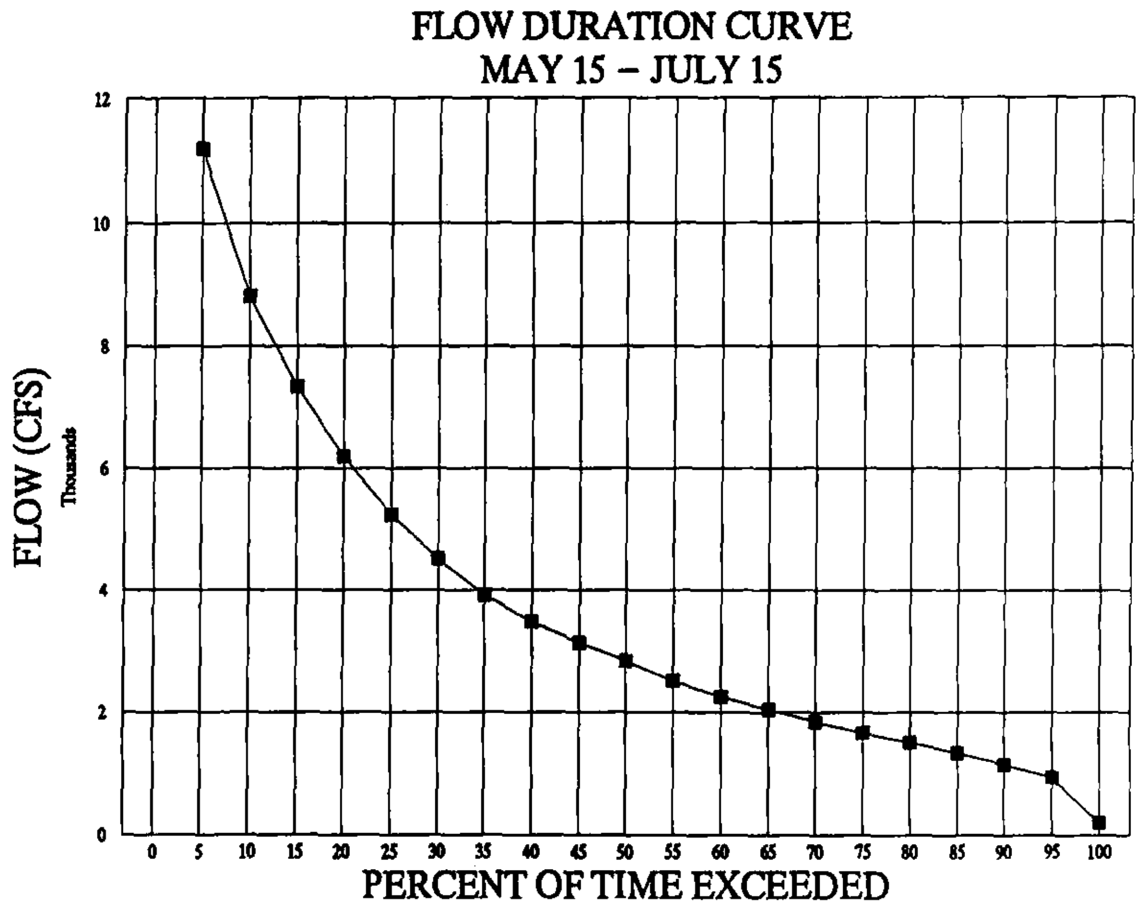
American Shad	Adult Upstream Migration
Alewife	Adult Upstream Migration
Yellow Perch	Pelagic Larvae

FIGURE 4-6.
FLOW DURATION CURVE FOR MAY 15 – JULY 15
MERRIMACK STATION – DRAINAGE AREA 2,535 SQUARE MILES

MAY 15 – JULY 15
Period of record from Sept 1941 to Oct 1978.

High FLow 25,816 cfs on June 26, 1944
Low Flow 212 cfs on June 19, 1949

Percent Time Exceeded	Flow (cfs)
0	
5	11,191
10	8,804
15	7,345
20	6,187
25	5,236
30	4,513
35	3,913
40	3,480
45	3,128
50	2,842
55	2,514
60	2,259
65	2,045
70	1,847
75	1,677
80	1,515
85	1,343
90	1,161
95	947
100	212



The May 15 to July 15 time period applies to the following species:

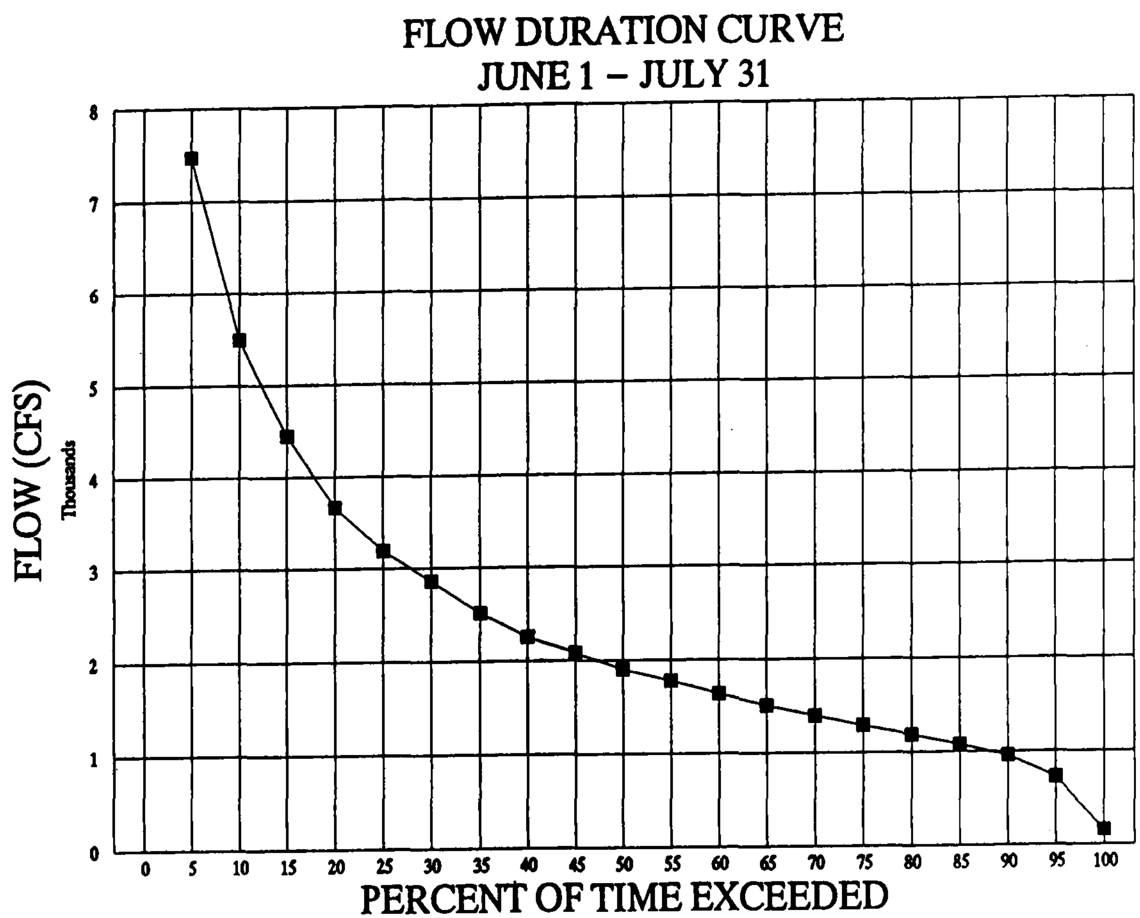
Smallmouth Bass Spawning – Incubation – Early Fry

FIGURE 4-7.
FLOW DURATION CURVE FOR JUNE 1 - JULY 30
MERRIMACK STATION - DRAINAGE AREA 2,535 SQUARE MILES

JUNE 1 - JULY 31
Period of record from Sept 1941 to Oct 1978.

High FLow 25,816 cfs on June 26, 1944
Low Flow 163 cfs on July 17, 1949

Percent Time Exceeded	Flow (cfs)
0	
5	7,477
10	5,488
15	4,453
20	3,662
25	3,193
30	2,863
35	2,512
40	2,259
45	2,080
50	1,903
55	1,772
60	1,634
65	1,506
70	1,393
75	1,290
80	1,185
85	1,080
90	963
95	729
100	163



The June 1 to July 31 time period applies to the following species:

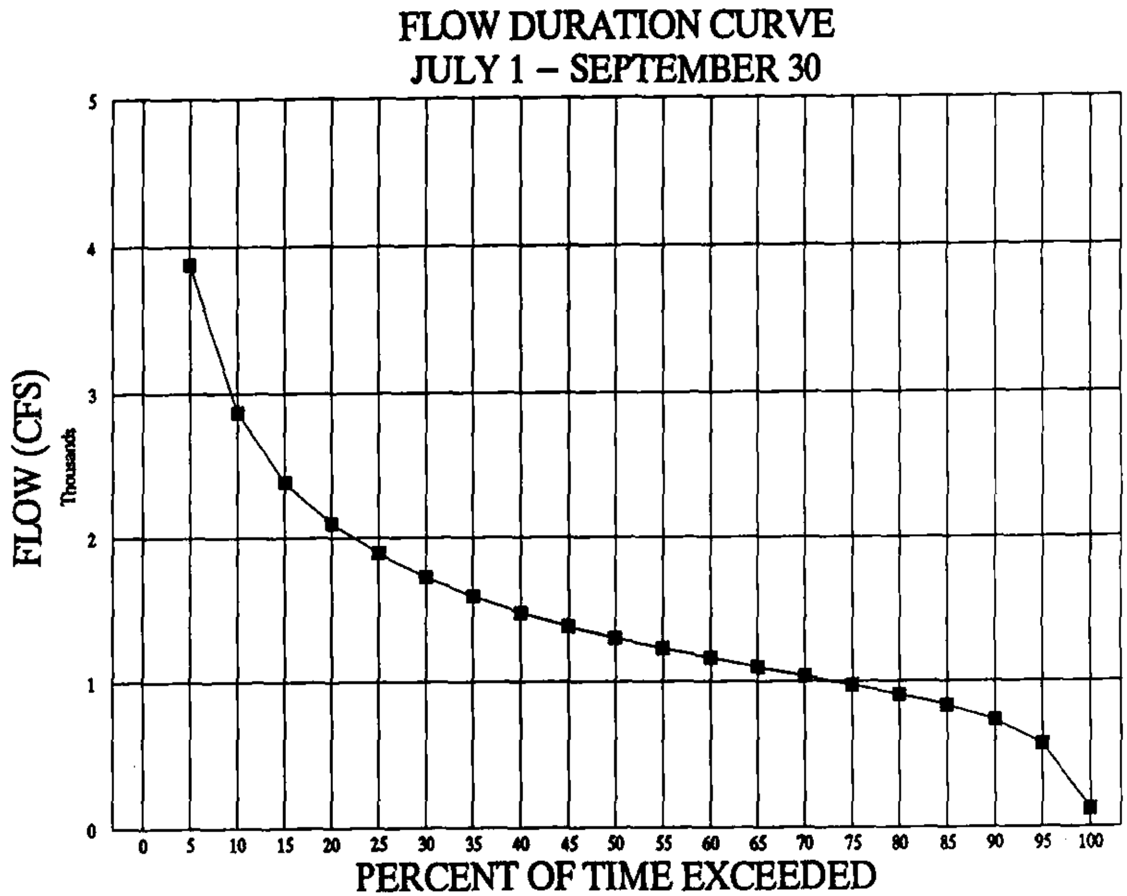
American Shad	Adult Downstream Migration	Largemouth Bass	Spawning - Incubation - Early Fry
American Shad	Eggs - Larvae	Pumpkinseed	Spawning - Incubation - Early Fry
Alewife	Adult Downstream Migration	Yellow Perch	Demersal Larvae/Fry

FIGURE 4-8.
FLOW DURATION CURVE FOR JULY 1 - SEPTEMBER 30
MERRIMACK STATION - DRAINAGE AREA 2,535 SQUARE MILES

JULY 1 - SEPTEMBER 30
Period of record from Sept 1941 to Oct 1978.

High FLow 22,501 cfs on July 1, 1973
Low Flow 123 cfs on Sept 5, 1949

Percent Time Exceeded	Flow (cfs)
0	
5	3,876
10	2,869
15	2,384
20	2,098
25	1,895
30	1,730
35	1,597
40	1,477
45	1,386
50	1,299
55	1228
60	1,165
65	1,098
70	1,037
75	976
80	910
85	832
90	732
95	564
100	123



The July 1 to Septmeber 30 time period applies to the following species:

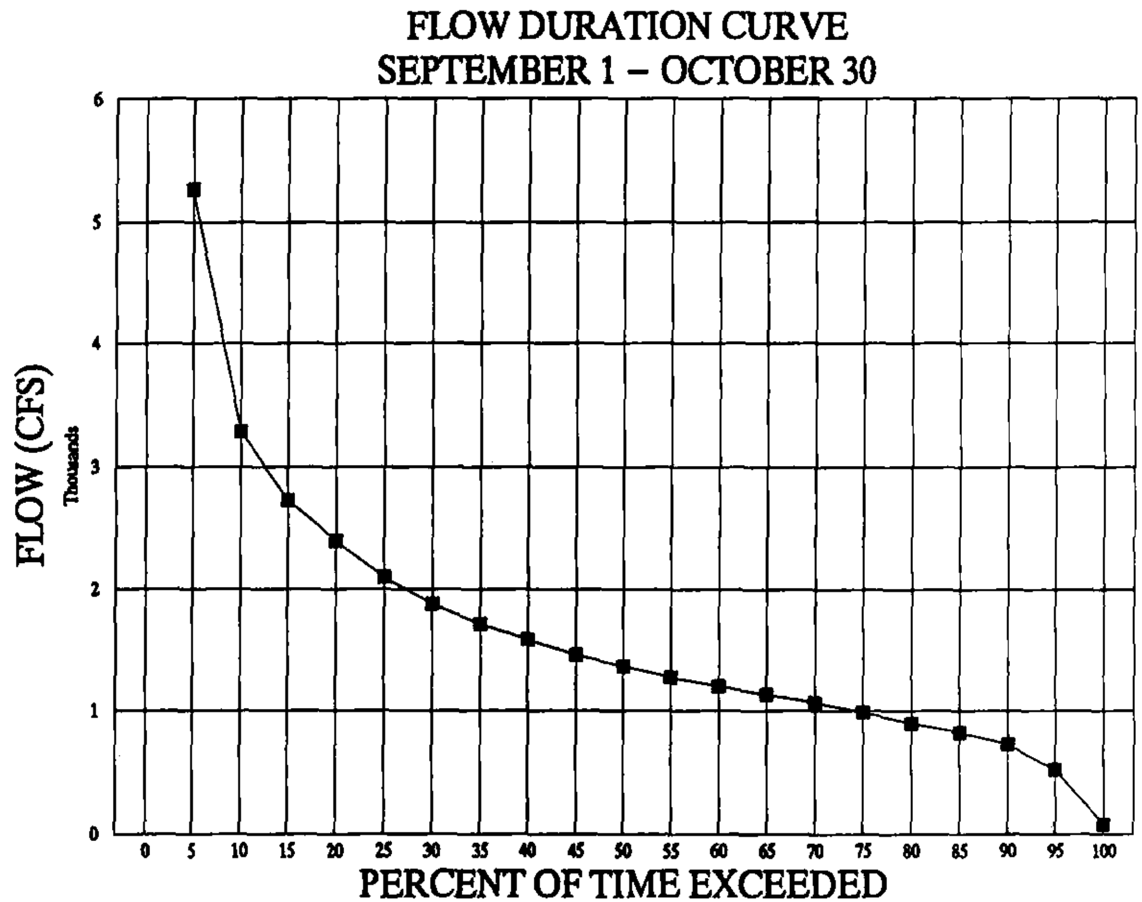
American Shad	Fry - Juvenile	Smallmouth Bass	Young-of-Year
Alewife	Fry - Juvenile	Largemouth Bass	Young-of-Year
		Pumpkinseed	Young-of-Year
		Yellow Perch	Young-of-Year

FIGURE 4-9.
FLOW DURATION CURVE FOR SEPTEMBER 1 - OCTOBER 30
MERRIMACK STATION - DRAINAGE AREA 2,535 SQUARE MILES

SEPTEMBER 1 - OCTOBER 30
Period of record from Sept 1941 to Oct 1978.

High FLow 22,136 cfs on Oct 8, 1962
Low Flow 78 cfs on Oct 11, 1964

Percent Time Exceeded	Flow (cfs)
0	
5	5,265
10	3,283
15	2,724
20	2,390
25	2,101
30	1,879
35	1,714
40	1,589
45	1,464
50	1,367
55	1,279
60	1,208
65	1,139
70	1,069
75	989
80	898
85	823
90	731
95	527
100	78



The September 1 to October 30 time period applies to the following species:

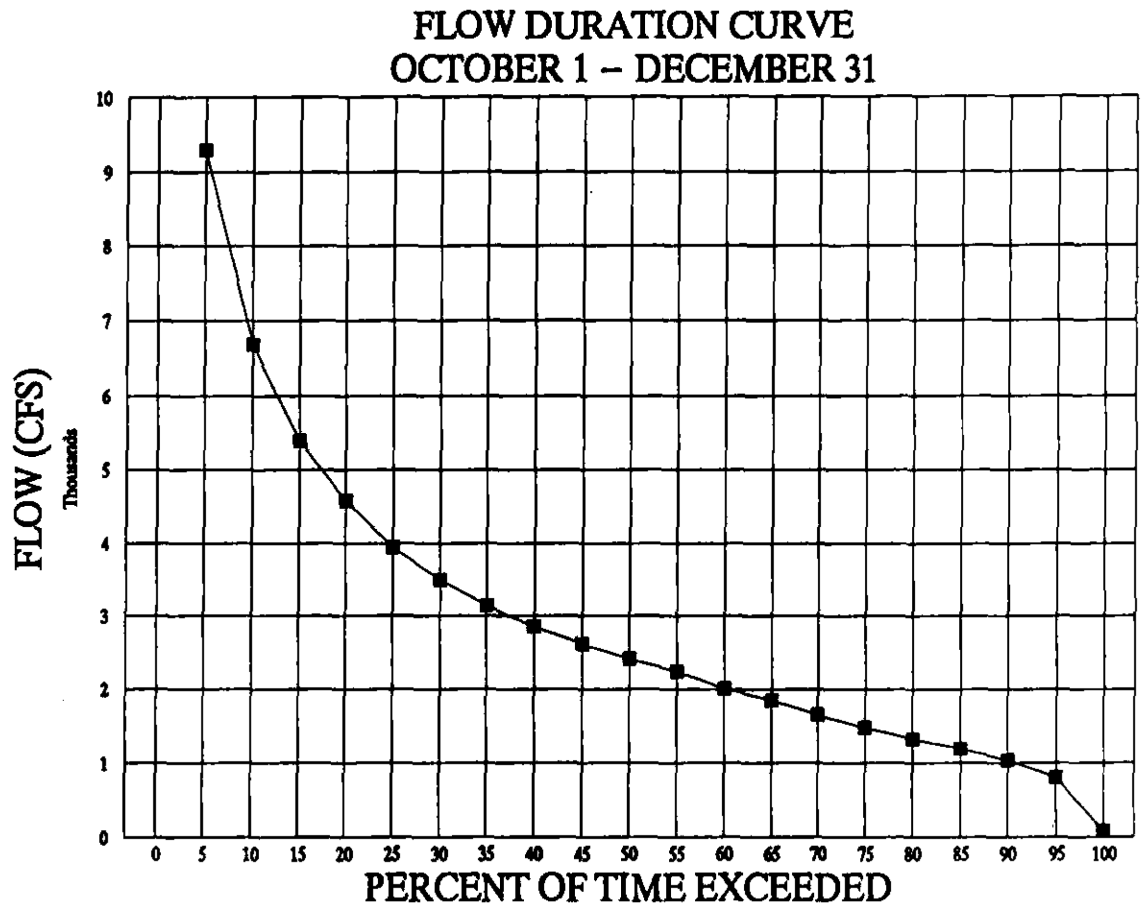
Atlantic Salmon	Adult Upstream Migration (Minor)
American Shad	Emigrating Juvenile
Alewife	Emigrating Juvenile

FIGURE 4–10.
FLOW DURATION CURVE FOR OCTOBER 1 – DECEMBER 31
MERRIMACK STATION – DRAINAGE AREA 2,535 SQUARE MILES

OCTOBER 1 – DECEMBER 31
Period of record from Sept 1941 to Oct 1978

High FLow 27,277 cfs on Dec 23, 1973
Low Flow 78 cfs on Oct 11, 1964

Percent Time Exceeded	Flow (cfs)
0	
5	9,297
10	6,680
15	5,393
20	4,574
25	3,942
30	3,500
35	3,140
40	2,855
45	2,619
50	2,421
55	2,244
60	2,012
65	1,852
70	1,649
75	1,482
80	1,325
85	1,191
90	1,032
95	799
100	78



The October 1 to December 31 time period applies to the following species:

Atlantic Salmon   Adult Downstream Migration (Minor) using typical temperatures reported in the literature for spawning, egg incubation, and larval/fry development in conjunction with temperature data for the Hooksett Pool (NAI 1979a; Appendix Table B-1). The seasons of interest for the target species are summarized in Table 4-1. The August 4, 1977 data are representative of flows that are exceeded 85% of the time during the summer seasons (e.g., June-July or July-September) and at least 90% of the time during other seasons of interest. The July 7, 1975 data represent flow levels exceeded 40% or more of the time during the summer seasons and more than 75% of the time during other seasons.

Tables 4-2 and 4-3 present an analysis of the temperature distribution in the cross sections for the two dates selected. On July 7, 1975 the average ambient temperature during sampling was 26°C. Table 4-2 presents the areas of the river channel cross section and the percentage of the total cross section area that were less than or equal to 1.1, 2.2, 3.3 and 5°C above ambient (i.e., 2, 4, 6 and 9°F above ambient, respectively) at various sampling locations from the discharge canal exit (Station Zero) to a distance approximately 2 miles (3.2 km) downstream (sampling stations were numbered sequentially at 500 foot (152 m) intervals, therefore, S-22 was 11,000 feet (3200 m) downstream from the canal exit). Table 4-3 presents similar data for the August 4, 1977 cross section samples. Both tables indicate that, with the exception of the discharge station itself, over half the cross sectional area of the channel downstream from the discharge canal remains within 2.2°C of the mean ambient temperature during sampling. Substantial proportions (> 45%) of the cross sectional area were within 1.1°C of the mean ambient temperature except for stations S-18 and S-22 on July 7, 1975 which had over 50% of the section area less than 1.5°C above ambient. At Station Zero, the discharge station, the area that is less than 1.1°C above ambient comprises approximately one third of the total cross sectional area.

NAI (1979a) summarized thermal plume configurations for a variety of conditions.

> The configuration of the thermal plume is dependent on the volume of cooling water utilized and river discharge. The thermal plume extends as a lens of warm water one to two meters deep southward from the discharge

TABLE 4-1.
SUMMARY OF SPAWNING AND EARLY LIFE STAGE INFORMATION FOR TARGET SPECIES

	SPAWNING TEMPERATURE RANGE (C)	PEAK SPAWNING TEMPERATURE (C)	RANGE IN INCUBATION DURATION (DAYS)	TYPICAL INCUBATION DURATION (DAYS)	PEAK SPAWNING PERIOD	SPAWNING - INCUBATION PERIOD	RANGE OF LARVAL/FRY DURATION (DAYS)	TYPICAL LARVAL/FRY DURATION (DAYS)	LARVAL - FRY PERIOD	REFERENCES
AMERICAN SHAD	7.5 - 24	14.6 - 22	3 - 4	3	LATE MAY - LATE JUNE	MID-MAY - MID-JULY		30	THROUGH JULY	Marcy (1976c), Scott and Crossman (1973)
ALEWIFE	5 - 22	7 - 10.9 12.8 - 15.6	3 - 6	6	MID-MAY - MID-JUNE	MAY - JUNE		30	THROUGH JULY	Marcy (1976b), Scott and Crossman (1973)
ATLANTIC SALMON			70 - 160	110	OCTOBER - DECEMBER	OCTOBER - APRIL	45 - 90		APRIL - JUNE	Mills (1989), Scott and Crossman (1973)
SMALLMOUTH BASS	11.7 - 21	16.1 - 18.3	2.5 - 21	3 - 10	MID-MAY - EARLY-JUNE	MID-MAY - LATE JUNE	12 - 40 (to dispersal)	15 - 30 (to dispersal)	LATE MAY - MID-JULY	Carlander (1977)
LARGEMOUTH BASS	11.5 - 29	16.7 - 21	2 - 21	3 - 8	JUNE	MID-MAY - EARLY JULY	up to 38 (to dispersal)	15 - 30 (to dispersal)	JUNE - JULY	Carlander (1977), Scott and Crossman (1973)
PUMPKINSEED	13 - 29	20 - 28		3	JUNE	LATE-MAY - AUGUST		11 (to dispersal)	JUNE - AUGUST	Carlander (1977), Scott and Crossman (1973)
YELLOW PERCH	2.5 - 14	5 - 10	6 - 50	14 - 21 8 - 10	APRIL	APRIL - MAY	30 - 45		MAY - JUNE	Muncy (1968), West and Leonard (1979), Scott and Crossman (1973), Ney (1978) Whiteside et al. (1985)

NOTES:

- Spawning period is determined based on likely period of occurrence of peak spawning temperatures in the Hooksett Pool. Periods of occurrence for later life stages are based on spawning period plus the typical duration for life stages subsequent to spawning.
- Information on the early life stages of Atlantic salmon and alewife are presented for completeness. These species are not expected to spawn in the vicinity of Merrimack Station.

TABLE 4-2.
TEMPERATURE DISTRIBUTION IN RIVER CROSS SECTIONS ON JULY 7, 1975

AMBIENT TEMP. – Minimum 25.7 C, Maximum 26.4 C; RIVER FLOW – 1,476 cfs

STATION	AREA WITH DELTA-T LESS THAN OR EQUAL TO CHANGE INDICATED								CROSS SECTION	
	1.1 C		2.2 C		3.3 C		5.0 C		TOTAL AREA	MAXIMUM
	SQ. FT.	% OF TOT.	SQ. FT.	% OF TOT.	SQ. FT.	% OF TOT.	SQ. FT.	% OF TOT.	SQ. FT.	TEMP.
ZERO	1,584	37.1	1,903	44.6	2,067	48.4	2,253	52.8	4,269	33.8
S-1	1,738	45.3	1,954	50.9	2,211	57.6	2,592	67.6	3,837	32.7
S-4	2,345	58.0	2,602	64.4	2,808	69.5	3,271	80.9	4,042	32.7
S-7	2,787	58.9	3,374	71.3	3,477	73.5	3,518	74.4	4,731	31.9
S-10	2,253	49.0	2,890	62.9	3,374	73.4	4,279	93.1	4,598	31.7
S-14	2,366	49.4	2,787	58.1	3,466	72.3	4,279	89.3	4,793	31.2
S-18	1,831	35.6	3,055	59.4	3,621	70.4	5,143	100.0	5,143	30.8
S-22	1,306	22.2	3,806	64.8	4,402	75.0	5,873	100.0	5,873	30.7

TABLE 4-3.
TEMPERATURE DISTRIBUTION IN RIVER CROSS SECTIONS ON AUGUST 4, 1977

AMBIENT TEMP. – Minimum 24.6 C, Maximum 26.3 C; RIVER FLOW – 823 cfs

STATION	AREA WITH DELTA-T LESS THAN OR EQUAL TO CHANGE INDICATED								CROSS SECTION	
	1.1 C		2.2 C		3.3 C		5.0 C		TOTAL AREA	MAXIMUM
	SQ. FT.	% OF TOT.	SQ. FT.	% OF TOT.	SQ. FT.	% OF TOT.	SQ. FT.	% OF TOT.	SQ. FT.	TEMP.
ZERO	1,068	33.8	1,321	41.8	1,431	45.3	1,718	54.4	3,160	34.9
S-1	1,960	61.4	2,123	66.6	2,268	71.0	2,521	79.0	3,193	34.6
S-4	2,653	77.2	2,730	79.5	2,808	81.7	2,929	85.3	3,435	33.8
S-7	2,356	62.8	2,653	70.7	2,753	73.3	2,841	75.7	3,754	33.4
S-10	2,257	63.3	2,532	71.0	2,753	77.2	2,962	83.0	3,567	32.7
S-14	2,510	63.5	2,719	68.8	3,039	76.9	3,314	83.8	3,953	32.5
S-18	2,455	56.6	3,270	75.4	3,424	78.9	3,964	91.4	4,338	31.9
S-22	2,224	46.3	2,896	60.3	3,414	71.1	4,261	88.8	4,800	30.9

canal mouth; bottom waters are affected only at the discharge canal mouth. This stratification provides an ambient zone of passage throughout the mixing zone. Under certain conditions of low flows and high utilization for cooling purposes, recirculation may be evident as far upstream as N-5, but is usually only visible upstream to Station N-1 (Appendix Figures B-5 and B-9). The plume typically flows across the river under low flow conditions, reaching the east bank at Stations S-1 to S-3, and disperses throughout the river width as it approaches Station S-4. Mixing with the ambient water is dependent on river discharge and meteorological conditions. Generally, mixing increases as river discharge increases. Thus, under low flow conditions (<30 cms), stratification is often evident as far downstream as Station S-24 which is immediately upstream of Hooksett Dam (Appendix Figures B-3 and B-7). Under higher flow conditions, the plume mixes completely with the ambient water farther upstream (Appendix Figures B-13 to B-17). Water leaving the pond over Hooksett Dam is usually fully mixed, with a ΔT of 0.4 to 2.3°C from ambient (Figure 3-3). Part of this ΔT is attributable to insolation warming the river downstream of the discharge, although this contribution of solar radiation has not been quantified.

4.2 Effects of the Plume on Anadromous Fish Migrations

River flows during the upstream migration period for adult shad and alewife (Figure 4-5) will generally (more than 90% of the time) be greater than those represented by the thermal profile data selected as representing near worst case conditions. The existence of a zone of near-ambient temperature water comprising at least one third of the river cross section should provide sufficient area for these fish to pass upstream through the plume area.

Downstream migrating adult and juvenile shad and herring are more likely to experience flow (Figures 4-7 and 4-9, respectively) and temperature conditions represented by the selected cross section data. Leggett (1976) worked with a small number of downstream migrating adult shad tagged with ultrasonic transmitters but they did not pass through areas of elevated temperature when passing the Connecticut Yankee Nuclear Power Station. Marcy's (1976b) study demonstrated that juvenile shad and blueback herring (and, presumably alewives) will avoid the highest surface temperatures associated with the plume and seek deeper, cooler (i.e., at near-ambient temperature) water when passing through the plume area. Thus, there will be a zone of passage for shad and herring under near worst case thermal conditions.

River flows during the downstream migration period for Atlantic salmon smolts (Figure 4-4) are generally well in excess of the flows represented by the selected cross section samples. McAvoy (1980, 1981) found that radio tagged smolts in the Connecticut River passed through the thermal plume as they migrated downstream past the Vermont Yankee Nuclear Power Plant in Vernon, VT. The smolts apparently skirted the edges of the plume before passing through it. McAvoy did not provide information on the temperatures that the smolts were exposed to as their depth was unknown. Since water at near-ambient temperatures is available to smolts in the depth range in which they normally migrate (< 4 m; Fried et al. 1978) they are expected to continue downstream through the discharge area at Merrimack Station.

Salmon smolts migrate past the Merrimack Station annually. Saunders (1992) provided information on travel times between dams on the Merrimack River for radio tagged hatchery smolts. Rates of travel between Eastman Falls dam and Garvins Falls dam, and between Garvins Falls dam and Amoskeag dam do not differ significantly (Mann-Whitney test) indicating that the thermal plume does not impede migration.

Adult Atlantic salmon upstream migration can be impeded by ambient temperatures observed in the Merrimack River. Salmon would not be expected to be migrating upstream during maximum summer ambient temperature conditions. Salmon are expected to enter the river and move upstream during periods of higher flows when ambient temperatures are below 24-24.9°C (Alabaster 1990). Thus, despite the typical flows occurring during the general period of upstream migration for adult salmon (Figure 4-5), upstream migration of salmon past Merrimack Station is expected when flows are at or above those represented by the July 7, 1975 temperature sampling data.

Shepard and Hall (1991) radio tagged 94 upstream migrating adult salmon in the Penobscot River between 1987 and 1990. They observed that salmon held position in free-flowing river sections in pools and at the mouths of cool tributaries when water temperatures were high (27-29°C maximum). Upstream movement during the summer occurred when temperatures dropped several degrees. Salmon did not remain in impounded areas (such as Hooksett Pool) and traversed them quickly. Shepard and Hall (1991) also noted that in one year a rapid rise in temperature from 20°C to 27°C in one week resulted in a number of observed mortalities. They stated that salmon that enter the river late in the season will be subject to high mortality from thermal stress and angling.

Adult salmon apparently sense and seek out cooler water. Their behavior in the Penobscot indicates that they would enter the Hooksett Pool only when temperatures downstream from Hooksett are tolerable. Since ambient temperatures are usually highest in downstream segments of the river salmon would probably traverse areas with temperatures similar to those found in deeper water in the lower Hooksett Pool before reaching Hooksett. Because there will be a substantial zone of water at near-ambient temperatures throughout the lower Hooksett pool, it is expected that the plume would not affect upstream migration.

Emigrating adult salmon generally move downstream during periods of high flow. Peak movement occurs during the early spring (Scott and Crossman 1973). At this time water temperatures are low (5-10°C) and river flows are high (Figure 4-3). The thermal plume would not be expected to influence their movements.

Despite the existence of a shallow surface layer of water at temperatures that would be expected to interfere with anadromous fish migrations, there is ample evidence that migrating anadromous fish sense and avoid areas of highest temperatures without a disruption in migration. The telemetry studies and juvenile clupeid behavior studies that were cited indicate that anadromous fish will pass through areas where surface temperatures are elevated. The thermal cross section studies have established that the surface heated layer at Merrimack Station remains relatively shallow under low flow conditions and there is an appreciable "zone of passage" throughout the area affected by the thermal plume. This, in conjunction with the fact that most target species life stages migrate outside of the period of lowest flows and highest river temperatures indicates that there will be little if any interference with fish migration by the thermal plume.

4.3 Plume Effects on Indigenous Fish Under Low Water Conditions

Review of the thermal cross sections in Appendix B indicates that during low water conditions the heated water tends to remain at the surface of the river and mix slowly as it progresses downstream. This results in a substantial area of water at temperatures that are within 1-2°C of ambient at depths below 1-1.5 m. Maximum temperatures near the surface in the area from the mouth of the discharge canal to approximately 600 m downstream along the east bank may exceed the acute temperature preference for all target species when ambient water temperatures approach summer maxima. Indigenous fish are expected to avoid the warmest areas of the plume and seek the zone of near-ambient temperatures in deeper water. Since water temperatures 1 m or more below the surface are near ambient, they are generally at or near preferred summer temperatures for all target species.

5.0 PART I.17.c-e: SEASONAL TEMPERATURE RESTRICTIONS

The information on target species thermal requirements presented in Section 2 forms the basis for an analysis of the need for seasonal temperature restrictions on the discharge from the cooling water canal at Merrimack Station. The purpose of seasonal temperature restrictions is to protect fish from adverse effects of exposure to elevated temperatures or sudden temperature reductions. Relative to establishment of criteria for the temperature elevations in the thermal discharge, the literature review has indicated that young and adults of the target species have the ability to respond to thermal gradients and select areas that are at preferred temperatures. Protection of the life stages that have developed enough swimming ability to rapidly alter their vertical position in the water column is not necessary because fish have only to move down to the zone 1-1.5 m below the surface to return to near-ambient temperatures (as described in Section 4.1). The life stages that require protection, therefore, are those that have not developed the ability to respond to temperature changes by adjusting their location in the water column, that is, eggs and larvae.

Further review of the life history information for the target species indicates that those target species expected to spawn in the Hooksett Pool have sinking eggs (American shad), eggs that remain in a nest during development (smallmouth and largemouth bass, pumpkinseed) or eggs that are attached to vegetation during development (yellow perch). Once they leave the nest, young bass and pumpkinseed both have better developed swimming ability and appear to be able to tolerate higher temperatures than yellow perch.

Larvae of American shad and yellow perch may be found in surface waters before they have developed sufficient swimming ability to rapidly change their location in the water column. Thus, the need for temperature restrictions should be considered during the periods when larval perch and shad may be present. The discussion in Sections 5.1 through 5.3 will, therefore, be restricted to identifying the conditions necessary to protect vulnerable life stages of target species, namely the larval life stages of yellow perch and American shad.

Criteria to protect fish from sudden temperature reductions during winter should take into account both the behavior of juvenile and adult fish in selecting and maintaining locations in the vicinity of the thermal plume and operational characteristics of the power station that tend to reduce the potential for occurrence of rapid temperature reductions. Much of the behavioral information was discussed in Section 2. Information on station outages and their effects on temperature in the discharge canal will be discussed in Section 5.4.

5.1 Issue c: Seasonal Maximum Discharge Temperature

Determination of a seasonal T_{max} at the point of discharge from the canal into the river, that would protect the anadromous and indigenous fish.

Among the target species, yellow perch appear to be as sensitive or more sensitive to high temperatures than other species. Yellow perch larvae may be present in surface waters until they attain lengths of 25-40 mm. NAI (1974, 1975, 1976, 1977b) collected YOY perch by seining primarily during June and July, indicating that they complete their "drifting," pelagic larval stage during that time. Because perch larvae may encounter the thermal plume at or near the surface during their pelagic phase, maximum discharge temperatures could potentially affect this species. The thermal tolerance data that are available indicate that UILT's for young perch range from 29.2-34°C for 12-83 hour exposures (Hokansen 1977, Spotila et al. 1979, Jobling 1981) and near 26°C for longer term (7-day) exposures (Cherry et al. 1977). The 26°C value for longer term exposure is, however, considered questionable because maximum reported growth optima for YOY perch occur at temperatures of 23-28°C (Jobling 1981) and maximum reported temperature preferenda range from 27-29°C (Coutant 1977, Hokansen 1977). Because exposure to the warmest part of the plume is transitory (less than an hour) with temperatures gradually returning to near-ambient, larval perch encountering the plume may be able to survive higher exposure temperatures than those reported in the literature.

American shad larvae and juveniles small enough to have difficulty in avoiding the thermal plume will be present through the month of July. The studies conducted by NAI (1977a) indicate that significant mortality occurs at temperatures greater than 33.3°C after a 30 minute exposure to the plume. This suggests that the need to restrict temperatures during June and July should be considered to protect larval shad from adverse effects.

During the remainder of the year, no life stages are present that would not be expected to be able to sense and avoid the warmest temperatures in the thermal plume.

5.2 Issue d: Summer ΔT

Determine, if found to be necessary, a summer Delta-T (downstream temperature minus upstream temperature) that would protect the anadromous and indigenous fish from artificially-heated river water that would be injurious to the aquatic community.

The data provided in the literature review indicate that yellow perch larvae acclimated at 18°C were able to tolerate a ΔT of 10°C for 24 hours (Hokansen 1977). No other data on larval perch tolerance of temperature changes was noted. Due to the lack of information on yellow perch response to temperature changes similar to those that might be encountered during passage through the plume (i.e., a relatively abrupt rise to the maximum ΔT followed by gradual cooling to temperatures 1-2°C above ambient over a period of several hours), it appears that additional information is necessary to assess the magnitude of thermal plume-associated ΔT's that can be tolerated by larval perch.

The studies conducted by NAI (1977a) indicated that the lowest ΔT that significantly affected shad larval mortality rates was 11.1°C. It was noted, however, that the shad larvae used in these tests had not begun to feed in the laboratory and were apparently stressed by factors other than the test conditions to which they were subjected. Shad larvae are probably able to tolerate greater ΔT's under natural conditions.

5.3 Assessment of the Need for Summer Temperature Restrictions

Available information indicates that summer temperature restrictions may be necessary to protect the most vulnerable resident species life stage (larval perch) from the warmest areas of the thermal plume during May and June. The range in UILT's reported for the species partially overlaps the range of maximum discharge temperatures during the period when larval perch may be present. Thus the worst case (29.2°C UILT; Black 1953, cited in Hokansen 1977) would indicate that larval perch survival could be adversely affected by passage through the plume, while other studies would indicate that discharge temperatures during the period when larvae are present are below the UILT (33-34°C; McCormick 1976, cited in Hokansen 1977). The potential for exposure of larval yellow perch to the thermal plume is also unknown. Juvenile fish seining indicated that small YOY perch could be collected along the shoreline; however, Tucker trawl sampling failed to collect larval perch in the vicinity of the intake or at several locations in the discharge canal (indicating that they were not present in deeper water). There is also a distinct lack of information on larval yellow perch tolerance of temperature changes such as those that might be encountered during passage through the plume.

The fisheries studies conducted by Wightman in 1967-1969 (Wightman 1971) and by NAI during 1972-1978 (NAI 1973,1974,1975,1976,1977b,1978,1979c) appear to indicate a declining trend in yellow perch abundance in fyke net catches since Merrimack Unit II began operation in 1968. Abundances of other resident target species in fyke net catches did not exhibit significant ($p < 0.05$) trends following commencement of operation of Merrimack Unit II (see Table 5-1), which supports the contention that operation of the station will have no effect on those species.

The existence of a correlation between yellow perch abundance and time does not necessarily imply that the trend results from plant operation. Yellow perch populations typically show large fluctuations in recruitment due to environmental and other factors (Ney 1978). River flows and other environmental conditions also affect netting success. Wightman (1971) noted that the catch in thermally unaffected areas of the Hooksett Pool was considerably lower in 1968 and 1969 than in 1967. Although a decline in perch relative abundance in thermally affected areas would be expected prior to any decline in unaffected areas, Wightman's data indicated that the ratio in

TABLE 5-1.

ABUNDANCE OF TARGET SPECIES IN FYKE NET CATCHES IN HOOKSETT POOL

WITH ANALYSIS OF ABUNDANCE TRENDS FOR DATA ADJUSTED TO A STANDARD SEASON

TOTAL CATCH (NUMBER) AND CATCH PER UNIT EFFORT (CPUE) FOR FYKE NET SAMPLING

Year	Effort	Months Sampled	Smallmouth Bass Number	Smallmouth Bass CPUE	Largemouth Bass Number	Largemouth Bass CPUE	Pumpkinseed Number	Pumpkinseed CPUE	Yellow Perch Number	Yellow Perch CPUE
1967	354	Jun-Sep	376	1.06	0	0.00	5243	14.81	3478	9.82
1968	425	Jun-Sep	172	0.40	2	0.00	2418	5.69	2245	5.28
1969	168	Jun-Sep	140	0.83	10	0.06	621	3.70	662	3.94
1972	48	Aug-Oct	150	3.13	4	0.08	279	5.81	302	6.29
1973	80	Jun-Oct	201	2.51	1	0.01	406	5.08	302	3.78
1974	96	May-Oct	119	1.24	3	0.03	563	5.86	271	2.82
1975	96	May-Oct	128	1.33	16	0.17	569	5.93	282	2.94
1976	96	May-Oct	83	0.86	2	0.02	274	2.85	213	2.22
1977	80	May-Sep	71	0.89	3	0.04	142	1.78	90	1.13
1978	96	May-Oct	146	1.52	0	0.00	369	3.84	158	1.65

Data from June/July for 60's - Not fished in Aug or Sept (Wightman)

CATCH AND EFFORT DATA ADJUSTED TO A "STANDARD" JUNE-SEPTEMBER FISHING SEASON

Year	Effort	Months Sampled	Smallmouth Bass Number	Smallmouth Bass CPUE	Largemouth Bass Number	Largemouth Bass CPUE	Pumpkinseed Number	Pumpkinseed CPUE	Yellow Perch Number	Yellow Perch CPUE
1967	354	Jun-Sep	376	1.06	0	0.00	5243	14.81	3478	9.82
1968	425	Jun-Sep	172	0.40	2	0.00	2418	5.69	2245	5.28
1969	168	Jun-Sep	140	0.83	10	0.06	621	3.70	662	3.94
1972	32	Aug-Sep	insufficient data							
1973	64	Jun-Sep	173	2.70	0	0.00	301	4.70	253	3.95
1974	64	Jun-Sep	110	1.72	3	0.05	429	6.70	151	2.36
1975	64	Jun-Sep	109	1.70	15	0.23	404	6.31	178	2.78
1976	64	Jun-Sep	77	1.20	2	0.03	251	3.92	73	1.14
1977	64	Jun-Sep	57	0.89	3	0.05	111	1.73	56	0.88
1978	64	Jun-Sep	112	1.75	0	0.00	226	3.53	158	2.47
trend analysis: slope (r)			0.071 (0.420)		0.004 (0.222)		-0.579 (0.626)		-.0560 (0.839)	
significance			n.s.		n.s.		n.s.		p < 0.01	

total # sets from Areas 1+2 in Hooksett Pool (Jun/Jul)

assumes all samples conducted and none were void catch-per-unit-effort (CPUE) between areas north and south of the discharge canal remained constant throughout his study despite the decrease in total CPUE for the Hooksett Pool. In addition, the fyke net catch (primarily age 2 and older fish) would not be expected to begin to show effects of thermal plume entrainment on the perch population until several years after operation of Unit II began. Thus, despite the fact that a trend exists, it does not correspond well with the expected timing of changes in abundance that would result from operation of Unit II. The observed decreasing trend in abundance may be an artifact of random natural factors that produced an exceptional catch in 1967 and poor year classes at the conclusion of the study. Further information on yellow perch temperature tolerances, larval distribution and/or abundance and population structure is necessary to fully assess the need for spring-summer seasonal temperature restrictions intended to protect the larval life stage of yellow perch.

Restrictions on plant operation also may be required to protect the larval life stage of American shad from passage through the thermal plume. At the present time, however, measures to protect larval shad from thermal exposure are unnecessary because shad have not yet reached the Hooksett Pool in appreciable numbers (PSNH acknowledges that NHFGD regularly stocks approximately 1,000 shad in the river upstream from Garvins Falls dam; and that a few of these may "drop back" into the Hooksett Pool and spawn there). There should be ample time to further explore the need for temperature restrictions necessary to protect shad that spawn in the Hooksett Pool since appreciable numbers of shad are not likely to migrate past Hooksett dam during the life of the present permit. Any temperature criteria developed for yellow perch larvae would be protective of shad larvae during the month of June.

5.4 Issue e: Winter ΔT

Determination of a maximum "Delta-T" (discharge temperature minus intake temperature) at the head of the canal due to a major plant/condenser shutdown. (Note: This is the maximum temperature excursion expected in the canal during an abrupt shutdown of the power plant during the winter).

5.4.1 Literature-based Canal ΔT

The information presented in the literature review on yellow perch behavior in the vicinity of thermal plumes during winter indicates that they regularly move between heated (10-14°C) and non-heated (0-3°C) areas and, therefore, would not be affected by plant shutdowns (Ross and Winter 1981, Ross and Siniff 1982, Kelso 1976). Largemouth bass, however, remain within warm plume areas. Information presented in Ross and Winter (1981) indicated that largemouth selected an area with ΔT's between 5 and 10°C in a thermal discharge with maximum ΔT's of 15°C above the near-zero winter ambient temperature. No information on winter behavior of smallmouth bass near thermal plumes at ambient temperatures typical of New England waters was found; however, Marcy (1976a) reported that smallmouth bass were caught by sport fishermen in the thermal plume at Connecticut Yankee during March (when ambient temperatures would be 0-5°C) and Wrenn (1975) reported that an ultrasonic-tagged smallmouth bass entered a thermal plume on the Tennessee River when ambient water temperatures fell below 10°C. Wightman (1971) caught one smallmouth bass in the Merrimack Station discharge canal during winter sampling in 1968-1970. Mr. Dennis Brown, PSNH production manager, has captured both largemouth and smallmouth bass while angling in the Merrimack Station discharge canal during the winter months. Both species have been caught in the canal at water temperatures ranging from 4.4-26.7°C (Dennis Brown, PSNH, unpublished data for 1987-1992). No information on winter behavior of pumpkinseed near thermal plumes was found; however, Wightman (1971) caught relatively large numbers of pumpkinseed in the Merrimack Station discharge canal during winter sampling in 1968-1970.

The information on largemouth and smallmouth bass tolerance of cold temperatures indicate that they have similar tolerances in this regard. Pumpkinseed lower thermal tolerances were not available, but they are probably similar to those for bass. Using data from a study conducted by Horning and Pearson (1973; cited in Carlander 1977), a regression analysis was performed to predict the ambient temperature at which 90% or greater survival would occur for specific acclimation (i.e., discharge canal) temperatures. The following regression equation was developed:

$$T_{amb} = -7.97 + 0.7598 * T_{canal} \quad (R^2 = 0.93)$$

where:

T_{amb} = the ambient temperature at which 90% or greater survival would be expected following a sudden decrease in canal temperature.

T_{canal} = the temperature in the canal prior to unit shutdown resulting in a sudden temperature drop.

The regression equation indicates that at an ambient temperature of 0°C 90% or greater survival would occur at a ΔT of 10.5°C (i.e., canal temperature 10.5°C). Higher ΔT's could be tolerated for shorter periods or at higher ambient temperatures. For example, a ΔT of 12.1°C to an ambient temperature of 5°C would result in ≥ 90% survival and a ΔT of 13.6°C to an ambient temperature of 10°C would result in ≥ 90% survival. Thus, on the basis of the information available, a winter ΔT of 10.5°C would appear sufficient to protect fish that may be present in the canal when ambient temperatures are near 0°C. When ambient temperatures exceed 10°C the ΔT at which survival would be > 90% is roughly equivalent to the 13.9°C theoretical ΔT through the condensers; therefore, at winter-spring temperatures above 10°C no restriction on the canal temperature would be necessary.

5.4.2 Winter Chill Events

Because the theoretical maximum ΔT through the condensers at Merrimack Station is 13.9°C, a 10.5°C ΔT at the head of the cooling canal would represent a substantial restriction of generation during a period of the year when electrical demand is high and availability of full plant capacity is desirable. Temperature monitoring data for the cooling canal at Merrimack Station were reviewed to determine how often "chill" events have occurred historically. Maximum and minimum daily temperatures were available for the winter months from November 1980 through April 1991. Chill events were defined as events in which the temperature in the canal dropped at least 10°C in a 24-hour period to a temperature of less than 10°C.

This review indicated that chill events occur several times per year in the Merrimack Station discharge canal. A total of 38 events were recorded during the 11-year period for which monitoring information was available. At least one event occurred during each winter period (see Table 5-2). A number of events (17) were recorded that showed temperature changes in excess of the theoretical maximum ΔT for the plant. These discrepancies probably resulted either because ambient temperatures were dropping during the period between maximum and minimum readings or because the automatic temperature recording system was not functioning properly. The more rapidly occurring chill events involved ΔT's ranging from 10.1-15.7°C (as recorded at Station Zero) over a period of 4-13 hours. The average rate of cooling during those events ranged from 0.9-2.9°C per hour with all but one event having average cooling rates of less than 1.4°C per hour.

5.4.3 Assessment of the Need for Winter Temperature Restrictions

Despite the large number of chill events recorded, no incidents of winter fish kills or distressed fish have been reported. Bass have been captured by angling within a week after a chill event on 4 separate occasions (Dennis Brown, PSNH, unpublished data for 1987-1992). This indicates that temperature restrictions based on the results of laboratory studies are overly conservative. The analysis presented in Section 5.3.1 assumes that fish will seek out the warmest areas of the canal and thus will be exposed to the maximum cold shock. In the few studies describing fish movement in the vicinity of thermal plumes in winter, fish of various species occupied areas of elevated temperature but did not move into the warmest areas. Another problem with this analysis is that the laboratory studies involve an instantaneous temperature change followed by exposure to continuous low temperatures. In the discharge canal, temperature changes are likely to take place over a period of several hours and, in most cases, involve a rate of change of less than 1.4°C per hour. Fish in the canal are apparently more readily able to acclimate to ambient temperatures because of the gradual cooling rate. This observation is supported by the study conducted by Becker et al. (1977) in which cooling rates of up to 10°C/h resulted in pumpkinseed being able to tolerate temperature decreases up to several degrees greater than would be expected on the basis of experiments involving essentially instantaneous cold shocks (see Section 2.6). Thus, given that chill events have occurred several times annually without apparent effects on any fish that may have been present in the canal, the development of a winter temperature restriction for Merrimack Station seems unnecessary.

TABLE 5-2.
CHILL EVENTS AT MERRIMACK STATION
NOVEMBER 1980 - APRIL 1991
CHILL EVENT IS DELTA-T > 10.0 C WITHIN 24 HOURS
MINIMUM TEMPERATURE IS < 10 C

EVENT START			EVENT END			EVENT SUMMARY		
DATE	TIME	TEMP C	DATE	TIME	TEMP C	DELTA-T C	TIME TO T-min DAYS:HOURS	CHILL RATE degrees C/hr
25-Dec-80	00:00	17.4	26-Dec-80	16:30	2.6	14.8	1 16:45	0.36
18-Jan-81	13:00	16.7	19-Jan-81	01:45	1.8	14.9	13:00	1.15
31-Jan-81	00:00	14.5	01-Feb-81	09:15	0.4	14.1	1 09:30	0.42
11-Feb-81	12:15	19.0	12-Feb-81	08:00	5.4	13.6	20:00	0.68
13-Feb-81	15:15	20.7	14-Feb-81	19:00	5.6	15.1	1 04:00	0.54
21-Mar-81	00:00	15.3	21-Mar-81	21:45	2.6	12.7	22:00	0.58
23-Dec-81	00:45	19.6	23-Dec-81	23:45	6.2	13.4	23:15	0.58
22-Jan-82	01:15	20.2	22-Jan-82	23:45	4.8	15.4	22:45	0.68
31-Jan-82	06:30	20.2	01-Feb-82	03:30	0.1	20.1	21:15	0.95
06-Feb-82	23:45	18.5	07-Feb-82	12:45	5.3	13.2	13:15	1.00
10-Feb-82	04:15	20.6	10-Feb-82	22:45	5.4	15.2	18:45	0.81
13-Feb-82	16:30	18.2	14-Feb-82	06:45	4.8	13.4	14:30	0.92
28-Mar-82	13:15	19.8	28-Mar-82	23:45	5.6	14.2	10:45	1.32
09-Dec-82	00:00	17.8	10-Dec-82	00:00	6.0	11.8	1 00:15	0.49
11-Jan-83	13:30	22.8	12-Jan-83	09:00	6.3	16.5	19:45	0.84
18-Jan-84	12:30	24.8	19-Jan-84	04:30	8.5	16.3	16:15	1.00
10-Feb-84	12:00	22.4	11-Feb-84	06:45	6.8	15.6	19:00	0.82
20-Feb-84	00:00	21.9	20-Feb-84	23:45	7.8	14.1	1 00:00	0.59
29-Feb-84	06:30	22.1	01-Mar-84	08:45	6.0	16.1	1 02:30	0.61
10-Nov-84	15:30	21.2	11-Nov-84	12:15	1.5	19.7	21:00	0.94
17-Jan-85	23:15	18.5	18-Jan-85	23:45	6.7	11.9	1 00:45	0.48
10-Apr-85	00:00	15.6	11-Apr-85	12:45	5.5	10.1	1 13:00	0.27
27-Dec-85	13:00	13.9	27-Dec-85	23:45	3.8	10.1	11:00	0.91
24-Jan-86	00:15	13.7	24-Jan-86	08:45	3.5	10.3	08:45	1.17
23-Nov-86	02:00	12.3	23-Nov-86	23:45	1.5	10.8	22:00	0.49
15-Dec-86	00:00	15.7	15-Dec-86	11:15	4.9	10.7	11:30	0.93
19-Dec-86	16:00	14.9	19-Dec-86	23:45	4.4	10.5	08:00	1.31
20-Jan-87	16:00	15.9	21-Jan-87	11:45	4.5	11.5	20:00	0.57
07-Feb-87	00:00	17.3	08-Feb-87	09:30	4.8	12.4	1 09:45	0.37
25-Feb-87	00:00	17.0	25-Feb-87	23:45	6.8	10.2	1 00:00	0.42
10-Mar-87	00:00	20.2	10-Mar-87	20:30	1.1	19.1	20:45	0.92
21-Mar-87	00:00	23.3	21-Mar-87	12:45	7.7	15.7	13:00	1.21
18-Feb-88	12:15	13.9	18-Feb-88	21:15	1.4	12.5	09:15	1.35
03-Jan-89	00:00	13.1	04-Jan-89	01:30	1.1	12.0	1 01:45	0.46
13-Feb-89	01:45	14.9	13-Feb-89	20:45	4.1	10.7	19:15	0.56
25-Feb-90	23:45	13.5	26-Feb-90	08:45	3.4	10.1	09:15	1.09
01-Mar-91	00:00	24.1	02-Mar-91	09:15	7.9	16.2	1 09:30	0.48
12-Apr-91	09:30	20.6	12-Apr-91	13:15	9.1	11.5	04:00	2.88

6.0 PART I.17.f: RESIDENT FISH IN THE COOLING WATER CANAL

Assess the resident fish population in the cooling-water canal, and determine if this population is a significant portion of the local fishery and must be protected. If the resident fish require protection, recommendations are to be made as to the type of physical or operational improvements are required.

Fish sampling in the old canal was conducted by Wightman (1971) during summer from 1967-1969 and during January in 1968-1970. Winter sampling indicated that yellow perch, bullheads, white sucker and pickerel moved into the canal or the thermal plume area. Wightman (1971) noted that abundance of fish in the canal during winter was reduced dramatically when Unit II began operation. He hypothesized that the reduction in numbers might be due to the lack of a surface-to-bottom thermal gradient in the canal itself with both units on line. He also noted that there was a station outage during the late fall of 1969 which may have resulted in a lack of attraction to the canal at the time when ambient temperatures would otherwise bring about winter dormancy in some species. From 1972-1976 NAI (1973, 1974, 1975, 1976, 1977b) sampled the old canal during the summer using electrofishing. The fish species typically present in the canal during summer included sunfish and bass. Yellow perch, white perch, bullheads and golden shiners were also present on some occasions.

During 1967-1969 (Wightman 1971) and 1977-1978 (NAI 1978,1979) fish mark-recapture studies were conducted to document movement of fish within the Hooksett Pool. According to the authors of the reports, the data consistently showed that during the summer months there is little movement of resident species within the Hooksett Pool and that most recorded movements were confined to within several hundred meters of the tagging location.

An analysis of summer electrofishing data collected by NAI between 1972 and 1976 indicates that the target species are distributed differently with respect to the discharge canal (Table 6-1). Pumpkinseed are consistently concentrated in the old canal (an area that has surface-to-bottom temperatures that are similar to the lower end of the present canal) and the mixing zone area in the immediate vicinity of the discharge. Although pumpkinseed,

TABLE 6-1.
TARGET SPECIES RELATIVE ABUNDANCES
IN AREAS SAMPLED BY ELECTROFISHING, 1972-1976

	AMBIENT ZONE	MIXING ZONE	OLD CANAL	LOWER HOOKSETT POOL	PERCENT OF POP. IN CANAL
STATIONS:	N-9/N-10 N-6/N-7	ZERO/S-1 S-4/S-5		S-17/S-18	
PUMPKINSEED					
1972	77.3	89.8	96.0	60.5	14.1%
1973	55.0	80.0	53.0	39.0	11.3%
1974	27.3	87.0	141.0	44.5	31.9%
1975	29.0	119.8	145.0	52.0	29.3%
1976	39.0	69.3	125.0	19.5	30.6%
MEAN	45.5	89.2	112.0	43.1	22.4%
95% C.I.	27.2-63.8	72.6-105.7	78.5-145.5	29.5-56.7	
SMALLMOUTH BASS					
1972	2.0	2.5	0.0	1.0	0.0%
1973	3.8	13.0	10.0	10.0	16.2%
1974	2.8	13.0	3.0	0.5	11.4%
1975	3.3	5.0	4.0	3.0	13.1%
1976	17.8	10.0	77.0	3.5	43.2%
MEAN	5.9	8.7	18.8	3.6	30.3%
95% C.I.	0.1-11.7	4.5-12.9	-9.9-47.5	0.3-6.9	
LARGEMOUTH BASS					
1972	16.3	7.5	12.0	9.0	10.2%
1973	1.8	2.0	3.0	1.5	18.1%
1974	13.0	16.5	24.0	8.0	20.4%
1975	15.3	24.5	51.0	5.5	32.9%
1976	9.8	5.5	5.0	0.5	8.8%
MEAN	11.2	11.2	19.0	4.9	20.5%
95% C.I.	6.1-16.3	3.2-19.2	1.7-36.3	1.6-8.2	
YELLOW PERCH					
1972	37.0	24.5	3.0	25.5	1.1%
1973	25.8	13.3	1.0	26.5	0.5%
1974	9.8	8.8	0.0	11.5	0.0%
1975	15.8	15.3	7.0	4.5	6.7%
1976	8.3	2.5	0.0	5.5	0.0%
MEAN	19.3	12.9	2.2	14.7	1.6%
95% C.I.	8.7-29.9	5.7-20.0	-0.4-4.8	5.4-24.0	

smallmouth bass and largemouth bass may exhibit high concentrations in the old canal and mixing zone area when temperatures there are in the species preferred range (as was the case during 1976), in other years they may be more common in other areas than they are in the canal and mixing zone area. The observed patterns in bass abundance indicate that there may be some localized movement into and out of the canal and mixing zone area that was not detected by the mark-recapture study. Yellow perch were most common outside the canal and mixing zone area.

The observed relative abundances provide a means of assessing the proportion of the total fish population that is present in the canal. Because pumpkinseed are noticeably concentrated in the canal area, the population of pumpkinseed in the Hooksett Pool is most likely to be affected by any event that adversely affects that portion of the population present in the canal. The canal is approximately 1.2 km in length; the mixing zone area is approximately 0.8 km feet in length; the lower Hooksett Pool area is approximately 3.0 km in length and the "ambient" area upstream of the discharge canal is approximately 5.8 km in length. These lengths represent weighting factors that can be used to determine the average density of individuals in the Hooksett Pool. If is assumed that abundances in sampled areas are representative of the entire area which the sample represents, then a species with an even distribution across all areas would have about 11% of its population in the canal. In the case of pumpkinseed, the weighted mean density in the entire Hooksett Pool area during the period 1972-1976 was 55.5 individuals per sample (10.8 km) while the density in the canal was 112.0 individuals per sample (1.2 km). This would indicate that the proportion of the population in the canal comprised, on average, 22.4% of the pumpkinseed population in the Hooksett Pool. Table 6-1 presents the annual and 5-year mean percentages of the population of the target species that were present in the canal during the summer months. A similar analysis was not possible for the winter period.

The above analysis of the proportion of the target species populations that may be present in the canal during the summer months relies on the assumption that the old canal sampling area is representative of the entire discharge canal. Temperatures in the old canal are similar to those recorded for Station Zero, near the downstream end of the present canal. The temperatures at which fish sampling was conducted in the old canal were, however, more representative of the lower end of the range of summer temperatures. The maximum temperature at which sampling was conducted was 32.8°C. On 12 of 15 occasions, temperatures at the time of sampling were less than 30°C, within or below the preferred temperature range of the resident target species. Thus, the resident target species would have been expected to be attracted to the old canal when sampling was conducted because of the favorable temperatures found there. The analysis provided does not, therefore, indicate that resident species were present in the old canal when temperatures were potentially harmful, nor does it provide an indication of the portion of the population that might be present when canal temperatures are near the summer maximum. In addition, the old canal is not similar to the present discharge canal in several respects. There is current in the discharge canal proper while the old canal is essentially a backwater. In addition, the discharge canal is dredged annually while the old canal is undisturbed. This indicates that the physical habitat present in the old canal may be substantially different from the habitat in the cooling canal. Such differences in habitat structure could translate into differences in the fish community present.

The analysis above indicates that the target species behave predictably in that they appear to be attracted to the vicinity of the discharge canal when favorable temperatures occur there. Since no incidents of fish kills or distressed fish that were related to high canal temperatures have been reported, it may be assumed that fish exit the canal as temperatures increase to unfavorable levels. Such behavior was reported by Block et al. (1984) for largemouth bass and bluegill in a cooling water canal. It appears, therefore, that protection of resident fish from unfavorable summer temperatures is unnecessary.

The lack of winter sampling data suitable for determining the portion of the fish community present in the cooling canal represents an area where information identified by the TAC as being important to assessment of the need for temperature restrictions is potentially lacking. The discussion of the need for winter restrictions on the ΔT at the head of the canal presented in Section 5.4 does, however, indicate that assessment of the proportion of the fish population resident in the canal during winter may be unnecessary. Because chill events have had no noticeable effect on fish present in the canal historically, it can be argued that the question that the population assessment is intended to answer is moot. Further study should, therefore, not be necessary.

7.0 BIOLOGICAL AND HYDROLOGICAL WORK SCOPE

Part I.18.a of the NPDES Permit for Merrimack Station requires that PSNH submit to the TAC:

> **"A preliminary report summarizing the information required in Part I.A.17.g. and a projection of the biological and hydrological work to be accomplished during the Summer of 1993, on March 1, 1993."**

A draft preliminary report was submitted to the TAC on December 1, 1992. On January 8 and 15, 1993 representatives of PSNH and its consultant met with the TAC to discuss the assessments contained in the draft preliminary report and to identify any additional studies that would be required to address the issues raised in Part I.17. of the NPDES permit. During the January 15 TAC meeting three studies were identified that should be completed during 1993-1994. The studies identified include:

1. An assessment of the effects of thermal inputs from Merrimack Station on the potential duration of the anadromous fish migration season.

2. An assessment of the potential for entrainment of yellow perch larvae in the thermal plume at Merrimack Station.

3. Assessment of the abundance of yellow perch in the Hooksett Pool relative to their historic abundance and collection of additional information on the on the spatial distribution of target fish species populations in the Hooksett Pool in relation to the portions of those populations in the present discharge canal.

This section presents the scopes of work for the above studies (in fulfillment of the requirements of Part I.18.a.). Each scope of work presents the objective of the subject study; a summary of the background rationale for the study; and a description of the approach to be followed in conducting the study. A draft final report on the results of these studies will be submitted to the TAC not later than February 1, 1995.

STUDY 1. ASSESS EFFECTS OF THERMAL INPUTS ON DURATION OF MIGRATION SEASON

Objective: Assess the effects of station operation on the normal pattern of seasonal warming in areas downstream from Merrimack Station. Determine if artificially accelerated warming will prematurely impede fish migrations.

Background: USFWS expressed a concern that operation of the station will advance the onset of temperatures that would result in cessation of upstream migration by anadromous fish. Although there was general agreement that an adequate zone of passage for anadromous fish is present at low flows (see Section 4), they observed that under higher flows more typical of the shad migration season temperature stratification may be less pronounced. They also observed that spill over the flashboards at Hooksett dam could result in the warmest water being transported downstream. The persistence of elevated temperatures in combination with thermally mixed conditions downstream (i.e., in Amoskeag Pool) may prematurely curtail upstream migration. USFWS requested that PSNH provide an assessment of how much earlier in the migration season temperatures occur that may impede upstream migration. NHDES requested that a similar analysis be conducted for the fall (downstream) migration season.

Approach: Water temperature data suitable for an assessment of effects of station operation on areas downstream from Hooksett dam are generally not available in published reports. PSNH proposes to collect field data sufficient for calibration and validation of a temperature model (e.g., USFWS' Instream Water Temperature

Model; Theurer, et al. 1984). The model will be used to assess the effect of operation of Merrimack Station on "mixed" temperatures between Hooksett Hydro at Amoskeag Station. The calibrated model will be used to simulate downstream temperatures with and without thermal inputs from Merrimack Station. Simulation results will then be used in conjunction with historic ambient temperature data for Station N-10 and river flow information to assess the effects of station operation on the occurrence of river temperatures at Amoskeag that could potentially impede migration.

Selection of the model to be used will be the responsibility of PSNH's consultant. The model will be able to simulate the effects of solar radiation, meteorological conditions (e.g., weekly or monthly average air temperature, relative humidity, cloud cover, wind velocity) and hydrologic conditions (e.g., transport related to flow and channel geometry) on water temperature with distance downstream. It is expected that monthly average meteorological conditions will be used as simulation input data. PSNH's consultant will also be responsible for specifying the locations and methods to be used for collection of water temperature and meteorological information to be used in model calibration. It is expected that water temperature information will be collected at a minimum of two points below the Hooksett dam. One monitoring location will be at Amoskeag dam, the other will be at a point downstream from Hooksett dam where mixed conditions would be expected.

The response variable of interest in the simulation will be mean daily water temperature at Amoskeag. Simulations will be conducted over a range of flows representative of those that occur during the migration season and at two or more levels of plant thermal output (corresponding, for example, to "ambient" conditions of 0 MW output and the maximum output of 440 MW or, where applicable, the presently proposed summertime maximum of 370 MW). The simulation output will be used to develop a response function relating the average temperature that would be expected to occur at Amoskeag to river flow and ambient temperatures at Station N-10 (e.g., 12, 16, 20 and 24°C). A separate response function will be generated for each month during the migration season and each level of plant output.

The response functions generated by the modelling exercise will be applied to historic data on daily river flow (from USGS gage data) and daily average ambient temperatures upstream from Merrimack Station (from PSNH monitoring for Station N-10) to predict the time series of temperatures at Amoskeag that would have occurred had Merrimack operated continuously at a specified level of thermal output. The time series data for each output level will be plotted to show the timing of occurrence of temperatures potentially unfavorable for migration. Time series will be developed for the periods May 1 through June 30 (shad and alewife upstream migration) and September 1 through October 31 (juvenile clupeid downstream migration). Ten years of time series information will be developed (1981-1990). The median time at which temperatures unfavorable for migration occur will be determined for ambient conditions and each level of station operation. A temperature-duration analysis of the ten year period of record will also be prepared for each migration period. The predicted temperature-duration curve for Amoskeag assuming that Merrimack Station was not operating will be compared with the predicted temperature-duration curve assuming that Merrimack Station was operating continuously at a specified level. The duration analysis will provide information on the number of additional days (on average) that unfavorable temperatures would occur as a result of station operation.

Assessment of the results temperature time series analysis will require development of criteria for the level and duration of temperatures that are likely to curtail or temporarily halt migration. For example, one or two days of temperatures above 24°C is not likely to completely curtail shad migration while a week of such temperatures would likely result in most shad stopping to spawn by the end of that period. In such an instance it may be more appropriate use the 7-day moving average temperature at Amoskeag to determine the time at which migration would be curtailed. PSNH and its consultant will consult with USFWS and NHFGD to determine appropriate criteria for determining the end of the migration period.

STUDY 2. POTENTIAL FOR ENTRAINMENT OF YELLOW PERCH LARVAE IN THE THERMAL PLUME

Objective: Assess potential entrainment of yellow perch larvae in Merrimack Station thermal plume. Describe the timing, duration and temporal abundance pattern of larval perch presence in the Hooksett Pool. Describe spatial distribution pattern of perch larvae in the Hooksett Pool relative to the Merrimack Station thermal discharge.

Background: Yellow perch larvae may be subject to entrainment into the Merrimack Station thermal plume. If so, it may be necessary to establish restrictions on maximum temperature and ΔT of the station discharge for their protection. Existing data are not sufficient to determine whether larval perch are presently subjected to entrainment in the thermal plume. If larval perch are being entrained, it is desirable to know both the times/ambient temperatures at which they are likely to occur and their density in the plume area relative to their densities elsewhere in the Hooksett Pool in order to assess the proportion of the population subject to entrainment in the plume when potentially lethal temperatures may occur.

Approach: Ichthyoplankton samples will be collected weekly during May and June using drift nets. Three locations in each of three areas in the Hooksett Pool will be sampled. The sampling areas represent the ambient zone upstream from the station (vicinity of Station N-10), the immediate area of the thermal plume (vicinity of Stations S-2 to S-3), and the thermally affected zone (vicinity of Stations S-19 to S-20). In each sampling area nets will be set at a mid-stream location and approximately 30-40 m from each bank. At each location samples will be collected at two depths, near-surface (approximately 0.2 m below the surface) and near-bottom (approximately 1.5-2.0 m depth).

Drift nets will be 50 cm diameter opening 505 µm (or smaller) mesh nitex with a length-to-width ratio of at least 4:1. A propeller-type flow meter (e.g., General Oceanics model 2030R) will be placed slightly off-center in the mouth of each net to allow calculation of the volume of water filtered.

On each sampling occasion nets will be fished for a 15-30 minute period to assure a minimum filtered volume of 50 m^3. Water temperature will be measured at the depth at which each net is fished at each location. If debris loads are high, sample duration will be shortened sufficiently to avoid net clogging and two or more reduced-volume subsamples will be composited to provide a sample meeting the minimum volume criterion. Samples will be preserved initially in 5-10% buffered formalin (circumneutral pH). Sample container volume will be minimized to the extent possible, consistent with adequate sample preservation. Sample containers will be labelled internally and externally and returned to the laboratory for processing.

Prior to sorting samples will be placed in a sieve to drain off preservative and rinsed. Samples will be sorted using appropriate lighting and magnification. Fish eggs and larvae will be removed from the sampled and preserved in fresh 3-5% buffered formalin pending identification. All remaining sample material will be returned to the sample container following sorting and fresh preservative will be added. Following initial sorting, three randomly selected subsamples from each weekly sampling will be re-sorted. If additional fish eggs and larvae from the re-sorted samples amount to 15 percent (average of three percentages) of the total from the original and re-sorted samples, or if any one re-sorted sample contains more than 25 percent of the total for that sample, all samples collected during that week will be re-sorted. Fish eggs and larvae will be identified to species where possible. A collection of reference specimens will be prepared and submitted to independent verification.

Estimated densities of eggs and larvae by species will be calculated for each sample based on the volume of water filtered. At a minimum, the following analyses of yellow perch larval density data will be conducted:

> A factorial analysis of variance (using log-transformed data, if appropriate) with Area, Location, Depth and Sample Date as factors. Significance tests of the effects of Area, Depth and the Depth x Area interaction will be of primary interest.
>
> An analysis of the correlation between water temperature and abundance of larval perch.
>
> The analysis of variance will be used to describe the spatial distribution of larval yellow perch. The null hypothesis in this analysis is that perch larvae are uniformly distributed spatially (i.e., with respect to

Area, Location and/or Depth). Tests of significance will be at α=0.05. Interpretation of the results will allow determination of whether perch larvae are more abundant outside areas immediately affected by the thermal discharge due either location in the Hooksett Pool or occurrence in deeper water that is less affected by the discharge. Determination of the water temperatures at which larval perch are most abundant will provide an indication as to whether they will potentially be exposed to plume temperatures outside their likely tolerance range. The findings relative to spatial and temporal distribution of larvae will determine the need for establishing seasonal restrictions on maximum temperature or maximum ΔT of the Merrimack Station discharge.

STUDY 3. INDIGENOUS FISH COMMUNITY ABUNDANCE AND DISTRIBUTION

Objective: 1. Compare present abundances of yellow perch with abundances observed during the 1970's. 2.) Determine the times at which target species are present in the discharge canal and assess whether the numbers in the canal represent a "significant" portion of the Hooksett Pool population.

Background: 1. There was a declining trend in abundance of yellow perch in fyke net catches during the 1970's while no trend in abundance of other target species was indicated. The observed pattern in perch abundance did not appear to be directly related to start-up of Merrimack Unit 2 and may have been an artifact of high variability in recruitment known to occur naturally in perch populations. Because perch was identified as a species that could potentially be affected by the station's thermal discharge (through larval entrainment), information on the present abundance of perch will provide some insight into whether the population has remained stable since the 1970's.

2. Although there was no fish sampling data available for the present discharge canal at Merrimack Station, data for the old canal indicated that a substantial proportion of the Hooksett Pool population of some species could potentially be present in thermally enriched areas when conditions were favorable. PSNH believes that further information on the proportion of each target species population using the present discharge canal is necessary.

Approach: The fyke netting program undertaken by NAI during 1972-1978 will be repeated in 1994 to provide fish community composition and target species abundance information. In addition, two fyke netting locations will be established in the discharge canal. Boat electrofishing will also be conducted in the discharge canal and at locations sampled by NAI during 1972-1976. Sampling will be conducted monthly from late May through October and seasonally during late fall (late November - mid-December, 1993) and late winter (late March - early April, 1994), ice conditions permitting, for a total of 8 sampling periods.

Fyke netting will be conducted at four locations in the river (N-10-east, N-10-west, S-2-west and S-3-east) and at two locations in the canal (upstream and downstream from the PSM's). At each location nets will be set twice during a one-week period for two days per set for a total sampling effort of 24 net-nights per sampling period. Electrofishing will be conducted by fishing 300 m sections along both banks at five locations in the river (N-9 to N-10, N-5 to N-6, S-0 to S-1, S-4 to S-5 and S-17 to S-18). In addition electrofishing will be conducted in the old canal, and above and below the PSM's in the discharge canal. Captured fish will be identified, weighed, measured, and released. Water temperature will be measured 30 cm below surface and near the bottom at all fyke net locations and at the mid-point of each electrofishing section.

Fyke netting catch-per-unit-effort (CPUE) data for yellow perch species will be compared with CPUE data collected by Normandeau Associates during the 1970's.

Both fyke netting and electrofishing data will be used to develop an assessment of relative abundance of target species between the canal and the sampling stations located in the river. An assessment similar to that used in Section 6.0 will be used to determine whether significant portions of the populations of target species occur in the present canal.

Temperature data will be used to assess whether or not a correlation can be established between fish relative abundance and water temperature both in the canal and in the river. The results of this assessment will be used to determine whether fish using the canal are being exposed to temperatures outside the range that they would normally experience in the river. When considered in conjunction with the assessment of the proportions of the populations present in the canal, this information will further define the risk to the target populations resulting from exposure to elevated temperatures in the canal.

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